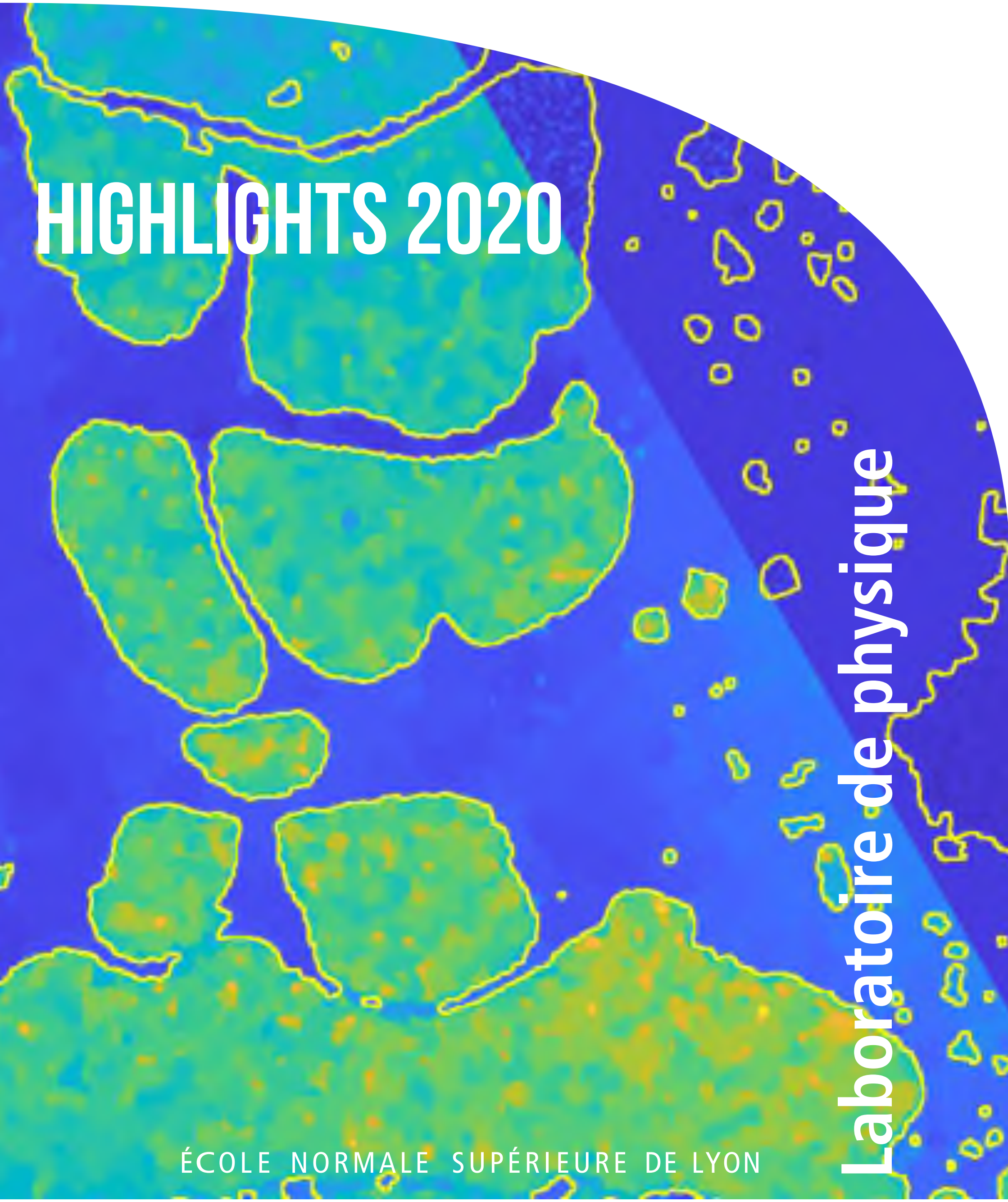
HIGHLIGHTS 2020



Laboratoire de physique

ÉCOLE NORMALE SUPÉRIEURE DE LYON

UNIVERSITÉ DE LYON

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Lyon 1

ENS DE LYON

Group photo taken in December 2019, during the annual general meeting of the Laboratoire de Physique.

Credits: Vincent Moncorgé

Thierry Dauxois
Director of the lab

Foreword

The 2020 issue of the "Highlights" publication of the Laboratoire de Physique gathers facts, events or research achievements of 2018 & 2019. 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 only a partial selection of the research topics addressed in the lab, which are detailed on our website.

Several members of the lab have been awarded distinctions and prizes like V. Bergeron with the 2019 CNRS innovation medal, P. Flandrin with vice-president position at the French Academy of science, or S. Ciliberto with the 2018 Jaffé prize and the 2019 Statistical & Nonlinear Physics Prize from the European Physical Society, just to quote a few of them. A. Dubois, D. Geyer, and P. Grasland-Mongrain were also rewarded for their early career (PhD and postdoc). We present here their brief portraits.

The purpose of this document is also to present some examples of recent scientific achievements within the laboratory to a wide audience, like the three Idex breakthrough projects ACADEMICS, TORE and TURBULLET, and the initiative Sciences^{2024}. Another richness of the Laboratoire de Physique can be found in its numerous international links exemplified by the creation last year of an International Research Project (IRP) with the Weizmann Institute and the Hebrew University of Jerusalem from Israel. We believe that the origin of these results lies in the excellent quality of our PhD students and postdocs, and the high level of expertise of our technical staff members that we briefly present in the document.

Let me conclude on a personal note. I was elected as Director of the lab in February 2011, and after two terms will transfer this responsibility to J.-C. Géminard in March 2020. My main goals were to develop or initiate research activities of the highest standard, while keeping a very broad spectrum of topics, preserving the collective dynamics and the excellent atmosphere. It was an incredible experience as well as a source of pride. I wish to thank all members of the lab for their help in making these goals achievable.

Lyon, January 2020

Contents

Lab Presentation

The Laboratoire de Physique (LPENSL) is affiliated to three institutions: École normale supérieure de Lyon (ENS de Lyon) and Université Claude Bernard Lyon 1 (UCBL), both members of Université de Lyon, and Centre national de la recherche scientifique (CNRS). 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 seven themes: Hydrodynamics and Geophysics, Soft Matter, Physics of Biological Systems, Mathematical Physics and Fundamental Interactions, Condensed Matter and Quantum Information, Infophysics, Signal & Systems, and Statistical Physics. 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 74 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 55 PhD students and 25 postdoctoral fellows, whose enthusiasm, talent and dedication help drive us forward into new areas of research.

Alizée Dubois
Delphine Geyer
Pol Grasland-Mongrain
PhD and postdoc excellence


Alizée Dubois


Delphine Geyer


Pol Grasland-Mongrain

A large proportion of lab members are PhD students and they all contribute to the science issued from the Laboratoire de Physique. Over the period 2018-2019, three students have been rewarded with specific young investigator (PhD and postdoctoral fellows) prizes, reflecting the high-level science of this place.

L'Oréal foundation rewarded Delphine Geyer in 2018 and Alizée Dubois in 2019 with the prize *For Women In Science* for their respective contributions in active matter and earthquake modeling. This prize is attributed every year to about 30 promising young female researchers in various fields, from biology to mechanical engeneering.

During her PhD thesis at the Laboratoire de Physique, Delphine Geyer provided the first experimental demonstration of two phenomena theoretically conjectured two decades ago in active matter field. She is currently a professor at Lycée Louis-le-Grand in Paris.

Alizée Dubois worked on the destabilization process of an interfacial crack, as a model of the early initiation process of a major seism. After a PhD at CEA Saclay, she joined ENS de Lyon as a teaching assistant.

Finally, Pol Grasland-Mongrain obtained the 2018 Young Researcher Prize from the Métropole de Lyon. During his PhD, and later on during a postdoctoral internship, he designed and explored new setups in medical imaging, combining ultrasound and magnets. He demonstrated that biological tissues elasticity could be measured by inducing shear waves using electromagnetic fields.

- A. Dubois, PhD, 2018, https://www.these.fr/s234801
- D. Geyer, PhD, 2019, https://www.these.fr/2019LYSEN026
- P. Grasland-Mongrain, PhD, 2013, https://www.these.fr/185888429

Sylvain Joubaud

Institut Universitaire de France

Plume dynamics and mixing

Sylvain in 5 dates

2008 PhD ENS de Lyon

2008 Postdoc U. Twente

2009 Lecturer ENS de Lyon
Chaire CNRS

2015 HDR

2018 IUF

Sylvain has been studying a wide range of subjects, sharing similar physical mechanisms. In all these topics, he has used a common methodology. He starts with simple experiments in which the complexity is gradually increased. Some insights from experimental measurements and results led to simplified theoretical tools and developments. Since 2009, he has shown a growing interest towards problems dealing with geophysical considerations. He has been interested in the non-linear nature of the propagation of internal waves in stratified fluids. Recently, fluid-particles in such environmental fluid have got a lot of his attention.

With this distinction, Sylvain will study experimentally the flow dynamics along with the heat and mass transfer induced by one or more plumes in a particle-laden flow. A "plume" is a volume of fluid moving in another one. Plumes strongly influence mass and heat transfer in many modern engineering techniques and industrial processes (mixing in chemical reactors, aerosol transfer, flows in petroleum industry, etc.). Moreover, they are also of huge importance in many biological and geophysical phenomena. Plumes have, so far, justly occupied a large body of modern research in fluid mechanics. However, in most of the applications, solid particles are often present alongside bubbles. He will then study questions such as: What are the universal laws governing the rising dynamics of the plume(s), its (their) interface(s) with the suspension, and the surrounding fluid flow? Can we quantify the influence of plumes on the mass and heat transfer enhancement in a wide variety of buoyancy-driven flows?

More and references

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- T. Dauxois *et al.*, Annual Review of Fluid Mechanics, 50, 131-156 (2018)

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Lucile Savary

ERC Starting Grant
IUPAP StatPhys Young Scientist Prize

Correlated quantum materials

Lucile in 5 dates

2014 PhD UC Santa Barbara

2014 Postdoc MIT

2016 CNRS researcher ENS de Lyon

2019 IUPAP StatPhys Young Scientist Prize

2019 ERC starting grant

Lucile's research focuses on the theory of strongly correlated quantum materials. She strives to understand how electrons (and other, so-called, "emergent" particles) behave microscopically inside materials and give rise to observable, or useful, phenomena on our scale. Down the road, new kinds of electronics and sensors might make use of new, unusual properties. Last year, Lucile was awarded an ERC starting grant, for the period 2020-2025, 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 so strong (or the latter so "quantum") that it becomes impossible to determine their speed, position, etc. Lucile's ERC project will help develop a broad and detailed understanding of thermal and electrical conduction in quantum materials. Léo Mangeolle, Lucile's first student, has already started studying the role of spin-phonon interactions in this context. In 2019, Lucile received the Young Scientist prize in Statistical Physics. This prize is awarded every three years at the StatPhys meeting, which many of the lab's members usually participate to. In Buenos Aires last year, this was again the case. Lucile also received the F. Nevill Mott Prize, awarded "to a person who has made significant contributions to the theory of strongly correlated electrons", the 2016 Michelson Postdoctoral Prize, awarded "in recognition of excellence in science and science communication", the 2014 Aspen Center for Physics Block Award awarded to a promising young physicist and was selected to be the UC Santa Barbara Graduate Division Commencement Speaker in 2014.

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

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Patrick Flandrin

Vice-president of French Academy of Sciences

Mechanical and computer sciences

Patrick in 5 dates

- 1982 PhD INP Grenoble CNRS researcher
- 1991 Joins ENS de Lyon, CNRS research associate
- 2010 Elected member of the Academy
- 2010 CNRS Silver Medal
- 2018 Elected vice-president of the Academy

Since it was created in 1666, the French Academy of sciences has been committed to the advancement of science and has advised government authorities. The Academy consists in an assembly of about 250 peer-elected members and its scientific coverage concerns all fields of exact and natural sciences. Patrick Flandrin has been elected member of the Academy in 2010, in the Section "Mechanics and Computer Science". After having been head of this Section from 2016 to 2018, he has been elected in December 2018 Vice-president of the Academy for the period 2019-2020.

Patrick Flandrin is a CNRS Research Director affiliated to the Laboratoire de Physique, working within the SISYPHE ("Signals, Systems and Physics") group that he created some 30 years ago and to which he still belongs. His main research interests are in signal processing, data science, and complex systems, with emphasis on nonstationary and multiscale methods. As Vice-president of the Academy, he is now part of a renewed board in charge of the global governance of the Academy, working together with the President Pierre Corvol and the two "Secrétaires perpétuels" Pascale Cossart and Étienne Ghys (who has also been elected in 2018, and is incidentally a CNRS mathematician affiliated to ENS de Lyon too, within its "Unit of Pure and Applied Mathematics").

More and references

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Benjamin Huard

Del Duca Young Investigator Support

Quantum information

Benjamin in 5 dates

2006 PhD CEA Saclay

2006 Postdoc U. Stanford

2008 CNRS researcher, ENS

2014 Affiliated researcher, ENS

2016 Prof. ENS de Lyon

Benjamin Huard, Audrey Bienfait and their group explore the physics of information in quantum devices, which they design, realize and measure. These objects can be viewed as quantum machines processing information. In contrast with ordinary devices, in which quantum mechanics enters only at the level of individual electrons, the degrees of freedom of these machines at the signal level behave according to the laws of quantum mechanics. They demonstrated for the first time the generation of nonlocal entanglement of microwaves, which enabled many quantum optics protocols in the microwave domain. They pioneered the use of Field Programmable Gate Arrays for feedback control of quantum systems and could realize several demonstrations of stabilization of quantum superpositions despite decoherence. They also measured the quantum trajectories associated with spontaneous emission of a two level system thanks to the exquisite precision of the microwave amplifiers they designed and fabricated. They also demonstrated the quantum Zeno dynamics of light and realized a quantum version of the Maxwell demon experiment. They currently have projects in thermodynamics of quantum information, microwave quantum optics, quantum measurement, long-lived quantum bits, topological pumps, spin sensing and quantum control of mechanical oscillators. After graduating from ENS and a PhD at CEA Saclay, Benjamin Huard worked as a postdoc at Stanford University. In 2008, as a CNRS researcher, he cofounded the Quantum Electronics group at ENS with Michel Devoret. He became professor at ENS de Lyon in 2016 where he founded the Quantum Circuit Group.

- Q. Ficheux *et al.*, Nature Communications, 9, 1926 (2018)
- N. Cottet *et al.*, PNAS, 114, 7561 (2017)

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Sergio Ciliberto

2018 Jaffé Prize (French Academy of sciences)
2019 EPS Stat. and Non-linear Physics Prize

Statistical and non-linear physics

awards

Sergio in 5 dates

1977 PhD U. Firenze

1990 CNRS research director

2000 Director of the lab

2010 ERC advanced grant

2012 Vice-president in charge of research at ENS de Lyon

All along his career, 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.

Sergio Ciliberto was rewarded recently by two renown scientific prizes: Jaffé Prize from French Academy of sciences in 2018, and EPS Statistical and Nonlinear Physics Prize in 2019. The first prize was attributed for all the major achievements reached during his carreer: experimental illustration of Landauer principle or scaling laws for sliding amplitudes in solid friction, just to quote a few of them. The second prize was attributed by European Physical Society for Sergio's seminal contributions over a wide range of problems in statistical and nonlinear physics.

Sergio Ciliberto worked initially in quantum optics, then later he investigated order-chaos transitions in nonlinear systems. He worked also in fluid turbulence as well as on crack dynamics in heterogeneous materials and aging of amorphous materials. He then continued with his ground-breaking investigations on fluctuations of the injected and dissipated power in out-of-equilibrium systems. All these diverse and significant contributions made him selected in 2010 by the ERC for an Advanced Grant. More recently, he investigated the connections between information theory and thermodynamics.

More and references

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- S. Ciliberto, Physical Review X, 7, 021051 (2017)

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Vance Bergeron

CNRS Innovation Medal 2019

Neuro-reeducative innovations

Vance in 5 dates

1993 PhD UC Berkeley

2001 Launching Airinspace start-up

2005 CNRS research director

2015 Creation of ANTS

2019 CNRS Innovation Medal

Nothing stops either science or Vance Bergeron's determination. Having become quadriplegic following an accident, this CNRS physicist at the Laboratoire de Physique develops solutions to improve the quality of life of paralyzed people through daily physical activity. With a thesis in chemistry from University of California at Berkeley, he met his future wife during a postdoc in France and decided to settle here. After a few years at Rhône-Poulenc, he joined the CNRS in 2000. Vance Bergeron then started working on biological air decontamination systems using cold plasmas. He took part in the creation of the Airinspace company, of which he became the scientific adviser, which equips oncology, haematology and severe burn intensive care units. Vance Bergeron is the author of more than a hundred scientific publications and some forty patents. In 2013, a car denied him priority and hit him while he was riding his bicycle to the laboratory. Having become quadriplegic and deprived of the use of his hands, Vance Bergeron turned to functional electrical stimulation, which remobilizes paralyzed limbs using weak electrical impulses. His research is notably supported by CNRS, ENS de Lyon, Hospices Civils de Lyon and the association Advanced Neurohabilitation Therapies and Sports (ANTS) that he co-founded. Vance initiated a startup project that will be created in 2020 by Amine Metani, one of his former PhD students. There they develop electro-stimulation bicycles and rowing machines for use in functional rehabilitation centers and sports halls dedicated to people with motor disabilities. ANTS has inaugurated the first hall of this type in France, where their prototypes will be tested in 2020.

- B. M. Doucet *et al.*, The Yale Journal of Biology and Medicine, 85, 2 (2012)
- L. Griffin *et al.*, Journal of Electromyography and Kinesiology, 19, 4 (2009)

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- web (association ANTS): https//ants-asso.com

Lab PHYS ENS de LYON

International Research Project

French-Israeli consortium

Non-equilibrium complex systems

Associated laboratories

- Laboratoire de Physique (Lyon)
- Institut de Physique (Nice)
- Dieudonné Lab. (Nice)
- Lagrange Lab. (Nice)
- Weizmann Institute (Tel Aviv)
- Hebrew University (Jerusalem)

An International Research Program (IRP), former called Laboratoire International Associé (LIA), is a research laboratory "without walls" supported by the CNRS, and aimed at structuring existing collaborations between researchers from different institutions and different countries. The IRP "Non-Equilibrium Physics of Complex Systems" was created in 2020 between French and Israeli research teams in nonlinear physics. It involves the Laboratoire de Physique in Lyon and three more labs from Nice (Institut de Physique de Nice, Laboratoire J. A. Dieudonné and Laboratoire J.-L. Lagrange), together with two Israeli institutions: the Weizmann Institute of Science and the Hebrew University of Jerusalem. This program aims at creating a multidisciplinary platform for exchanging approaches and developing new viewpoints and methods to promote progress within a broad spectrum of problems.

This International Research Program intends to gather physicists of various backgrounds, either experimentalists or theoreticians, internationally recognized experts in statistical physics, fluid turbulence and condensed matter within its wide definition. The scientific project aims at studying a wide spectrum of natural and physical systems that involve either soft matter or turbulent flows. While the two main parts of the scientific project concern different themes, they share the property that they are different manifestations of Non-Equilibrium Complex Systems. This allows us to tackle them using common tools, which constitutes the "bridge" betweent the different communities involved in the project.

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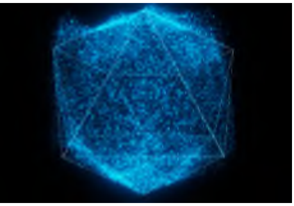
consortium

Artists in Residence

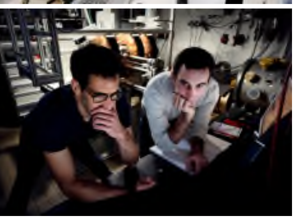
Alex Andrix, algorithmic art



After an initial scientific training at École Centrale de Lyon and at the Swedish KTH Royal Institute of Technology, Alex Andrix dedicated to the artistic practice of setting virtual particles in motion with force field equations. His encounter with physicist Mickaël Bourgoin at a digital art festival and subsequent 6-week incubation at the Laboratoire de Physique sparked his current main project: *Variations Physiques*, a set of virtual reality trips inspired by physics.

Along with the movements of a violin-based composition, particles in *Variations Physiques* evolve smoothly under the influence of force field equations. The trip depicts three experiments in the fields of turbulence and magneto-hydrodynamics, such as a rotating plasma column. A second immersive trip was created in 2019 about galaxy formation, gravitational waves and collective intelligence.

Vincent Moncorgé, photography



Vincent Moncorgé's work allows him to shed light on the world in which we live. Being a photographer is primarily about giving the subject all your attention, and through the act of shooting the photograph, giving the subject meaning. Whether through a person, an environnement, or an event, he does as much as possible to offer a new look, a rediscovery of what might seem banal, too removed from our interests or, on the contrary, too familiar. Vincent spent few weeks in the lab, in order to get a true glimpse of the science and life there. The Laboratoire de Physique gave him the necessary freedom to get as close as possible to a documenting and therefore an ethnologic piece of work.

"*For those who ask themselves the whom, how, when and where, I hope these photographs will give them a closer look and maybe an better understanding*", says Vincent about his stay in the lab.

- Alex Andrix: http://alexandrix.com
  http://variations-physiques.fr
- Vincent Moncorgé: http://vincentmoncorge.com

Focus

focus

Scientific Breakthrough ACADEMICS

Machine learning & data science for complex and dynamical models

Learning intricate models from data?

The project, called ACADEMICS and coordinated by Pierre Borgnat at the Laboratoire de Physique, has the originality of combining Machine Learning (ML) and Data Science (DS) for the purpose of scientific research into two challenging directions: 1) Computing and information processing: develop new theoretical frameworks and learning algorithms adapted to difficult scientific contexts involving heterogeneous, irregular, error-prone, dynamic and complex data, while taking into account prior knowledge whenever it is relevant. 2) Complex and dynamic models learning: leverage the synergy between ML and DS to devise data-driven models in two scientific domains: climate modeling, and the quantitative understanding of social systems. Focusing on these two case studies, the project tackles the key issue of how to learn intricate models from numerous, heterogeneous and dynamic data, possibly using deep learning methods.

Methodological issues in ML & DS

Several methodological issues in machine learning and data science are theoretically studied in the project, with three focus: 1) Representation and model learning for complex data: How to find sparse latent spaces for complex data or graphs, and how to learn compressed models? How to identify exceptional phenomena? 2) Estimation and learning from multi-source and/or dynamic data: How to transfer a model learned from source data to related but different target data? How to learn from multi-source complex data? 3) Distributed and adaptive machine learning for graphs and complex models: How to design distributed optimization-based learning? How to develop adaptive and distributed model inference in high dimension? All these questions are tested and used on two meaningful and important studies: climate modeling and computational social science.

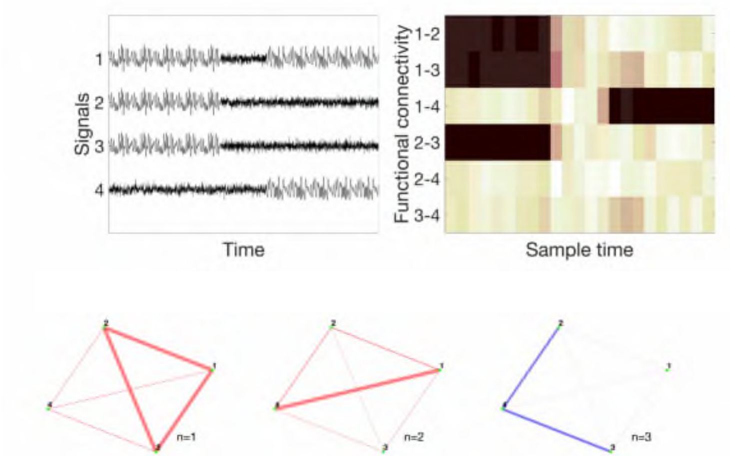
Joint research: signal processing - physics - computer science

The project brings together researchers from the laboratory and from several computer science laboratories of Lyon and Saint-Etienne: LIP, LIRIS, Laboratoire Hubert Curien). It develops as well scientific animation on these topic at the level of Université de Lyon. At the Laboratoire de Physique, the expertise of the Sisyphe group in signal processing, and of the physicists working in climate modeling, are especially mobilized in the case study about climate. Central interrogations are, for instance, how to learn effective dynamic models, or how to predict the dynamics toward specific states of climate, firstly in a nonparametric way by means of ML tools and secondly, by mixing several data sources (from observations and simulations). A key challenge is how to incorporate the physics, or prior knowledge for other case studies, e.g. computational social sciences or neuroscience, into Machine Learning approches.

ACADEMICS

focus

Machine learning and data science



Legend: For iEEG data in neuroscience, sketch of an extraction method of graphs representing modes (2 in red) activated at different times during an epilectic seizure, and an unsynchronized mode in blue. Reference: G. Frusque *et al.*, "Multiplex network inference with sparse tensor decomposition for functional connectivity", 2020.

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Collaborators: P. Abry, P. Borgnat, F. Bouchet, P. Flandrin, C. Herbert, P. Jensen, N. Pustelnik (LPENSL), C.-E. Bréhier (ICJ), P. Gonçalves, M. Foare (LIP), M. Karsai (CEU), R. Gribonval, J.-P. Magué (ICAR), M. Sebban, A. Habrard, C. Largeron, C. Laclau, E. Morvant, B. Jeudy, G. Picard, C. Ducottet, A. Zimmermann (LHC), C. Robardet, C. Garcia, S. Duffner, A. Aussem, M. Plantevit, R. Cazabet (LIRIS)

References:

- E. Bautista *et al.*, Applied Network Science, (2019)
- Y. Kaloga *et al.*, Signal Processing Letters, 26:9, 1275-1279 (2019)
- B. Ricaud *et al.*, Comptes Rendus Physique, 20 (5), 474-488 (2019)

Scientific Breakthrough TORE

Topological revolution

The ToRe project, coordinated by David Carpentier from the Laboratoire de Physique, aims at exploiting the extreme robustness provided by topology to design quantum devices, novel quantum matter, acoustic and photonic metamaterials and account for climate dynamics.

Scientific context

In the mid-twentieth century, the theoretical physicist George Gamow remarked that only number theory and topology had no application to physics. Fifty years later, no area of physics does not feature topological concepts. Over the last decade, topology sparked a new line of research in solid-sate physics, leading to the 2016 Physics Nobel prize. Today, this topological revolution extends beyond solid-state physics and offers a single framework to understand a host of phenomena from the atomic to the planetary scale. Topology is revolutionizing physics. The ToRe collaborative project is organized to address mathematical, physical and engineering challenges along four strategic axes.

Waves topology

Over the past two years, we have theoretically established the existence of topologically-protected waves in 1) microfluidic materials powered with active fluids and 2) oceanic Kelvin waves related to the El Niño phenomenon. We will experimentally establish the propagation of topological sound waves in active-fluid metamaterials, and lay out a theoretical framework to classify the topological fluid waves that control ocean and atmospheric dynamics.

Quantum technologies

Quantum circuits, the building blocks of a quantum computer, are currently hampered by their sensitivity to their environment. Topology offers a new route to engineer robust quantum devices. By suitably coupling model artificial atoms – superconducting quantum bits – to microwaves, we plan to realize such a device, a topological energy pump.

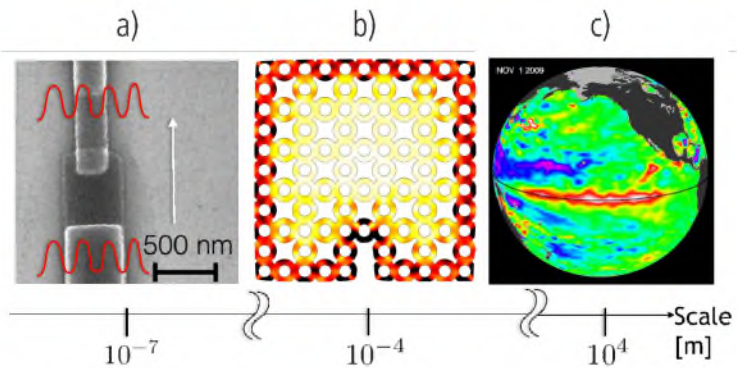
Photonics

Topology makes it possible to design maximally robust states of light. We plan to theoretically model and experimentally realize such states in metasurfaces at the nanoscopic scale. The detection of long lived states in optical cavities will pave the way to a new paradigm of all-optical integrated circuit and topological lasers.

Theory and mathematics

The roots of our project lie in intimate connexions between the modern mathematical theory of topology and the properties of a number of physical systems. Our interdisciplinary group of theoretical physicists and mathematicians will exploit and develop these connections in both ways. First by unveiling new topological waves from quantum matter to climate dynamics. Second by extending the theory of topology to account for these new types of topological waves discovered by members of the consortium. We will implement these newly discovered topological invariants to improve the numerical schemes to study the oceanic system.

From quantum technologies to climate science



Legend: Waves are ubiquitous in nature at all scales. Their topological properties lead to robust phenomena, e.g. a) power exchange mediated by a quantum artificial atom, b) sound wave localized (red) at the boundary of fluid metamaterials, and c) temperature waves (red) trapped along the Earth's equator before an El Niño event.

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Collaborators: B. Huard, P. Delplace, D. Bartolo, A. Venaille, K. Gawedzki, L. Savary (LPENSL), H.-S. Nguyen, L. Ferrier (INL / ECL-INSA), J. Kellendonk, N.-V. Dang, A. Duran, D. Perrot, D. Le Roux, J.-M. Stéphan (ICJ / UCBL)

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- P. Delplace *et al.*, Science, 358, 1075 (2019)

Scientific Breakthrough TURBULLET

Particles drifting and propelling in turbulent flows

The consortium

TurBullet is a scientific consortium of Université de Lyon, funded by IDEXLyon and coordinated by Mickaël Bourgoin. It focuses on the investigation of turbulent particle laden flows, in situations where particles drift and/or self-propell in the fluid. This is for instance the case of settling particles or living entities, which are omnipresent in natural and industrial systems. The consortium gathers mathematicians, physicists, mechanical engineers, astro and geophysicists and combines theoretical, experimental and numerical investigations, from 6 leading laboratories of Université de Lyon (LPENSL, ILM, LMA, CRAL, LGL and ICJ).

Scientific challenges

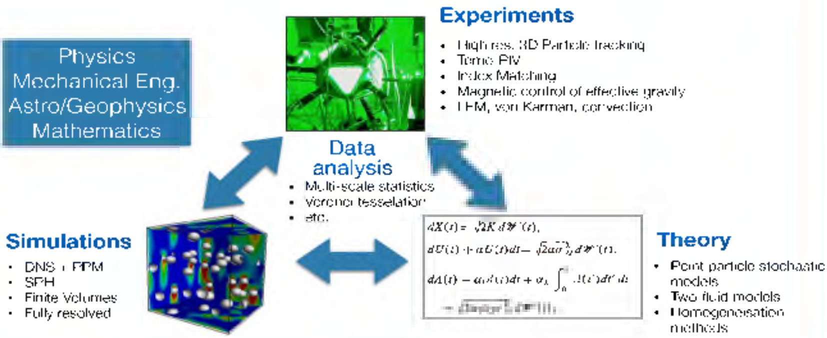
In spite of its apparent simplicity, the problem of spherical particles settling in a fluid hides a whole hierarchy of rich intricate phenomena, some of which are still shrouded in mystery. The question is by no means just rhetorical, as it impacts numerous real situations, such as the atmospheric dispersion of pollutants, dynamics of dust in proto-planetary accretion disks, transport of grains in geophysical flows, sprays in industrial processes and living entities flying in the atmosphere or swimming in the oceans, to cite just a few examples. Unveiling the fundamental mechanisms of drifting particles in turbulence is to improve our capacity to accurately model and predict such particle-laden flows.

Systems of interests

As an example, we can mention astrophysical applications. Major contemporary observation instruments (ALMA, Herschel, SPHERE, JWST) scrutinise the sky at millimetric wavelength and therefore detect indeed the light scattered by dust in space. Understanding its dynamics and its coupling with the surrounding gas has become a major challenge to interpret the observations. Besides, it is also from this coupling that planets emerge form the dust. In the geophysical context, erosion processes rely heavily on particles-flow interactions: eolian transport of sand grains, rainfalls, landslides, river transport, sediment deposition. Within the lithosphere, partial melting, crystallization and transport of grains in magma chambers and ducts contribute to the chemical differenciation of the crust. In the deep interior of the Earth, a possible scenario of the secular cooling of the liquid iron core involves the settling of solid iron grains leading to the formation and growth of the solid inner core. Beyond the sole case of particles with a uniform gravitational drift, similar coupled mechanism also occur when the drift arises from electro/magneto-static interactions on charged/magnetized particles (relevant in particular in geo and astrophysical systems but also in industrial processes), from phoretic phenomena (induced for instance by thermo or diffusio-phoresis), or from the self-propulsion of active entities (such as bacteria, plankton, fishes, birds, etc.) among other examples.

TURBULLET

Multidisciplinary project for particle dynamics



Legend: Our project gathers scientists from physics, mechanical engineering, mathematics, astrophysics and geophysics, with a broad range of expertise in state of the art experiments, simulations and analytical tools.

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References:

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- K. Gustavsson *et al.*, New Journal of Physics, 21, 083008 (2019)
- D. Buaria *et al.*, New Journal of Physics, 21, 043004 (2019)
- N. Machicoane *et al.*, Review of Scientific Instruments, 90, 035112 (2019)

focus

Sciences^{2024}

Sport and sciences, a golden alliance

Mixing sport and sciences

Nowadays, the first places in sport competitions are a few thousandths of second apart and all aspects of performance must be worked on so that the athlete can stack the odds in his/her favor. Scientific disciplines are therefore called upon to help improving the sportive performance. In this context, Sciences^{2024} was launched in 2018 to contribute to the improvement of sport equipment and gesture with the tools of physics, mechanics and mathematics. The initiative, which is coordinated by Christophe Clanet (LADHYX) brings together 11 higher education institutions, among them Ecole normale supérieure de Lyon, who pondered, together with sports federations, on studies to be conducted by scientists with a view on helping athletes in their quest for performance. The objective set is, in particular, to significantly increase the number of medals at the 2024 Olympic and Paralympic Games in Paris, which gives a reasonable deadline for in-depth work.

Organization of Sciences^{2024}

In the Sciences^{2024} framework, a preliminary step, a series of "extractions", consisted for the scientists in attending training sessions of our national teams and establishing, together with the coaches and athletes, a list of questions relevant to each discipline. These questions, shared among all participants in the initiative, have been classified, according to their level of difficulty, to give rise to internship topics or other more ambitious research projects worth longer time effort.

Sciences^{2024} in the lab

Within the Physics Lab, researchers are involved in the development of at least six research themes. During several meetings with sport federations or sportsmen and sportswomen or coaches, the researchers identified points on which science could try to make a contribution. More precisely, scientific questions involve optics, mechanics, hydro- and aero-dynamics. These questions have already been the subject of more than ten internships, one PhD thesis and one postdoctoral fellowship. Problems under consideration are: the alteration of the shooting aim by the mirage effect, the link between the table tennis paddle coating and the ball rebound properties, the optimal underwater trajectory after diving in a swim race, the distance between riders for drafting optimization in cycling, the effect of geometry, inflation, camber on the rolling resistance of the athletic wheelchair.

Sports and sciences

Legend: Logo of the Sciences^{2024} Consortium (left), and snapshots of experiments studying the rebound of a tennis table ball (top right), and the friction of a wheelchair tire (bottom right).

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Collaborators at LPENSL: V. Dolique, H. Gayvallet, J.-C. Géminard, S. Joubaud, P. Odier, S. Paulin, P. Rigord

References:

• C. Clanet, Annual Review of Fluid Mechanics, 47 (2015)
• https://sciences2024.polytechnique.fr

Staff

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

staff

instrumentation

mechanics

PhD

- I. Andrade - *Wrinkling and folding induced patterns in thin sheets* (M. Adda-Bedia)
- N. Bain - *Hydrodynamics of polarized crowds: experiments and theory* (D. Bartolo)
- E. Bautista-Ruiz - *Laplacian powers for graph-based semi-supervised learning* (P. Goncalves / P. Abry)
- C. Cabart - *Emergence d'effets à N-corps en optique quantique électronique* (P. Degiovanni)
- J. Cambe - *Understanding complex dynamics of social systems* (P. Jensen)
- N. Cottet - *Energy information in fluorescence with superconducting circuits* (B. Huard)
- G. Davis - *Attracteurs d'ondes internes de gravité : des résonnances en cascades : une approche expérimentale des régimes linéaires et non-linéaires* (T. Dauxois / S. Joubaud)
- V. Désangles - *Forçage à grande échelle d'une colonne de plasma faiblement magnétisé : influence d'une cathode émissive de grande taille* (N. Plihon)
- V. De Zotti - *Pelage d'un ruban adhésif sur un substrat hétérogène* (S. Santucci / L. Vanel)
- Q. Ficheux - *Quantum trajectories with incompatible decoherence channels* (B. Huard)
- D. Geyer - *Phases denses et ondes acoustiques de la matière active* (D. Bartolo)
- C. Goeller - *Quasi-local 3D quantum gravity: exact amplitude and holography* (E. Livine)
- S. Goomanee - *Rigorous approach to quantum integrable models at finte temperature* (K. K. Kozlowski)
- C. Granero Belinchón - *Multiscale information transfer in turbulence* (S. Roux / N. Garnier)
- P. Husseini - *Interactions non-linéaires d'ondes internes de gravité et mélange en milieu stratifié* (P. Odier / T. Dauxois)
- H. Kabalane - *Analyse génomique et modélisation mathématique de la réplication de l'ADN* (B. Audit)
- S. Lacroix - *Modèles intégrables avec fonction twist et modèles de Gaudin affines* (M. Magro / B. Vicedo)
- C.-E. Lecomte - *Instabilité washboard: formation de rides mécaniques sur un lit de sable* (N. Taberlet)
- T. Lestang - *Approches de physique statistique pour le calcul numérique d'évènements rares dans les écoulements turbulents* (F. Bouchet / E. Lévêque)
- T. Louvet - *Phases relativistes en matière condensée* (D. Carpentier / A. Fedorenko)
- A. Morin - *Mouvements collectifs en milieux désordonnés* (D. Bartolo)
- R. Pedurand - *Instrumentation for thermal noise spectroscopy* (L. Bellon)

defenses

PhD

- B. Pezelier - *Facteurs de formes et fonctions de corrélations de systèmes intégrables quantiques* (J.M. Maillet / G. Niccoli)
- C. Picard - *Mise en suspension de particules immergées par injection de gaz* (V. Vidal / S. Joubaud)
- G. Pillet - *Attracteurs d'ondes internes à trois dimensions : analyse par tracés de rayons et étude expérimentale* (T. Dauxois)
- V. Raban - *Magnetic excitations in spin ice and the fluctuation-dissipation relation* (P. Holdsworth / L. Berthier)
- A. Renaud - *On wave-mean flow interactions in stratified fluids* (F. Bouchet / A. Venaille)
- J. Reneuve - *Modélisation de la structure fine de la turbulence quantique et classique* (L. Chevillard)
- M. Roux - *Inférence de graphe par test multiple : application à la neuro-imagerie* (S. Achard / P. Borgnat / I. Tannas)
- H. Sevi - *Analyse harmonique sur graphes orientés et applications : de l'analyse de Fourier aux ondelettes* (P. Borgnat / G. Rolling)
- J. Thibaut - *Bosons in a gauge field: from exotic condensates to quantum Hall liquids* (T. Roscilde)
- J. Vessaire - *Dynamique et effets collectifs de particules en turbulence* (M. Bourgoin / R. Volk)
- E. Woillez - *Stochastic description of rare events for complex dynamics in the solar system* (F. Bouchet)

Habilitations à diriger des recherches (HDR)

- J. Boutier - *Cartes planaires et partitions aléatoires*
- P. Delplace - *Topological properties of waves*
- T. Gibaud - *Bio-sourced particles for soft matter physics*
- N. Giuliano - *Separation of variables for quantum integrable lattice models*
- F. Montel - *Transport de biomolécules dans des nanopores biologiques et artificiels*
- A. Naert - *Physique statistique hors-équilibre : expériences dans des systèmes macroscopiques*
- N. Plihon - *Dynamos, turbulence magnetohydrodynamique et turbulence plasma*

HIGHLIGHTS 2020

Lab PHYS
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