CentraleSupélec

RESEARCH CENTRE

Laboratories & Research teams,
Remarkable Equipments

CentraleSupélec

université PARIS-SACLAY

CVN

CENTER FOR VISUAL COMPUTING

CENTRE FOR VISUAL COMPUTING
CENTRE DE VISION NUMÉRIQUE
CENTRALESUPÉLEC | INRIA

Inria cnrs

Computational vision is one of the most challenging research domains in the engineering sciences. The aim is to reproduce human visual perception through intelligent processing of visual data.

CVN aims at proposing innovative techniques towards automatic structuring, interpretation and modeling of big (visual) data. CVN is associated with Inria Paris-Saclay through a joint research project-team (OPIS). Researchers of CVN are also members of the *Fédération de Mathématiques* de CentraleSupélec (FR CNRS 3487). Our primary objective is to remain a reference center of international scientific excellence and to contribute significantly to the theory and practice in the field of computer vision, artificial intelligence, and (bio) medical imaging.

Research themes

OPTIMIZATION

Variational problems requiring the estimation of a very large number of variables have now to be tackled, especially in the field of inverse problems (e.g., $\geq 10^9$ variables in 3D imaging). In addition to the curse of dimensionality, another difficulty to overcome is that the cost function usually reads as the sum of several loss/regularization terms, possibly composed with large-size linear operators. These terms can be nonsmooth and/or nonconvex, as they may serve to promote the sparsity of the sought solution in some suitable representation or to fulfill some physical constraints. In such a challenging context, we develop advanced deterministic and stochastic optimization methods based on fixed point iterations, proximal techniques, majoration-minimisation (MM) approaches, and distributed/parallel implementations.

ARTIFICIAL INTELLIGENCE

Machine learning methods have led to impressive results in various domains of Data Science. Nevertheless, the fundamental reasons for their excellent performance are often still poorly understood. We are developing robust, explainable, and efficient inference methods. Deep neural networks are the current state-of-the-art methods for solving a wide range of diverse tasks in signal/image classification or regression. We are working on reliable design and learning techniques for neural networks. We address challenges raised by partially annotated data and weakly supervised learning. Machine learning on graphs is also an important task with a plethora of practical applications. Our goal is to develop a systematic framework for large-scale data mining and representation learning on graphs.

IMAGE PROCESSING

Imaging devices provide a huge amount of information at various scales thanks to a wide range of modalities (MRI, Xray, PET, ultrasound, microscopy, ...). These images can be multispectral, volumetric or correspond to sequences of 2D or 3D fields. Our group has developed a long-term expertise in image analysis, segmentation, denoising, restoration, and reconstruction. Advanced image models are built thanks to convex or nonconvex variational approaches. Bayesian methods are also employed, as well as techniques based on mathematical morphology and graphs.

APPLICATION DOMAINS

Health

- Computer aided diagnosis
- Computer assisted surgery
- Image biomarkers

Complex industrial systems

- Non destructive control
- Safe systems
- Optical flow
- Decision making

HIGHLIGHTS 2023

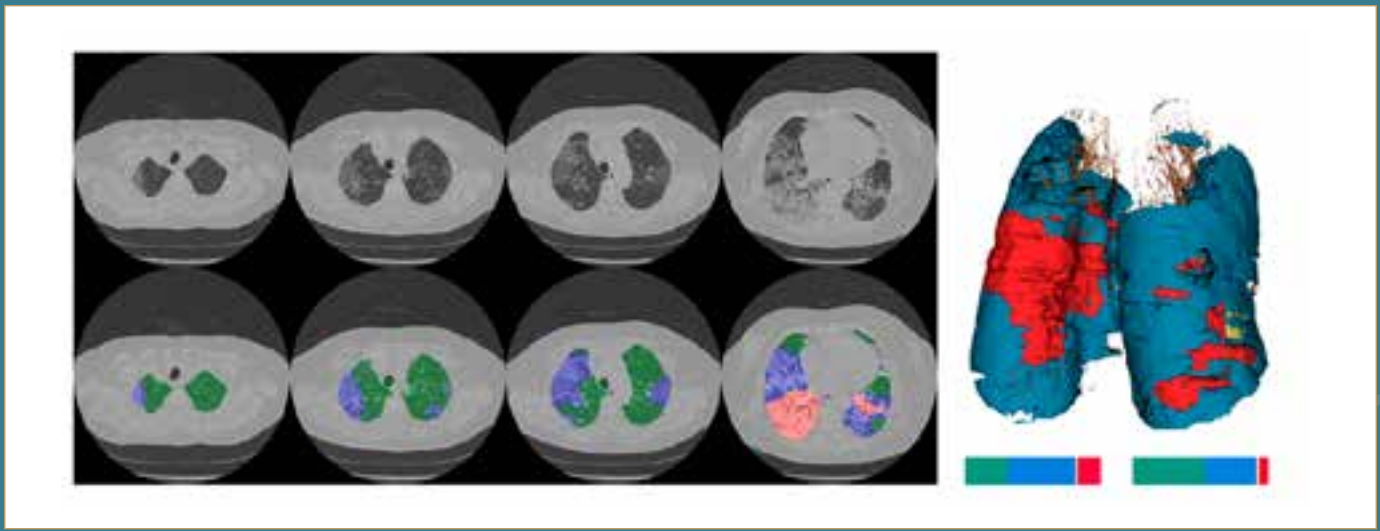
Yunshi Huang, Emilie Chouzenoux and **Jean-Christophe Pesquet** in collaboration with V. Elvira from University of Edinburgh proposed a new fast inference method for training Bayesian neural networks. This led to the best oral talk award at the International Conference on Machine Learning and Intelligent Systems (MLIS).

Younes Belkouchi and Hugues Talbot in collaboration with **P.-H. Cournède** and **Institut Gustave Roussy** proposed a new score for defining the progression of tumors in immunotherapy treatment.

Alexandre Duval, under the supervision of **F. Malliaros,** developed a generative graph flow model for crystal structures in collaboration with MILA in Montréal. This model has potential applications in improving the efficiency of renewable energy production and storage.

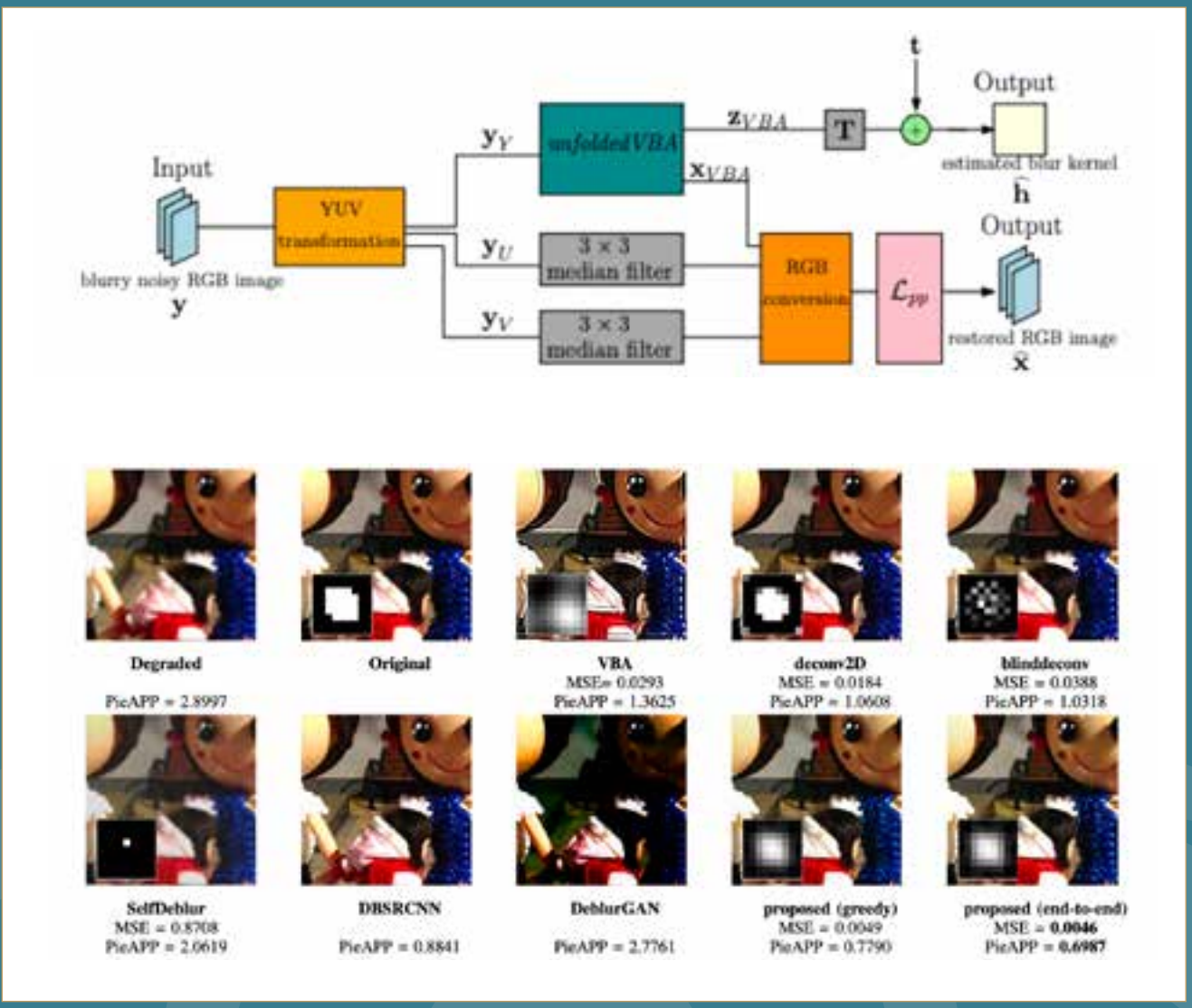
Marion Savanier received an Accessit Ph.D. ICT Award from the University Paris-Saclay and Institute Polytechnique of Paris in 2023. She also received the 2nd award for the Impact in Science PhD award delivered by CentraleSupélec Foundation.

EXAMPLES OF STUDIES



New image restoration method based on deep learning.

In collaboration with two Paris hospitals and a startup, and using a dataset including medical exams of about 1000 patients, we have developed an approach based on ensembling of neural networks for quantifiying covid-19 pulmonary lesions (green correspond to healthy areas, blue, yellow, and red to more and more severe lesions). [https://hal.archives-ouvertes.fr/hal-02586111]



Understanding Images using end-to-end trained deep Gaussian CRFs.

The unknown blur degradation model is estimated and inverted (blind context). The proposed neural network architecture is explainable since it is designed by unrolling an iterative Bayes Variational Approach.

[https://hal-centralesupelec.archives-ouvertes.fr/hal-03881393].

Industrial Partners

- CEA
- Essilor
- General Electric Healthcare
- Heartflow
- Safran
- Schneider Electric
- SNCF
- Thales

Academic Partners

Institut Gustave Roussy (FR), Kremin-Bicêtre Hospital (FR), Henri Mondor Hospital (FR), European Hospital Georges Pompidou (FR), Pitié-Salpêtrière Hospital (FR), Université Gustave Eiffel (FR), École des Ponts-ParisTech (FR), North Caroline State University (USA), Stanford University (USA), StonyBrook University (USA), University of Pennsylvania (USA), University of California at Los Angeles (USA), Sup'Com Tunis (TU), Technical University of Munich (DE), Heriot-Watt University (UK), University of Edinburgh (UK), University College London (UK), Aalto University (Finland), Polithenica University (RO), Ecole Polytechnique de Montreal (CA), University of Toronto (CA), Indraprastha Information Institute of Technology, Hyderabad (IN), Aristotle University of Thessaloniki (GR), Polish Academy of Sciences (PO).

Partnerships and Collaborations

- DATAIA
- Bernoulli Lab

Key figures

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EM2C, CNRS UPR 288

LABORATOIRE ÉNERGÉTIQUE MOLÉCULAIRE & MACROSCOPIQUE, COMBUSTION

Energy and transportation have become significant issues likely to disrupt the general organization of society severely. The scarcity of oil, the rational use of fossil fuels, reducing emissions, developing renewable energies, and climate change risks pose many scientific questions. High-level academic research on energy and combustion from molecular scales to more macroscopic scales and applied studies, in partnership with leading companies and research centers in the field of transport and energy, allows the EM2C laboratory from CNRS at CentraleSupelec, to contribute significantly to the advancement of knowledge of these problematic issues.

Energy research at the heart of the Twenty-First Century industrial challenges

The laboratory's research activities are organized around three axes: combustion, non-equilibrium plasmas, physics of transfers, and transverse action in Applied Mathematics.

Combustion activities focus on the understanding, control, simulation, improvement, and optimization of combustion. The objectives are a better understanding of basic mechanisms and their interactions simultaneously developed through experimentation, modeling, and high-performance numerical simulations. This research is also based on innovations in diagnostics, sensors, actuators, control methods, and means of simulation.

Research on non-equilibrium plasmas includes fundamental studies using advanced optical diagnostics of the hydrodynamics and chemical kinetics of non-equilibrium plasmas at atmospheric pressure. In parallel, we consider applications to the fields of energy (ignition and stabilization of lean mixtures of fuel, hydrogen production), aerodynamics, atmospheric re-entry (VUV radiation, ablation), bio-decontamination.

Research conducted in the physics of transfers' team is around the energy transfer by radiation in gaseous media, transfers in porous media, and nano-thermal sciences. By combining fundamental approaches and the development of effective heat transfer models, this research addresses scientific and technological barriers related to applications as diverse as atmospheric re-entry spacecraft, transfer within the core of a nuclear reactor, or nanomaterials.

Transversal action in applied mathematics links fundamental mathematical and numerical tools on the one side and applications on the other side to provide solutions when stumbling blocks are to be found. Mathematical modeling, numerical analysis, scientific computing, and high-performance computing (HPC) improve the resolution of complex problems such as multi-phase flow simulations. Strong interaction with experimental researchers in the laboratory is also used to validate the developed models and codes and an in-depth understanding of the studied physical phenomena.

EXAMPLES OF STUDIES

Progress have been made for the development of reduced order models of disperse two-phase flows, where equations are filtered, so that only large scales are resolved. First, an original mathematical method, using an infinite sum of Ornstein-Uhlenbeck processes, has been developed to construct stochastic models aiming at reproducing the intermittency, which are phenomenon, corresponding to violent fluctuations of the dissipation field of the turbulent flow. This formalism allows not only to unify the writing of the existing processes but also to develop a new one, more versatile and more efficient in computation time. Moreover, a new kinematic model based on divergence-free wavelets has been proposed, to recover the properties of the unresolved scales. This allows to recover the heterogeneous spatial distribution of inertial particles in a turbulent flow.

In collaboration with Rodney O. Fox, two quadrature-based moment methods were developed for the description of population of particles such as droplets, bubbles or soots. One is the hyperbolic quadrature method of moments (HyQMOM), which is a globally hyperbolic velocity moment method, able to describe phenomena like particle trajectory crossing, a key point for the accurate prediction of the density of inertial particles when using Eulerian models. The other one is the generalized quadrature method of moments (GQMOM), which generalizes QMOM, used for the description of the size polydispersion of the particle population. GQMOM provides a more accurate moment method than QMOM, at nearly the same computational cost.

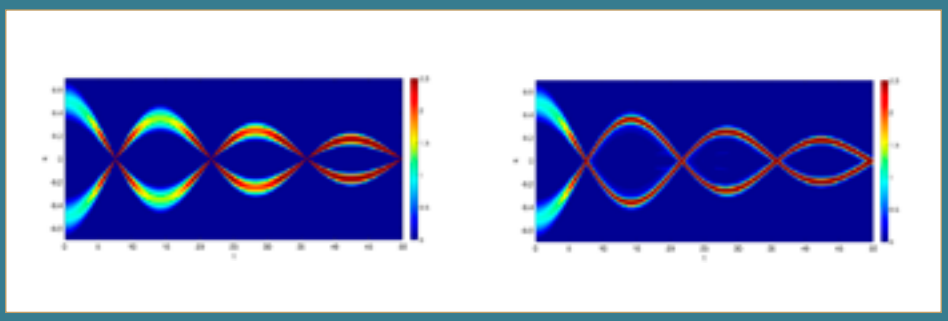

Fig.1: Number density for the analytical solution (left) and simulation with HyQMOM using 5 moments (right) of two crossing jets.

Progress have been made for the simulation of the acceleration and transition from deflagration to detonation of hydrogen/air flames, which is critical for nuclear safety. A high-order numerical solver was developed. Coupled to multiresolution techniques for mesh adaptation and immersed boundary methods for non-trivial geometric configurations with structured meshes, this allows to accurately capture the different stages of the flame acceleration and the transition to detonation and to reproduce the experimental observations.

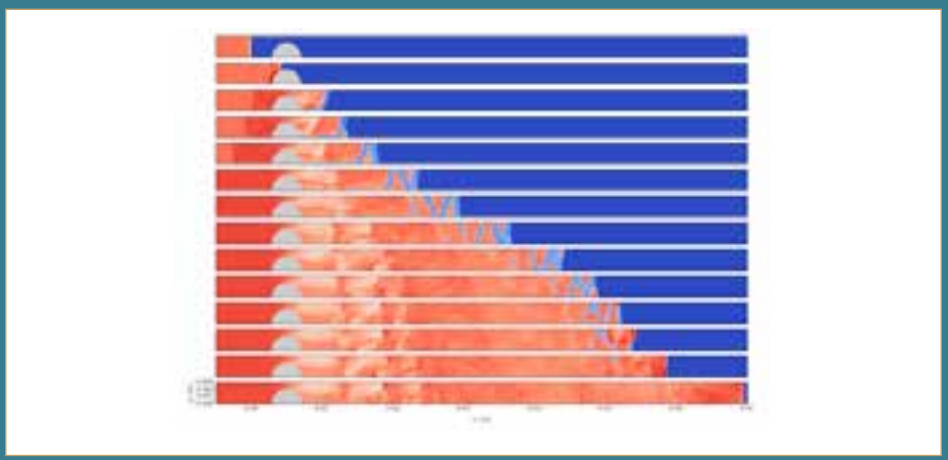

Fig.2: Temperature field evolution illustrating the detonation re-initiation.

A sharp interface approach was developed for computing two-phase flows with surface tension and phase change in the low Mach regime, where conventional compressible solvers lose accuracy. High-order approaches for interface advection and curvature estimation were proposed, as well as a new low Mach correction, able to recover a good asymptotic-preserving property, in the context where the interface is treated as the contact discontinuity via the Ghost Fluid method for a sharp interface. Several numerical test cases have been employed to validate and improve the present numerical approach's performance.

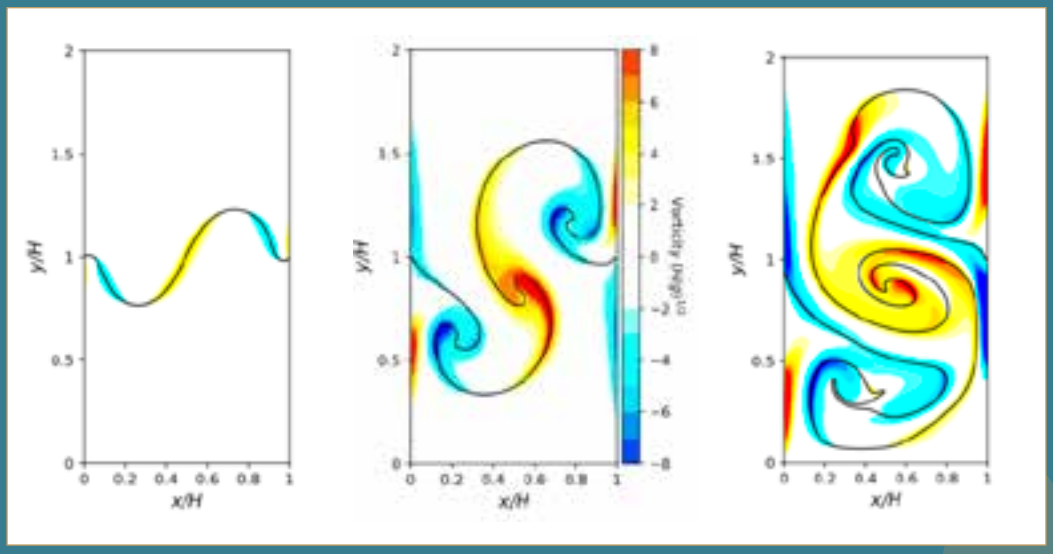

Fig.3: Vorticity of Rayleigh-Taylor instabilities obtained with the present compressible Level-Set scheme, at three dimensionless times: (t= 1, 3, 5). The black lines show the interface.*

The path towards carbon-free aeronautical propulsion and power generation necessitates the adoption of disruptive technologies and new fuels. Among them, hydrogen constitutes an interesting option because its combustion in air produces no carbon compounds. However, hydrogen flames raise many difficult issues: their high burning velocity promotes flashback, and their elevated adiabatic temperatures promote NOx emissions. To control these two phenomena, hydrogen and air must be quickly premixed to avoid hotspots, and the mixing has to be lean to reduce the flame temperature and NOx formation. These items are investigated in a laboratory scale test combustor (SICCA). This system, used to investigate the dynamics of swirled flames, has been equipped with a novel hydrogen injector operating in a lean direct injection mode (LDI). This unit uses a cross-flow injection to obtain a balance between premixing (to reduce NOx emissions) and resistance to flashback (for safety and operability issues). Parametric studies performed to investigate the behavior and structure of the flame throughout the operating domain have uncovered regions where the flame is detached from the injector and operates in a stable manner and regions where dynamical phenomena are manifested leading to combustion instabilities. Lifted flame configurations have been identified as promising candidates for further investigations that will include NOx emissions measurements and systematic determination of Flame Describing Functions, to assess their potential dynamic behavior. The novel injector will then be tested in the annular chamber MICCA for a complete assessment of the hydrogen-air flames' dynamics in a more realistic annular configuration.

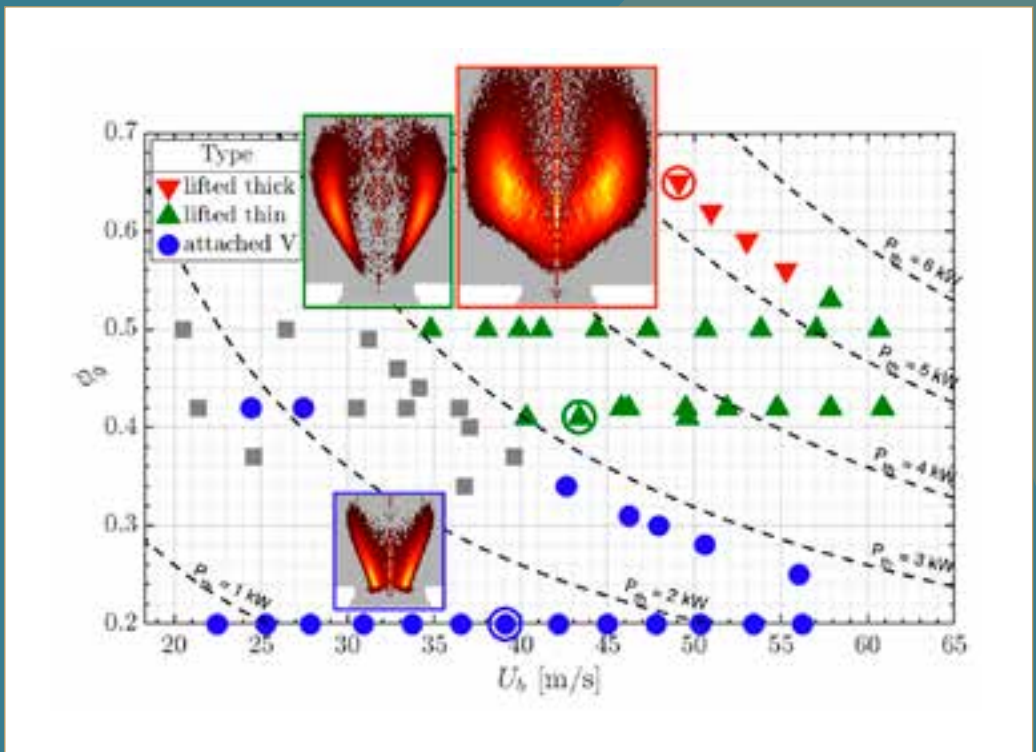

Fig.4: Map of the operating domain of SICCA using the CFI-X1 injector. Grey symbols correspond to unsteady operating points. In the higher thermal power range the flames are detached from the injector and are less sensitive to instabilities.

Industrial Partners

- AIRBUS
- AIR LIQUIDE
- ARIANE GROUP
- CEA
- CNES
- DGA
- EDF
- ENGIE
- ESA
- FLUIDYN
- IFPEN
- IRSN
- MBDA
- NAVAL GROUP
- ONERA
- ORANO
- RENAULT
- SAFRAN
- Stellantis
- THALES...

Academic Partners

CERFACS, CORIA, CETHIL, ENS, ESPCI, Fresnel Institute (Marseille), IMFT, LPGP, LPP, LIMHP, LISN, PC2A, CMAP, Canadian Nuclear Laboratories, Colorado State University, Johns Hopkins University, Old Dominion University, Pennsylvania State University, Stanford University, Yale University, University of Rochester, MIT, Nasa Research Centers, Magdeburg, University of Potsdam, Autonomous University of Madrid, University Asunción Paraguay, JAXA, Iowa State University...

Key figures

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GEEPS - UMR 8507

GROUP OF ELECTRICAL ENGINEERING – PARIS

The laboratory GeePs is a joint unit of CentraleSupélec, Université Paris-Saclay, Sorbonne Université and CNRS. It is located on two sites: the CentraleSupélec campus of the Paris-Saclay University in Gif-sur-Yvette and the Pierre & Marie Curie campus of the Sorbonne University in Paris.

With more than 250 collaborators, consisting of 127 permanent staff (researchers, lecturer-researchers, engineers, technicians and administrates), about 70 PhD students, numerous visiting scholars and trainees, it is one of the most important laboratories in the field of "Electrical Engineering" in the "Ile de France" region.

The research conducted in the laboratory combines a three-pronged approach: theory – numerical modeling - experimental characterization / validation. It is distributed over **three research departments** that assure a continuum of activities that extend from materials to electronic or energy conversion systems.

The research activities are supported by **two transverse centers of expertise**. The first center capitalizes the historical competence of the laboratory in numerical modeling of electromagnetic systems with an orientation towards multiphysics and coupled problems on the one hand, and the complex electromagnetic environment on the other hand. The second gathers together the numerous experimental platforms of the laboratory with the primary objective of pooling together instrumentation skills and sharing know-how and resources.

The three departments and the two expertise centers interact through **thirteen themes** (research groups) whose activities address five major societal issues as shown in figure next page.

MATERIALS: PHYSICS & COMPONENTS

In the "Materials" department, we are interested in new materials for applications in the field of electronics and electrical energy, for better efficiency, lower cost, or to avoid toxicity problems, or to achieve better stability and offer more outstanding durability.

We study the fundamental aspects of materials, their electrical properties, but also physical or physico-chemical properties, mechanical, magnetic, ferroelectric, piezoelectric aspects, along with multiphysical couplings. These studies extend to the operation and properties of components made from these materials, which can be integrated into systems. We develop original characterization platforms and techniques, as well as adapted numerical modeling.

Our main application areas are in the themes: Photovoltaics, Nanoelectronics, Electrical Contacts and Connecting Devices, Power Electronics and Sensors and Functional Materials.

ELECTRONICS: WAVES, COMPONENTS, SYSTEMS

The electronics department aims to address the societal challenges defined within the GeePs' scientific project, by offering a wide range of solutions and methods in the field of hardware information processing.

To this end, it is developing a strategy promoting transversality and studies at interfaces, and conducting research in close connection with the industrial partners and the academic world on a national and international level. It focuses its activities around:

- Ultra-low power consumption, miniaturization and reliability of integrated circuits and systems (autonomy of connected objects, bio-sensors)
- Control of the generation, propagation and detection of electromagnetic waves (detection, localization and focusing of energy and information)
- Multiphysical coupling of functional materials (energy transfer and energy harvesting)
- Electromagnetic control of complex media and CEM (modeling and inverse problem)

The Electronics Department, structured around five themes, three of which are cross-cutting, has strong skills in the field of integrated electronics, electromagnetic waves and sensors.

For all of these activities, Electronics Department relies on significant hardware and software resources embodied by the two centers of expertise of GeePs.

ENERGY – COMPONENTS, CONVERSION AND SYSTEMS

Electrical energy systems have to fit into a context of energy decarbonization, which places electricity as a key vector for the exploitation of renewable energies, and into a process of massive electrification of uses. Whether in land or air transport, in energy distribution, or in certain

sectors such as health and well-being, equipment must satisfy constraints of reliability, energy efficiency, compactness and flexibility. In embedded applications, higher levels of integration bring components physically closer together, and increase the complexity of system behavior through new couplings and interactions.

The "Energy" department aims to design, model, control and optimize electrical and electronic energy systems in order to broaden the fields of use of these systems (more electric aircraft, carbon-free vehicles, smart-grids, biomedical applications, etc.) by meeting the challenges arising from the constraints on applications.

Among these, we note:

- Improving energy efficiency and performance (in particular through system design and control),
- Integration (compactness, miniaturization...),
- Reductions of mass and cost,
- Improving reliability (in diagnosis, detection, protection, ...).

Research groups address 5 major themes:

- Actuation,
- Power Electronics,
- Transmission and Distribution Electricity Networks,
- Electrostatic, Electrical discharges, Arcs, Plasma Processes.

THE TWO EXPERTISE CENTRES

Electromagnetic and Multiphysical Modeling

The Expertise Centre "Electromagnetic and Multiphysics Modeling" results from a historical expertise and a significant role played by the laboratory in developing of numerical models and simulation tools in Electrical Engineering. This is supported by over twenty modeling servers run by the department with access to the *CentraleSupélec Mesocentre* computing platform providing computing power, and electrical engineering and multiphysics modeling software both in-house and commercial.

This expertise is connected to various research subjects carried out within the different groups in GeePs. Researchers develop their own original dedicated modeling approaches, open source tools, or even exploit cutting edge commercial software. An important target of the Expertise Center concerns the dissemination of know-how.

The objectives are as follows:

1. Maintain and disseminate the expertise related to modeling and numerical methods. Promote modeling / simulation tools between the different groups of GeePs. To this end, the center organizes scientific meetings or discussions for better dissemination of skills around modeling methods and software.

2. Set up Master level scientific animation courses/ internships related to electromagnetic and multi-physics modeling in connection with the research topics of the laboratory.

3. Identify, share, and optimize computing resources within the constituent research groups and the different sites in coordination with the CRI (the digital resource center), and promote local communication and remote access to simulation tools via the expertise center.

Characterization Instrumentation Platforms

The disciplinary fields of the GeePs, which range from materials physics to component and systems engineering. In each of its domain of expertise, a recognized and solid know-how in both material and electrical characterization has been acquired over time. Through its research activities, the laboratory has a long history, and the skills, in the development of original instrumental devices to extend its experimental analysis capabilities. When appropriate, those devices can be commercialized. The GeePs has also invested in high end, specialized, complementary equipments assuring its leading position locally and nationally.

The expertise center has the mission of supervising the experimental platforms and its equipments. Its main objectives are focused on:

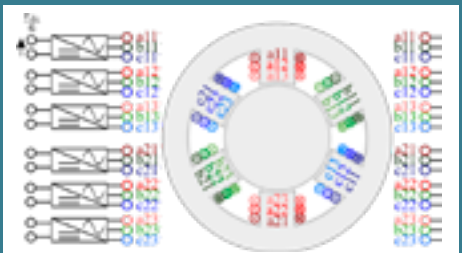
- The identification of equipment, expertise, and instrumental developments in order to facilitate the provision of equipment,
- The promotion of internal know-how,
- The listing of equipments, instrumental developments, and software requirements to set up training and funding actions following the scientific orientations of the laboratory's themes,
- The communication on our technical resource and expertise in order to stimulate the use of specific equipments for service providing,
- Setup price list for internal and external provision of service.

HIGHLIGHTS 2023

- **Frédéric Reymond-Laruina** received the Thesis prize IEEE PES France 2023.
- **Vincent Andraud** was awarded the *Prix de thèse Ampère-SEE 2023* by the *Société de l'électricité et de l'électronique*.

- **Alexandre Bach** received the Best presentation prize symposium SATES 2023.
- **Vladimir Pineda-Bonilla** was awarded the *Roland Coehlo prize* for the best poster presentation for his poster entitled *Analysis of the effects of partial discharges in a power cable for aeronautical use*).

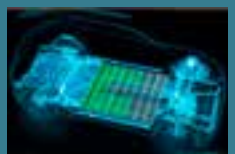
- **Fractional Power Supply drive train (CTAF)**
The patented CTAF concept enables us to rethink the structure of drive trains, including power electronics, control and the electric machine, by extending the principle of fractioning this assembly to a level well beyond the most recent achievements. The new concept makes for a much more flexible combination of source(s) and machine(s), with additional degrees of freedom to enable a true optimization continuum and resilient, potentially multi-source operation (GeePs/ SATIE cooperation).



Principle and realization of the fractioning of a motorization chain

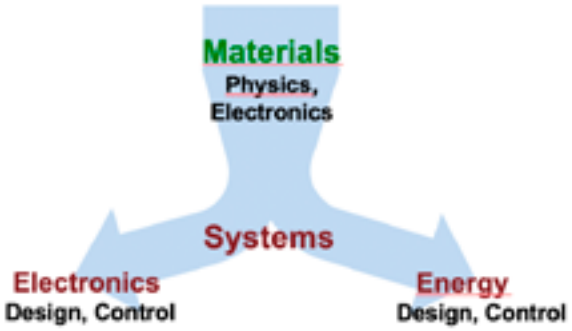
- **Intelligent Battery Integrated System (IBIS)**
After four years of design, modeling and simulation, a team of twenty-five engineers and researchers from CNRS, Stellantis and Saft unveiled on 20 July 2023 an innovative prototype energy storage battery that integrates the functions of inverter and charger. This integration makes it possible to create a battery that is more efficient, more reliable and less expensive. For electric vehicles, it frees up space and improves range. In the field of stationary energy storage and renewable energy integration, the IBIS concept offers turnkey installations with improved availability, optimized use of installed energy and a smaller footprint.

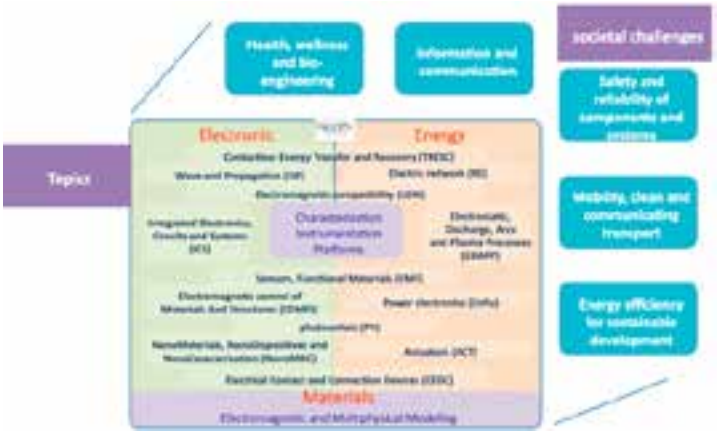
The IBIS project is funded by the *Plan d'Investissement du Futur* (France 2030), administered by ADEME (Agence de gestion de l'environnement et de l'énergie) and coordinated by Stellantis. It brings together industrial partners Saft (TotalEnergies Group), E2CAD and Sherpa Engineering, as well as three CNRS research laboratories (GeePs, SATIE, LEPMI) and the Lafayette Institute.



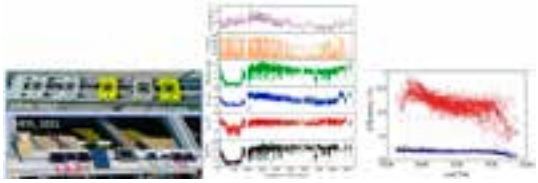
Three phase power generation

Renewable energy plant with stationary storage batteries

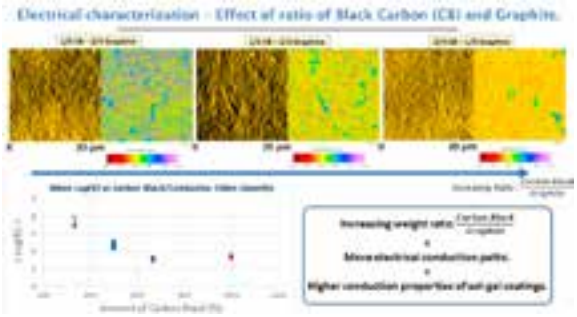




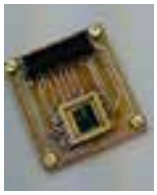
Organization of the laboratory



PV platforms at SIRTA and long-term evolution of the output PV parameters of perovskite solar cells

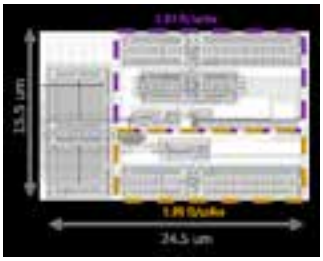


Characterization by conductive probe AFM (Résiscope) of sol-gel coatings with two types of fillers (carbon black and graphite) for conducting properties. Sol-gel coatings with three different compositions are shown here. For each image : topography on the left and electrical resistance on the right (J. Acquadro PhD).

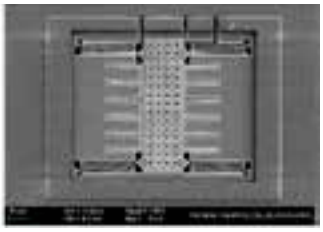


Infrared detector array based on amorphous semiconductor Y-Ba-Cu-O in its integrated circuit package mounted on a test printed circuit board. Technology in collaboration with C2N.

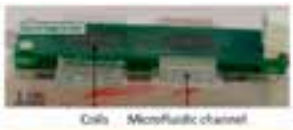
Materials: Physics & Components department



New design of ultra-low power neuro-inspired device



Micro electronic design for vibratory energy harvesting



Lab-on-chip, detection of biological agents

Micro-Transducer for remote supply

Data and Energy focusing: antenna arrays and metasurface antenna

Electronics: Waves, Components, Systems Department

Installation of the Turning Sun into Water project

Test bench 15000 rpm 60 kW

Energy – components, conversion and systems Department

Industrial Partners

- Airbus Helicopters
- Amphénol Socapex
- CEA
- CETIM
- DGA
- EDF
- EFI Automotive
- FORVIA
- IFP Energies Nouvelles
- Nidec Corporation,
- ONERA
- Quantom
- Renault
- RTE
- Safran
- SNCF
- Stellantis
- Thales,
- Valeo
- ITE IPVF
- ITE VeDeCom
- SuperGrid Institute
- IRT SystemX
- IRT Saint-Exupéry

Academic Partners

L2S, C2N, Esycom, ESTACA, LMD, LPGP, LMPS, SATIE, LIMSI, XLIM, IMN, ICMMO, LSPM, Inst. Fresnel, IRDL, GScop, Hôpital Marie Lannelongue, GdRs SEEDS / Ondes / SOC2, FedPV, GDRi Sinergie, ELyT-Max, Texas University, Politechnico Turin, Univ. Patras, Univ. Rep. Paraguay, Univ. JiaoTong Xi'An, Univ. Rabat, Nanyang Technological University of Singapore, LRI 3288 CINTRA (Singapore), KEK Tsukuba (Japon), Chang Gung University (Taiwan), Chulalongkorn University (Thailand), UFSC (Universidade Federal de Santa Catarina), Aalto (Finland).

Key figures

• Professors, Associate Professors & Researchers	96
• Engineers & Administrative staff	31
• PhD Students	68
• PostDocs	18
• Visiting Professors	8
• Publications of the year (WoS)	114

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IETR, UMR CNRS 6164

INSTITUT D'ÉLÉCTRONIQUE ET DES TECHNOLOGIES DU NUMÉRIQUE

IETR, Institute of Electronics and Digital Technologies, is a joint laboratory between the CNRS (INSIS), Rennes and Nantes universities, INSA of Rennes and CentraleSupélec. It also hosts researchers associated through the hosting agreement between the University of Western Brittany, ECAM Louis de Broglie, ESEO, IFSTTAR-Nantes.

The laboratory has about 380 people, faculty members, PhD students and technical and administrative staff, located on several sites in Brittany and *Pays de la Loire*. The IETR has a large set of technical platforms to carry out life-size experiments.

The Rennes campus of CentraleSupélec houses 4 of the 13 teams of the laboratory.

Teams

AUT TEAM (Automation)

The aim of the Automation team is to develop algorithmic control and analysis solutions for large and interacting systems. Anticipating known reference trajectories and disturbances as well as taking into account constraints and multi objectives, most activities are based on Model Predictive Control. From a methodological point of view, the work focuses on:

- The distribution and hierarchization of the analysis, identification, control and state estimation of dynamic systems, particularly hybrid ones that involve both continuous and logical behaviors.
- Consideration of the safety and robustness of distributed control applications when one of the cooperating actors becomes non-cooperative.

Based on its methodological and application knowledge, the team contributes to the development of Intelligent Energy Systems, in particular through its works on:

- Energy efficiency of systems,
- Energy management and integration of renewable energies in positive energy buildings,
- Integration of active buildings into energy distribution networks,
- Active management of distribution networks and micro-grids to ensure optimal operation and flexibility.

AIMAC TEAM (Artificial Intelligence for Multimodal Affective Computing)

In the area of Affective Computing, we analyze, synthesize and track emotions. We develop tools drawn from Artificial Intelligence (Auto-encoders and GANs) applied to the fields of image, voice and text.

The team offers a new way of representing emotions that makes it possible to follow a person's emotional state over time. This real-time analysis of a user's emotions is multimodal: it exploits the voice, speech, context, gesture and facial expressions. Current work focuses on stress detection and micro-expressions spotting and analysis in a medical context. The tools developed come from Deep Learning mainly: GAN, VAE, CNN and auto-encoders mainly. The research work of the AIMAC team has been enhanced through the creation of three startups: Dynamixyz (Performance Capture), 3D Sound Labs (Binaural Reproduction) and Immersive Therapy (Tinnitus App.).

SIGNAL & COMMUNICATIONS DPT. (SC)

The Signal and Communications (SC) department is composed of two thematic teams: the SIGNAL team, which brings together skills in signal processing, algorithms and digital communications, and the ASIC team, which brings together skills in embedded electronic systems and architectures.

The two teams, which are multi-site and multi-institutional, are highly complementary and are based on cross-disciplinary skills ranging from circuits and architectures to signal processing algorithms for communications systems.

For the IETR, the SC department deals with signal processing, algorithms, digital communications and embedded electronic systems and architectures, including the creation of prototyping platforms to meet the needs of future radio transmission systems. Thus, four transversal axes to the two teams SIGNAL and ASIC ensure thematic coherence:

- Axis 1: Digital communication systems,
- Axis 2: Embedded and secure communicating systems,
- Axis 3: Communicating electronics,
- Axis 4: Networks and communication infrastructures.

Each of these axes is found in both teams and is broken down into scientific and technological locks.

HIGHLIGHTS 2023

- Accepted project : CMA xG (Compétences et Métiers d'Avenir)
- Accepted project : PEPR TASE on Advanced Energetics Systems
- 3 new PhD Students
- SATIE research group from ENS Rennes joined IETR AUT Dept.

EXAMPLES OF STUDIES

❑ Anticipate the future behavior of the system using its dynamic model

Prediction Model:

$$\begin{cases} x_{k+1} = f(x_k, u_k) \\ y_k = g(x_k) \end{cases}$$

❑ Define the objectives of the control on an H prediction horizon

Criterion:

$$J_g = \sum_{k \in H} (J_{eco} + J_{incon})$$

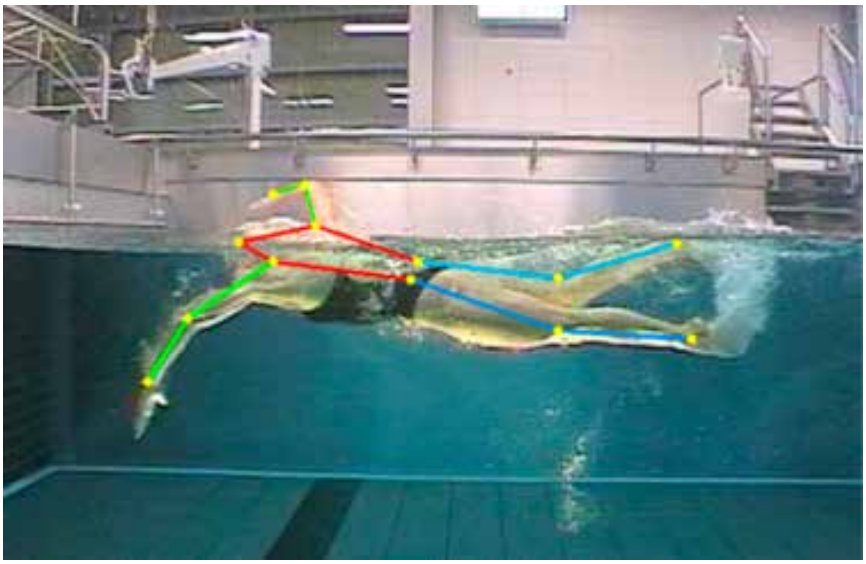
❑ Formalize the constraints of the system

Constraints:

$$\sum_{m \in M} P_m^{max} u_{m,k} \leq P_k^{global\ max}$$

❑ Find the future control sequence to apply to the system in order to optimize the criterion

Predictive control



The SWIMXYZ project, labeled by DigiSport, focuses on capturing and analyzing a swimmer's movements in order to improve his performance

SC Test Bed

- *10 Universal Software Radio Peripheral (USRP) Boards*
- *2 Windows stations*
- *1 Linux station*

Industrial Partners

- Bouygues,
- Delta Dore,
- Enensys,
- GDI Simulation,
- Orange,
- SAFRAN,
- Siradel,
- Thales.

Academic Partners

ITMO University, French hospital research laboratories (Rennes, Angers), EUR Digisport, IIIT Delhi, Liège University, Patras University, Poznan University of Technology, Zhejiang University, Mahindra University, Patna University...

Key figures*

• Professors, Associate Professors & Researchers	15
• PhD Students	20
• PostDoc	1
• Publications of the year (WoS)	14

*CentraleSupélec only

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CentraleSupélec within

IRISA, UMR CNRS 6074

INSTITUT DE RECHERCHE EN INFORMATIQUE ET SYSTÈMES ALÉATOIRES

Research axes

Irisa, Research Institute in Computer Science and Random Systems, is currently the largest French research laboratory (850+ people) in the field of computer science and information technology. The laboratory covers all the themes within these fields, from computer and network architecture to artificial intelligence, including, e.g., software engineering, distributed systems and virtual reality.

IRISA, is a joint laboratory of nine institutions, in alphabetical order CentraleSupélec, the CNRS, ENS Rennes, IMT Atlantique, Inria, INSA Rennes, Inserm and Rennes and South Brittany universities. Focused on the future of computer science at large, with internationally recognized expertise, IRISA is present on three sites in Brittany (Rennes, Lannion, Vannes), at the heart of a rich regional research and innovation ecosystem.

Its multidisciplinary approach gives rise to a force of women and men who give their best for the fundamental and applied research, training, exchanges with other disciplines, scientific mediation, know-how and technology transfer.

In order to remain at the leading edge of computer science and information technology, while accompanying the digital transition of society and other scientific disciplines, the laboratory is structured in seven scientific departments, along with seven transversal axes addressing societal challenges such as cybersecurity, health, environment and ecology, transport, robotics, energy, and culture.

The Rennes campus of CentraleSupélec houses one of the 40 teams of the laboratory.

CIDRE TEAM (Confidentiality, Integrity, Disponibility & Repartition)

CIDRE is a joint research group between Inria, Rennes university, CNRS and CentraleSupélec, focusing on the security of distributed information systems. The long-term ambition of the team is to contribute to build distributed systems that are trustworthy and respectful of privacy, even when some nodes in the system have been compromised.

With this objective in mind, the CIDRE group focuses on three different aspects of security, namely trust, intrusion detection, and privacy as well as on the bridges that exist between these aspects.

With this objective in mind, the CIDRE team focuses mainly on the three following topics:

- Attack comprehension
- Attack detection
- Attack resistance.

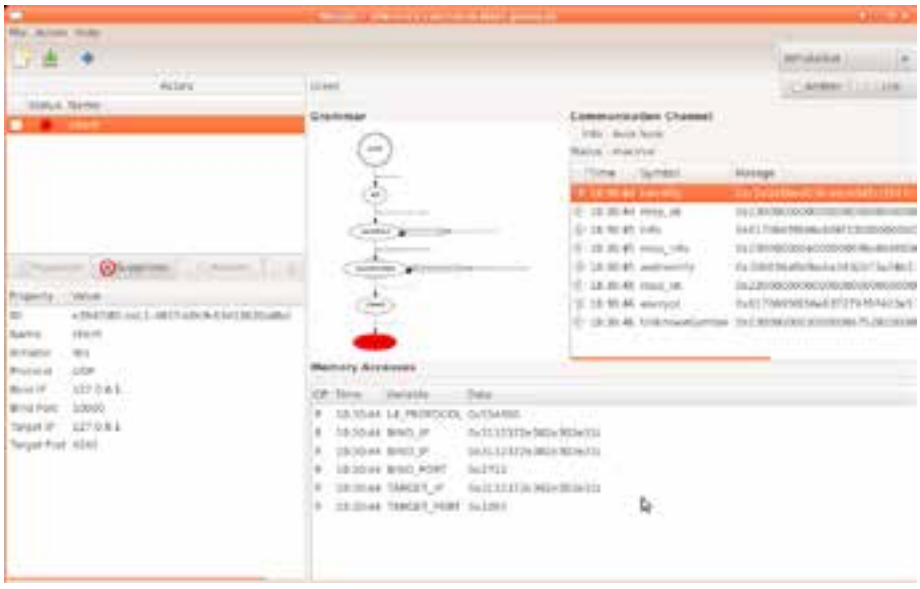
HIGHLIGHTS 2023

Accepted projects: **PEPR Defmal**, **SecureEval**

Accepted project: **CMA Cyber**

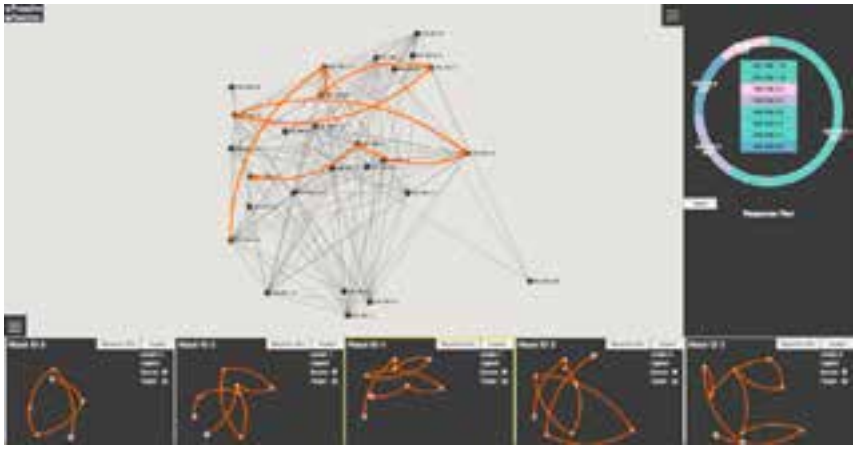
New organization proposal about CIDRE team to be splitted into two teams: **PIRAT** and **SUSHI** in 2024

EXAMPLES OF STUDIES



Protocol Analysis with the Netzob software

Execution of Android malicious code with GroddDroid



VEGAS: security alerts visualization

Hardware information flow monitoring with HardBlare

Industrial Partners

- CISCO,
- Hackuity,
- HEWLETT-PACKARD,
- Malizen,
- NOKIA,
- OBERTHUR,
- ORANGE,
- THALES...

Academic Partners

University of Luxembourg, ENSI Bourges, ENSI Caen, IMT, INSERM, LabSTICC, LAAS, La Sapienza University, LIRIS, Nantes University, National University of Singapore, Technische Universitat of Hamburg-Harburg

Key figures*

• Professors, Associate Professors & Researchers	19
• PhD Students	14
• PostDoc	1
• Visiting Professor	1
• Publications of the year (WoS)	8

*CentraleSupélec only

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L2S, UMR 8506 CNRS

LABORATORY OF SIGNALS AND SYSTEMS

The laboratory of Signals and Systems (L2S) is a joint research unit of the CNRS, CentraleSupélec and the University of Paris-Saclay created in 1974. Research at L2S focuses on fundamental and applied mathematical aspects of control theory, artificial intelligence, data science, information, signal and image processing, communication, and network theory.
The laboratory is organized into three main scientific domains: systems and control, signal processing and statistics, networks and telecommunications. Interdisciplinary themes related to life and health sciences, industry, and energy have an essential place.

Thematic groups

The laboratory is structured in 3 thematic groups:

SIGNALS AND STATISTICS GROUP

focuses on signal and image processing and statistical modeling. Research activities are inspired from data processing challenges in various application fields such as health engineering, nondestructive testing of materials, acoustics, remote sensing, astrophysics, transportation, electrical and mechanical engineering. Our research aims at proposing solutions to big and possibly heterogeneous data analysis, statistical learning, data mining, temporally and spatially correlated signal analysis, optimal design of experiments, and inverse problems in signal and image processing. The proposed methods and algorithms rely on various tools such as multivariate statistics, numerical optimization, random matrix theory, sparse representation, and Bayesian inference. The group is also interested in Algorithm-Architecture Matching issues, at the interface between signal processing and High Performance Computing. This activity aims at fully exploiting the significant potential of parallel computing of signal processing algorithms on GPU and FPGA hardware accelerators.

SYSTEMS AND CONTROL GROUP

deals with fundamental control theory methods and their applications. Its activities are carried out in a broad international context. Among its research interests, one can distinguish the following topics: modeling; estimation, identification and observation; stability, synchronization and robustness; geometric control; predictive and optimal control; optimization, formal methods and artificial intelligence for systems and control; nonlinear, switched and hybrid systems; infinite-dimensional systems (PDEs, systems with time delays...); networked and multi-agent systems; stochastic systems. In parallel, applications are conducted through academic and industrial collaborations. They concern energy systems (smart grids, wind farms, energy conversion, batteries, electric vehicles, etc.); health and life sciences (neurosciences, oncology, bioreactors, artificial respiration, etc.); autonomous systems (robotics, cobotics, drones, autonomous vehicles, etc.); transport (automotive, aeronautics and rail); industry 4.0 and quantum technologies.

TELECOMS AND NETWORKS GROUP

carries out research in the field of wireless mobile and self-organizing networks, from Physical to Application layers. Its main interests are in cross layer design, coding, modeling and performance evaluation, as well as resource allocation. It also has a strong interest in the connection between communication and energy networks. It is making heavy use of such tools as joint source-protocol-channel coding and decoding, robust image and video compression, distributed source coding, game theory, information theory and stochastic geometry.

Projects

The laboratory takes part in various types of projects. These include:

- **9 European projects**: **ERC-PROCSYS** (Towards programmable cyber-physical systems: a symbolic control approach), **ICT-RISE 6G** (Reconfigurable Intelligent Sustainable Environments for 6G Wireless Networks), **RIA-ATHLETE** (The Exposome from Evidence to Translation), **MSCA-INTEGRATE** (jolnt wireless commuNicaTion and sEnsinG by hologRaphic surfAce TranscEivers), **MSCA-META WIRELESS** (Future Wireless Communications Empowered by Reconfigurable Intelligent Meta-Materials), **MSCA-PATHFINDER** (Harnessing multipath propagation in wireless networks: A meta-surface transformation of wireless networks into smart reconfigurable radio environments), **MSCA-SURFER** (SUrface waves in smart Radio Frequency EnviRonments), **MSCA-TOAST** (Touch-enabled Tactile Internet Training Network and Open Source Testbed), **MSCA-5GSmartFact**

(Industrial Doctorate Training Network on Future Wireless Connected and Automated Industry enabled by 5G).

- **5 Industrial Chairs: APHP- Centrale-Supélec- INRIA Chair** (Exploration of frailty related to aging), **FORVIA** (Processing of Massive and Heterogeneous Data for Intelligent Vehicles), **ORANGE** (6G Durable), **RTE Chair** (Digital transformation of electricity networks), **TRANSVALOR** (Intelligence Artificielle pour la Simulation du Forgeage).

- **4 Industrial actions**: **Risegrid Institute** (Research institute for smarter electric grids, coordinated by L2S), **OpenLab with PSA** (Electrical engineering for mobility), **BPI WIFIP** (SUrface waves in smart Radio Frequency EnviRonments), **Scientific Interest Group LARTISSTE** in Uncertainty Quantification (Paris-Saclay area).

- **5 Projects in the frame of "Programmes d'Investissement d'Avenir"**: Institut DATAIA, LABEX DIGICOSME, OI HCODE, ITE "Super-Grid", RHU REVEAL Reshape the EValuation Efficiency and Accuracy of non-small cell Lung cancer.

- **Several ANR Projects:** BWMs, Dark-ERA, ESTHER, HANDY, HEIDIS, HERMIN, IGNITION, MAESTRO 5G, MindMadeClear, NEPTUNE 3, NICEWEET, Q-COAST, ReVeRY, RELOAD, ROCH, RubinVase, SAMOURAI, SMARTinMS, SPATIALX, UMICROWD, ZL-LVC.

HIGHLIGHTS 2023

- **Antoine Girard** was elevated to IEEE Fellow for "for contributions to formal verification and synthesis of cyber-physical systems".

- **Antonello Venturino** and **Cristina Stoica** received the 2023 Control Engineering Practice Best Paper Award for the paper "Multi-vehicle localization by distributed MHE over a sensor network with sporadic measurements: Further developments and experimental results", co-authored with Sylvain Bertrand, Teodoro Alamo and Eduardo F. Camacho.

- **Riccardo Bonnalli** received the 2023 IEEE Control Systems Magazine Outstanding Paper Award for the paper "Convex Optimization for Trajectory Generation: A Tutorial on Generating Dynamically Feasible Trajectories Reliably and Efficiently", co-authored with D. Malyuta, T. P. Reynolds, M. Szmuk, T. Lew, M. Pavone, and B. Açikmeşe.

- **Gilles Chardon** is a chair holder of the AI program with Forvia (ex-Faurecia): Processing of Massive and Heterogeneous Data for Intelligent Vehicles.
- **Emmanuel Vazquez** was the general chair of the annual workshop of GdR Mascot-Num on Uncertainty Quantification (Le Croisic, April 2023, 130 participants).

- **Nabil El Korso** and **Charles Soussen** were appointed associate editors of IEEE Transactions on Signal Processing.
- The chair with Orange on "6G and sustainability" was inaugurated, and **Salah El Ayoubi** was appointed as its chairholder.

- **Marco Di Renzo** was the recipient of the IEEE COMSOC Fred W. Ellersick Prize.
- **Giuseppe Valenzise** was appointed as the Chair of the IEEE SPS MultiMedia Signal Processing Technical Committee.

SIGNALS AND STATISTICS

The Square Kilometer Array (SKA) radiotelescope in South Africa (left) and Australia (right)- SKAO credit. ANR Dark-era aims to tackle the SKA HPC challenges for the imaging pipeline

SYSTEMS AND CONTROL

Human-robot interaction test bench for co-manipulation control laws validation.

TELECOMS AND NETWORKS

Left : original uncompressed point cloud,
Middle : compressed point cloud using the proposed data-driven geometry compression method based on learned convolutional transforms,
Right : MPEG anchor.

Industrial Partners

- ALSTOM
- ATOS
- AVANTIX
- BRAKES
- BULL
- CEA
- CNES
- DxO
- EDF
- FALGUIERES
- FORVIA
- GE MEDICAL
- HITACHI
- HUAWEI
- IEEE
- IFPEN
- Institut Pasteur
- INTERDIGITAL
- IRCAM
- IRT SYSTEM X
- Just AI
- LNE
- MeilleursAgents
- MICHELIN
- MITSUBISHI
- NOKIA
- ONERA
- OpenLab PSA
- ORANGE
- PICKUP
- PSA
- RTE
- SAFRAN
- SHERPA
- SNCF
- STELLANTIS
- SYSNAV
- TCT
- THALES
- TOTAL
- TRANSVALOR
- VALEO
- VEDECOM

Academic Partners

At national level, the laboratory cooperates with most French laboratories of our areas of research.

At international level, the laboratory has 58 partnerships (38 in Europe, 10 in North America, 3 in South America, 2 in Australia, 4 in Asia, 1 in Africa).

Key figures

• Professors, Associate Professors & Researchers	97
• Engineers & Administrative staff	11
• PhD Students	90
• PostDocs	13
• Visiting Professors	9
• Publications of the year (WoS)	265

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LABORATOIRE GÉNIE INDUSTRIEL

CentraleSupélec

université PARIS-SACLAY

Industrial Engineering Research Department

Industrial engineering is a well-established discipline worldwide. Despite the variety of names of research departments, curricula and doctoral schools in international universities, it often amounts to "Industrial, System Engineering and Management". The objects of study of our scientific discipline are (1) Product-Service Systems and (2) as-is and to-be production or activity systems.

These systems' purpose is to deliver adapted and optimal performances and create value to users through functions and services. These systems are designed, manufactured and delivered, exploited, maintained, updated and recycled. These systems are described by their architecture, are made of components, are configurable and demonstrate different properties like robustness, flexibility, agility, resilience, safety... Our scientific language is also made of processes, resources, performances, costs, risks, business models, decisions, needs, preferences, competencies, projects, tasks, flows, stakeholders, value chains, supply chains, innovation, strategy, investments, economic and societal impacts...

The Industrial Engineering (IE) Department (Laboratoire Genie Industriel, LGI) studies production, activity or socio-technical systems along their life cycles. These systems are engineered by humans and must be observed, diagnosed, specified, designed, improved, manufactured, deployed, exploited, regulated, maintained and recycled. These systems (see Figure 1) are industrial systems (production systems, value chains, ecoparks), complex products (airplanes, cars...), complex factories, transportation systems, health systems, energy networks, service systems and construction systems.

Key principles of our research are: multidisciplinarity, life-cycle thinking (see Figure 2), societal and economic issues, model-based engineering approaches.

The systems studied are often characterized by the following:

- The presence of sophisticated technical components but also of human agents (organizations, policy makers, operators),
- A large number of individual components that interact,
- Heterogeneity of these components, each with specific individual behavior,
- Systems that must often be analyzed at different physical, spatial and temporal scales and from different points of view (technical performance, cost, environmental impacts, material flows, skills...), see for instance Figure 3,
- A system feedback on its components and the emergence of macroscopic properties.

The control of such systems presents many challenges and issues from both a technical and scientific point of view as well as practical and application perspectives like financial profitability, efficiency, continuity and reliability of service, security, resilience. The integration of technical systems is already challenging regarding, for example, aerospace, automotive or energy systems, but it is even more complex when it comes to inter-network systems ("System of Systems" paradigm) such as health systems, human mobility infrastructure, distribution of products and services, transport and regulation of energy, gas, water, and other socio-technical systems including human or various agents such as organizations with different and even contradictory strategies, goals and preference.

Our scientific approach consists in adequately modeling for analyzing and simulating (see Figure 4) in order to better understand the system behavior through virtual experiments on models and, ultimately, finding optimal solutions for the design, deployment and monitoring. Often many life cycle phases of these systems must be modeled and analyzed: collection of needs and requirements specification, development (architectural design, dimensioning, validation, manufacture and market launch or startup), system management (its regulation, its maintenance, its failure modes, its upgrade, its dismantling and end of life).

TEAMS

LGI is organized in 4 research groups, 5 transversal themes and 5 research chairs. The 5 transversal themes are: Mobility systems, Energy systems, Healthcare systems, Industry of future, Circular economy.

THE RESEARCH AXES OF THE 4 RESEARCH GROUPS

1. Design Engineering (DE)
Design complex products, services and systems, Define design processes and methods, User-centered design, Eco-design and design for a Circular Economy, Systematize innovation, Manage knowledge and skills.

2. Operations Management (OM)
Design and manage the supply chain, Manage production, Predict demand, Manage supply, Manage logistics and transportation, Size the industrial system, Manage health system operations.

3. Risks, Reliability and Resilience (R3)
Analyze and lower industrial risks, Increase system reliability and service continuity, Move from corrective to preventive maintenance, Enable flexibility and resilience.

4. Sustainable Economy (SE)
Modeling and simulating the technico-economy... of the development of electric vehicles and recharging stations, of the French energy mix, of global carbon capture, of the use of hydrogen, Circular Economy.

LGI affiliates its PhD Doctorates at Doctoral School *Interfaces*, and the diploma are delivered under the following disciplines: *Industrial Engineering, Complex Systems Engineering, Computer Science, Engineering Economy.*

LGI belongs to the *Engineering and Systems Science* Graduate School of Paris-Saclay University, through its *Industrial and Manufacturing Engineering* discipline topic.

THE 5 ENTERPRISE CHAIRS

Supply Chain - *L'OREAL, SAFRAN, SAINT-GOBAIN* - Since 2010
Chair holder: **Evren Sahin**

Risk and Resilience of Complex Systems - *EDF, ORANGE, SNCF* - Since 2010
Chair holder: **Anne Barros**

Open Lab Carbon Economics in Mobility (continuing the Chair Armand Peugeot - Hybrid technologies and the economics of electro-mobility, since 2014) - *STELLANTIS* - Since 2024
Chair holder: **Yannick Pérez**

FlexTech – Human-Systems Integration - From Rigid Automation to Flexible Autonomy - *Armée de l'Air, CS GROUP, THALES / ESTIA* - Since 2019
Chair holder: **Guy André Boy**

Alliance Circular-IT - Digital solutions for circular industrial and territorial ecosystems - *MANITOU Group, General Electric Healthcare, MEWS Partners, Communauté d'agglomération Paris-Saclay (CPS), SIOM (Syndicat Inter-communal des Ordures Ménagères), CSTB (Centre Scientifque et Technique du Bâtiment)/ IRT SystemX* - Since 2022
Chair holder: **Bernard Yannou** assisted by **Ghada Bouillass**

HIGHLIGHTS 2023

Operational launch of the **CircularIT Alliance** (with the start of 4 PhD theses)

Renewal of the **RRSC Chair** (2nd season) and the **Supply Chain Chair** (4th season)

Closing of:

- season 2 of the Anthropolis chair and publication of a collective work: https://link.springer.com/book/10.1007/978-3-031-45795-1
- season 2 of the TotalEnergies Chair: Managing Procurement Risks in Complex Projects

Launch of:

- European ITN Marie Curie Training42Phase project (CS carries 2 WP)
- European ULTIMO project (following AVENUE project) on autonomous buses
- ANR project GreenLocal3D: Global approach for the recycling in short circuit of used plastic by additive manufacturing
- ANR JCJC ResuSpace project (CS carrier)
- ANR AMI PowDev project, part of PEPR TASE (CS holder)

Launch of ***Marcel Boiteux Lectures*** in economy

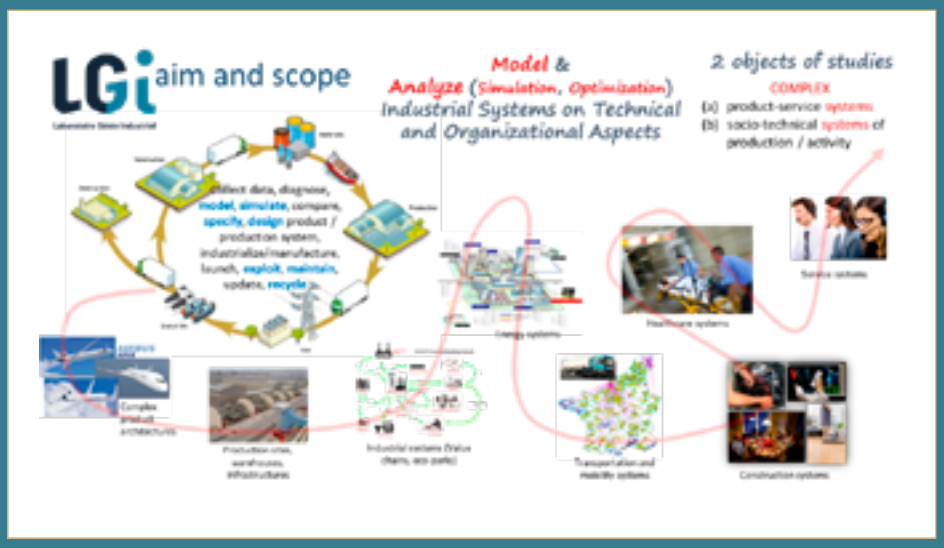

Figure 1
LGI studies production, activity or socio-technical systems along their life cycles

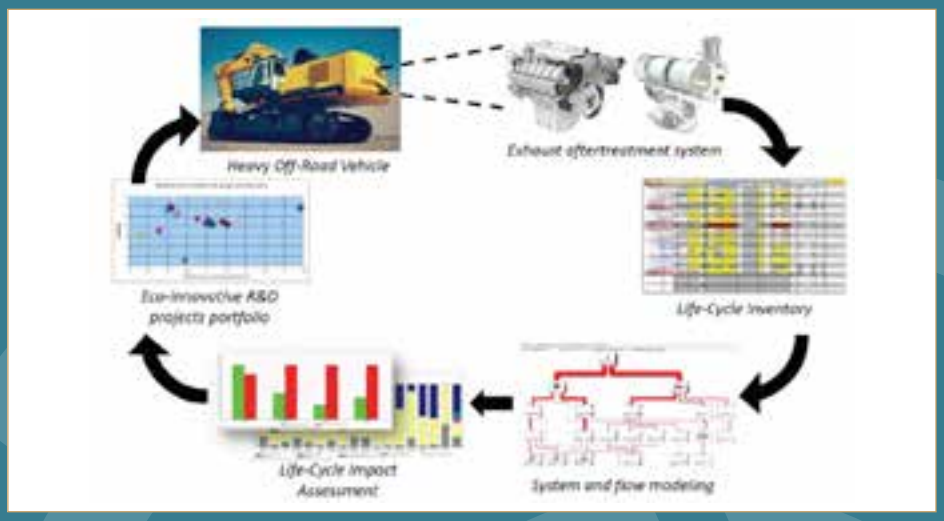

Figure 2
Life Cycle Assessment & Eco-Design of complex industrial systems

Figure 3
Simulation of a kitting automated cell (robot-operator collaboration upstream of an assembly line)

Figure 4
Optimization of patient flows in emergency services

Industrial Partners

- Automotive industry/transport: RENAULT, STELLANTIS, RATP, SNCF, Manitou Group, Style & Design
- Aeronautics and space: THALES, SAFRAN, CS Group, Armée de l'air, ESA
- Energy: EDF, RTE, ENGIE, CEA, AIR LIQUIDE, IFPEN
- Control: SCHNEIDER Electric, SIEMENS
- Consulting: BI Consulting, Mews Partners, ALTEN, IKOS
- Defense: DGA
- Goods: LVMH, L'OREAL
- Construction: EIFFAGE, VINCI CONSTRUCTION, CSTB
- Research institutes: CEA, IRT SystemX, VEDECOM, ARS (Agence Régionale de Santé), INRAE, CSTB
- It & networks: ORANGE, NOKIA Bell Labs
- Health: AP-HP (Assistance publique – Hôpitaux de Paris), General Electric Healthcare, Silver Valley, Institut Gustave Roussy, Hôpital La Pitié Salpêtrière, Hôpital Marie-Lannelongue
- Local authorities: CPS (Communauté d'Agglomération Paris-Saclay), SIOM (Syndicat Intercommunal d'Ordures Ménagères)

Academic Partners

More than 50 collaborations in France and abroad: **Australia** (University of Queensland, Université de Melbourne), **Austria** (University of Vienna), **Belgium** (Université de Louvain, Université de Mons), **Brazil** (UFRJ, PUC, Université de Lavras, UNIFEI), **Canada** (Mc Gill University, ETS), **China** (Beihang University, Ecole Centrale Beijing, Wuhan University of Technology, University of Honk Kong), **Denmark** (DTU), **Egypt** (the American University in Cairo), **Finland** (Aalto University), **France** (ERPI/Université de Lorraine, LISN/Université Paris-Saclay, CRD/Université Paris-Saclay, I2M/ENSAM Bordeaux, Université de Strasbourg, ESTIA, INRAE, UTC, ENSCI les Ateliers), **Germany** (Université de Magdeburg, TU Munich, Friedrich-Alexander University of Erlangen-Nuremberg, University of Mannheim), **Italy** (Université de Catane, Politecnico di Milano, Politecnico di Turino), **Japan** (Chiba University, RITE-Kyoto), **Lebanon** (Université de Beyrouth), **Luxembourg** (Université de Luxembourg), **Marocco** (Ecole Centrale de Casablanca), **Netherlands** (VU University Amsterdam), **Norway** (University of Stavanger), **Poland** (Poznan University of Technology), **Portugal** (University of Coimbra), **Qatar** (Hamad Bin Khalifa University), **Singapour** (SUTD), **Spain** (University of Valencia), **Switzerland** (HEC Lausanne, ETHZ), **Tunisia** (ENIT, ENIM), **Turkey** (Koç University), **UK** (University of Liverpool, University of Bath, The Open University), **USA** (Northwestern University Chicago, MIT, Penn State University, University of Michigan, Clemson University, Georgia University of Technology, Iowa State University, University of Minnesota, University of Illinois at Urbana-Champaign, Illinois University).

Key figures

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• Publications of the year (WoS)	48

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LABORATOIRE DE GÉNIE DES PROCÉDÉS & MATÉRIAUX

The LGPM research department works on two fields of investigation in close interaction: chemical and biochemical engineering and materials. Modeling, simulation and experimentation are the common pillars of the different research themes addressed.

Sustainable industrial production as a key challenge for the Twenty-First Century

This complementarity makes possible to start from the understanding of microscopic phenomena to the intensification of transformation and elaboration processes through the simulation and optimization. Scaling-up and multi-scale approaches are therefore often at the heart of its actions and are the preferred means of moving from academic studies to industrial applications. Our know-how, firmly anchored in process engineering, is applied to the sustainable aspects of material transformation processes (material and energy savings, optimization and intensification), bioprocesses (use of living organisms to consume and transform biomass into added value products) and the development of bio-materials.

These Departmental competences have been strengthened by the participation of the LGPM in the creation of a Centre of Excellence for Industrial Biotechnology (CEBB) at the end of 2010 in Pomacle (close to Reims/Grand-East Area). Altogether 75 researchers, post-doctorate and PhD students located on both sites (campus Paris- Saclay and campus Reims-Pomacle) are deeply involved in the promising fields of the bio-economy and decarbonization of the industry.

The Department is organised in three Teams:

MATERIALS & BIOMATERIALS

- Liquid metals, wetting and reactivity at high temperature
- Wood, bioproducts, bio-based materials, building materials
- Coupled heat and mass transfer
- Elaboration and transformation processes
- Characterization, upscaling, multiscale modeling

CHEMISTRY & SEPARATIVE PROCESSES

- Separation and purification by liquid-liquid extraction, membranes, electro-chemistry, preparative chromatography, crystallization
- Multiphase flows (liquid films, drops, bubbles, particles), deposition
- Process intensification
- Trace analysis and sample preparation - Exobiology

BIOPROCESSES

- Biological processes (suspended and immobilised cultures)
- Multi-scale modeling and bioreactors control
- Cell/community characterization (biofilm structure, microalgae characterization on *lab-on-chip systems*, ...)
- Use of microorganisms to treat wastewater/ produce biofuels (lipids from microalgae, methane generation, ...)
- Production and purification of high value molecules

REMARKABLE EQUIPMENT/SKILLS

2D and 3D imaging:

Confocal Laser Scanning Microscope (CLSM), Environmental SEM + EDS, Interferometric microscope, Nano-tomography, Optical Coherence Tomography (OCT), Particle Image Velocimetry, Raman microscope, Image processing tools.

Analysis/characterization:

ATG/DSC coupled with GS-MS, BET, CHNSO, DMA, triple quadrupole ICP-MS Spectroscopy (UV, IR, MS, Raman, fluorescence X), UHPLC-Orbitrap (HRMS), UHPLC-IMS-QToF (TIMS-ToF), laser and morphological size analysers, flow cytometry, liquid and gas chromatographs, mass diffusion, mineralizer, Motorized MicroProfiling System for O_2 and pH measurements permeability, rheometer, sorption isotherms, tensiometer, wetting measurements at high temperature, chromatic confocal measurement of film thickness.

Processes and pilot devices:

Bioreactors, Drying, Dispensed metal drop device, Electrodialysis, twin-screw extruder, Liquid-liquid extraction, Photo-bioreactors, Preparative chromatography, Reverse osmosis, Powder flowability tests (rotating drum), Thermal treatment, Ultra- and nano-filtration, Versatile annealing device.

Modeling/simulation:

CFD (OpenFOAM), Discrete modeling of particles (LIGGGHTS), Discrete and continuous modeling of Bioprocess, Machine learning, Chemometrics, Image-based representation, Meshless methods (LB, MPM...), Multiscale modeling of reactive and bio-active transfer in heterogeneous media, Up-scaling. Access to HPC computers (Ruche, Romeo).

(a) Twin screw extruder enables the elaboration of new biomaterials, the extraction of molecules of interest from biomasses and reactive extrusion to be carried out by adding various reagents and enzymes. It's a versatile tool calibrated for research and scale-up. (b) example of a new biocomposite produced with agro-industrial by-products to substitute traditional plastics.

APPLICATION DOMAINS

- 2G/3G biofuels,
- Astrobiology,
- Biogas purification,
- Bioprocessing design and evaluation,
- Biotechnologies,
- Developping innovative bio-sourced materials,
- Digital twins applied to sustainable development,
- Exobiology,
- Hydrogen production from biomass,
- Instrumental development for space application and search for trace of life in the universe,
- Iron coating,
- Liquid metal heat exchanger,
- Mould/ yeast / bacteria / microalgae production,
- Tissue scaffold for bone regeneration.

EXAMPLES OF STUDIES

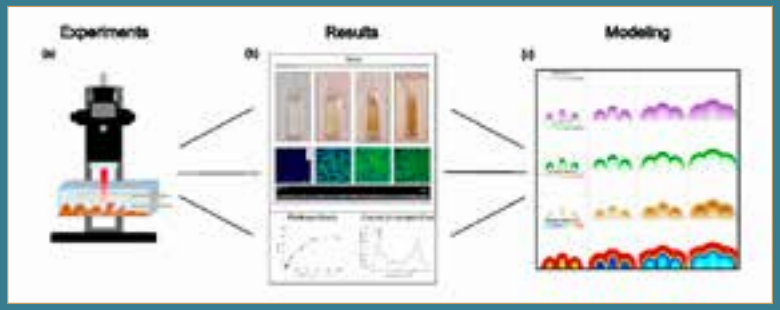

Fig 1. Microalgae biofilms are spatially organized communities with a great biotechnological potential, and the coupling of experimental and computational strategies represents a robust approach to finely characterize these complex biological systems. A fluidic device was developed to cultivate and characterize microalgae biofilms using optical methods, such as confocal laser scanning microscopy (CLSM) and optical coherence tomography (OCT) (a). Metabolism was also monitored by measuring cells photosynthesis and biochemical composition (b). This experimental setup allowed to show that cell physiology is more affected in thicker biofilms as a consequence of alterations in local environmental conditions (Fanesi et al., Biotechnology and Bioengineering https://doi.org/10.1002/bit.28147). Computational approaches can be used to investigate hypothesis that are too complex for experimental strategies. Using a spatial 2D-model, microalgae biofilm development was simulated and it was found to be inhibited by oxygen accumulation and water limitation (c) (Polizzi et al., PLoS Computational Biology https://doi.org/10.1371/journal.pcbi.1009904). These works suggest that biofilm 3D architecture and metabolism are key traits that must be fully understood to optimize their utilisation in bioprocesses.

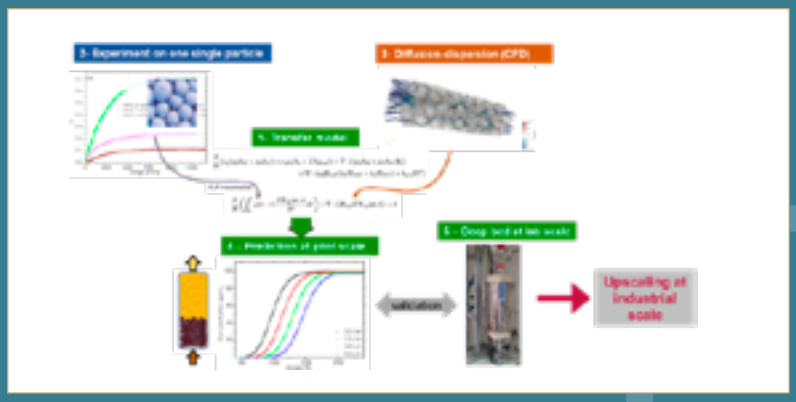

Fig.2.1 Scientifc approach used to design and optimize the process for eliminating H_2S and CO from H_2 on an industrial scale using numerical simulation, supported by lab measurements and validated by a lab pilot

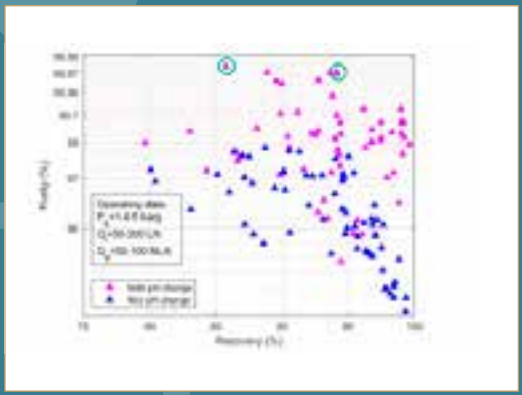

Fig.2.2 – H_2 purity and yield with the new patented process (with pH swing) and the previous one (without pH swing)

Contribution to the design and optimization of H_2 purification from syngas, as part of the PIA3 "Vitrhydrogène" project led by Haffner Energy (2018-2022) and funded by ADEME ("Démonstrateur de la Transition Ecologique et Energétique" programme). LGPM worked to eliminate pollutants: (Fig 1.1) For H_2S and CO, experiments were carried out first on a grain scale (by TGA), then on a fixed bed scale, which made it possible to estimate the capacity of the solid phases, the reaction kinetics and any equilibria. This information was used to produce two numerical tools for estimating performance depending on the operating conditions, with the aim of optimizing and sizing this purification system. (Fig 1.2) For CO_2, using a digital twin, an "in silico" solution was obtained for reducing the residual CO_2 to below 10 ppm. After validation in a laboratory pilot, the process was patented (FR3106284), then optimized, in order to follow the evolution of the syngas enrichment and purification chain.

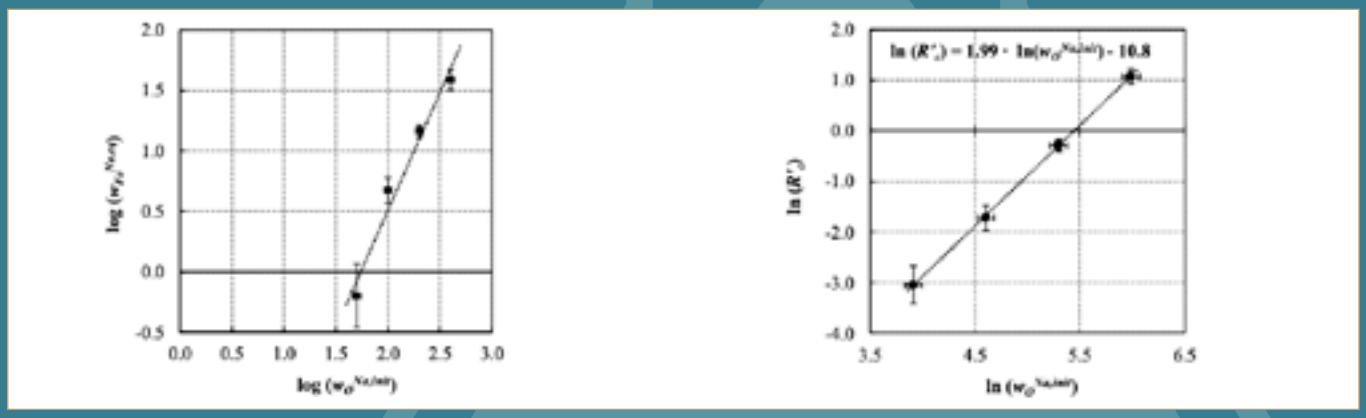

Fig. 3.1. Variation in the mass fraction of iron in liquid sodium at equilibrium as a function of the dissolved oxygen content at 550 °C.

Fig. 3.2. Thickness loss rates R'_c of iron in µm/year, at 550 °C as a function of dissolved oxygen content in ppm (50, 100, 200, 400 ppm).

Liquid sodium can be used as a heat transfer fluid in heat exchangers. Under isothermal conditions at 550 °C, the equilibrium iron concentration $W_{Fe}^{Na,eq}$ follows a power law of order 2 as a function of the dissolved oxygen content $W_O^{Na,init}$ in liquid sodium (Fig. 3.1), due to the formation of a soluble complex $NaFeO_2$. An equilibrium law of this complex in liquid sodium was developed as a function of temperature and dissolved oxygen content (S. Meddeb et al. J. Nucl. Mater. (2022) https://doi.org/10.1016/j.jnucmat.2022.153785). The rate of pure iron dissolution in liquid sodium R_c' follows a power law of order 2 as a function of the dissolved oxygen content (50-400 ppm) (Fig. 3.2). The corrosion kinetics measured is limited by the transfer of the soluble complex through the mass transfer boundary layer [S. Meddeb et al. J. Nucl. Mater. (2023) https://doi.org/10.1016/j.jnucmat.2023.154541).

Industrial Partners

- AIR LIQUIDE
- ARCELORMITTAL
- ARD
- BIOREA
- CEA
- CHENE et Cie
- CNES
- CRISTAL UNION
- DRY4GOOD
- EDF R&D
- ECOTECNILIN
- EUROPEENNE DE BIOMASSE
- GENOMINES
- GIVAUDAN
- GRT gaz
- HAFFNER Energy
- IFPEN
- INALVE
- INEVO
- INTERNATIONAL ZINC ASSOCIATION
- LESAFFRE
- Metha'groupe
- MIYOSHI
- NUTROPY
- OLYGOSE
- PROCESSIUM
- PRONOE
- PROSNY NC
- SANOFI
- STH Biotech
- SYNOVANCE
- TIPEE
- THALES ALENIA SPACE
- TMA Process
- VEOLIA
- V.E.R.A. SAS
- VICAT
- VITO
- WIGWAM
- YPSO-FACTO

Academic Partners

International: School of Mathematical Sciences QUT (Australia), University of São Paulo (Brazil), São Paulo State University (Brazil), EMBRAPA (Brazil), ITAL (Brazil), Federal University of Rio de Janeiro (Brazil), Université du Québec in Abitibi-Témiscamingue (Canada), Danish Technological Institute (Denmark), Gottingen University (Germany), Institut Von Karman (Germany), Max Planck Institute for Solar System Research (Germany), Technical University of Dresden (Germany), University of Hannover (Germany), University of Padova (Italy), TU Delft (Netherlands), Wageningen University (Netherlands), University of Almeria (Spain), Engineering school of Monastir (Tunisia), Engineering School of Sfax (Tunisia), Higher Institute of Biotechnology of Beja (Tunisia), University of Carthage (Tunisia), Imperial College London (UK), GSFC-NASA (Maryland, USA), JPL-NASA (Pasadena, USA), Ohio State University (USA).

France: AgroParisTech, ENS Paris Saclay, ESIEE (Noisy-le-Grand), GEPEA (Nantes), IFREMER, INRAE (Antony, Jouy en Josas, Narbonne), IMFT (Toulouse), INRIA, INSERM, IS2M (Mulhouse), Institut de Matériaux Microélectronique, LRGP (Nancy), Nanosciences de Provence, SMS (Université de Rouen), Sorbonne Université (UPMC), Unilasalle Beauvais, Université Picardie Jules Verne, Université Reims-Champagne Ardenne, Université de technologie de Compiègne, Université de Lorraine, Université la Rochelle, Université Savoie Mont Blanc.

Key figures

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• PhD Students	20
• PostDocs	7
• Publications of the year (WoS)	31

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CentraleSupélec within

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LABORATOIRE INTERDISCIPLINAIRE DES SCIENCES DU NUMÉRIQUE

LISN, located on the Orsay campus, is a research laboratory created in January 2021, as the result of the union of 7 LIMSI research groups and 7 LRI research teams. It is a Joint Research Unit (UMR) with CNRS, University Paris-Saclay, INRIA and CentraleSupélec. LISN is a multidisciplinary research laboratory that brings together researchers and teacher-researchers from different disciplines in the Engineering and Information Sciences, as well as Life Sciences and Human and Social Sciences.

LISN hosts about 400 people, including 170 researchers and 150 Ph. D students. Its research forces cover a broad spectrum of fundamental and applied research in computer science and engineering science. It is composed of five departments corresponding to interdisciplinary themes.

Research Departments

ALGORITHMS, LEARNING, AND COMPUTATION

The main research axes concern computational models and their robustness (from high performance computing to quantum computing, including neural networks, and distributed algorithms), processing architectures (graphs, distributed processing), and methods (eg. continuous optimization, combinatorics, stochastics; statistical learning and information theory). The teams which composed this department are Learning and Optimization (A&O, team transverse with Data Sciences department), Graphs, Algorithms and Combinators (GALaC), and Parallel Systems (ParSys).

INTERACTION WITH HUMANS

The Human-Centered Interaction Department brings together researchers from 6 internationally renowned teams. It focuses on Human-Computer interaction with a multidisciplinary approach combining computer science, signal processing, and humanities, to design not only innovative hardware and software interfaces but also to explore social interaction and collaboration between humans and computers.

The range of this research allows the department to develop work that is both fundamental and application-oriented, to evaluate the relevance of these models in their real use, and methodological, on the design and evaluation aspects.

FLUID MECHANICS AND ENERGY MECHANICS

The field of mechanical and energy engineering must rapidly advance to address societal issues such as global warming, energy and health crises. Unprecedented volumes of data from experiments and field measurements, affordable large-scale simulations, and a wealth of efficient numerical tools put the understanding, modeling, optimizing, and controlling of nonlinear multiphysics phenomena at stake within reach.

The approach of this department lies at the interface between computer science, physics and applied mathematics. We wish to preserve an equilibrium between interdependent activities: understanding fundamental turbulent fluid mechanics phenomena; tackle large-scale complex multiphysics coupled problems and take advantage of our physical knowledge while considering data as an inherent part of modeling, experiments, and simulations. In this context, we are very open to recent machine learning developments which provide a powerful information-processing framework that can augment our current lines of research with broad-spectrum applications in the energy, transport, health and environment sectors.

DATA SCIENCE

The Data Science department brings together 4 teams with complementary expertise, covering the modeling, collection, management, analysis and construction of data and knowledge. Digital traces of all human activities are available today in all fields. The available data is often massive, heterogeneous, dynamic and of variable quality (the 4 Vs: Volume, Variety, Velocity, Veracity). The Data Science department is therefore interested in responding robustly to the challenges of the 4 Vs in terms of scaling up, with respect to data volume and velocity, and in terms of resisting biases regarding diversity and quality.

The expertise of the members of the Data Science department covers a wide spectrum: databases, data mining, semantic web, knowledge representation, algorithmics, combinatorics, stochastic and distributed optimization, machine learning and neural networks (supervised, unsupervised, structured), communication networks, simulation, validation and transfer to industry.

LANGUAGE SCIENCE AND TECHNOLOGIES

Language is an essential vector for human communication, the recording and transmission of information and knowledge. Its modeling and computer processing are major challenges for the advancement of knowledge and technology in a field with a strong societal impact, and are an intrinsic part of Artificial Intelligence.

Transversal actions

The departments work together on five cross-cutting actions. The aim is to develop new directions and take advantage of the originality and diversity of the expertise of LISN members.

- Deep Learning for Physics and Physics for Learning.
- Computer sciences and SHS
- Arts and Sciences
- Visualization and exploration of big data
- Responsible Research

Cooperations

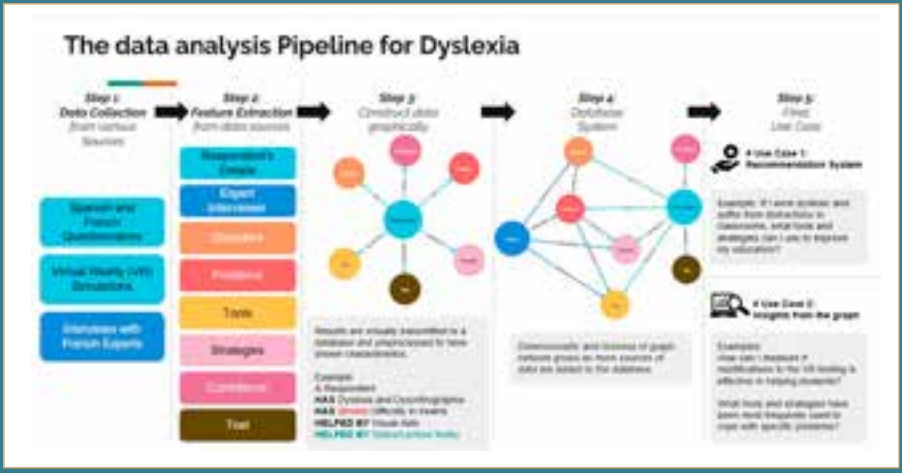
The laboratory participates in a large number of national and international projects, including those funded by ANR, the French National Research Agency, by Digiteo and by the European Union (in particular the KIC ICT Labs from EIT). LISN members participate in many editorial boards of international journals and program committees of international conferences. The laboratory is also highly productive, with over 4000 publications in last five years, and is strongly involved in software production and transfer.

LISN is a member of ED STIC, SMEMAG and SSMH and participates in the Graduate Schools *Computer Science, Engineering and Systems* and *Sport, Movement and Human Factors* of the University Paris-Saclay. LISN is also a partner in System@tic Paris Region, a world-class competitiveness cluster with more than 200 industrial, academic and institutional members in the area of complex software and systems. LISN is strongly involved in the Investments for the Future programs launched in 2010 by the French government. It leads the Equipex Digiscope, the Labex Digicosme, participates to the IRT SystemX, the DataIA Institute, the labex LASIPS, the SaclayIA research equipment which includes the Lab-IA platform, managed by people from LISN.

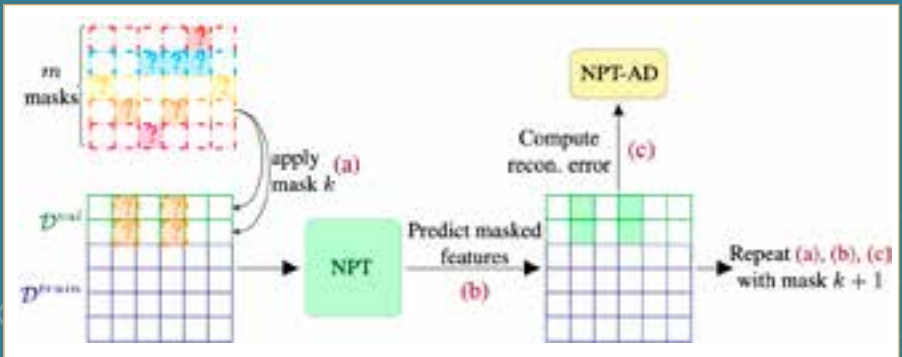
Application Domains

- Health
- Automotive,
- Bioinformatics,
- Telecommunications,
- Transportation,
- Energy,
- Transport,
- Bank/Finance.

EXAMPLES OF STUDIES



The data analysis Pipeline for Dyslexia



In order to enhance anomaly detection methods, we propose to rely on Non-Parametric Transformers to learn to rebuild the masked features of normal samples. This is the first anomaly detection method to combine both feature-feature and sample-sample dependencies. It outperforms existing state-of-the-art methods based on both the F1-Score and AUROC on 37 datasets.

LUSIS Chair

CentraleSupélec and Lusis, a top-tier provider of high-performance transactional platforms for payment systems and financial markets, have created a research Chair of Artificial Intelligence applied to fraud detection in payments and algorithmic trading.

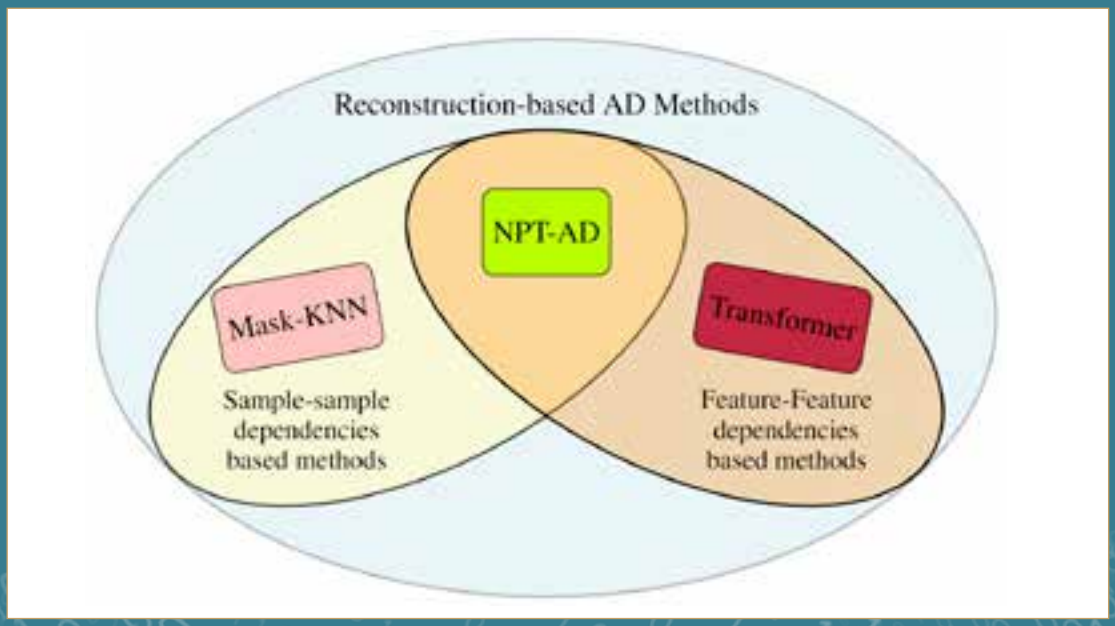
Launched in 2020, the chair has focused its efforts on two primary research axes:

- Fraud Detection in Credit Card Payments
- Reinforcement learning for portfolio allocation

These two axes have one core concept in common, namely time series: customer-merchant interaction flows in the first case, stock market quotation flows in the second case.

Specifically, we have directed our focus towards the modeling of time series data using transformers. While transformers are renowned for their versatility and performance, their symmetrical architecture presents unique challenges when applied to time series analysis, which inherently flows in one direction. To address this, we are exploring novel transformer-based architectures that can simultaneously capture dependencies between features, particularly crucial for detecting fraud and anomalies.

In the realm of the portfolio allocation problem, we focus on DecisionTransformer-like architectures designed to supplant traditional reinforcement learning, as well as from contributions from statistics such as copulas.



We introduce NPT-AD (https://arxiv.org/pdf/2305.15121.pdf) as the first anomaly detection method which relies on both feature-feature dependencies and sample-sample dependencies. NPT-AD beats all SOTA methods on 31 anomaly detection datasets.

Industrial Partners

- AIRBUS,
- ATOS
- BULL
- DAIMLER
- DASSAULT
- EDF
- FACEBOOK
- IBM
- L'OREAL
- LUSIS,
- MITSUBISHI
- NOKIA
- ORANGE
- PHILIPS
- QWANT
- SAP
- SCHNEIDER
- SIREHNA
- SNCF
- STMicroelectronics
- SYSTRAN
- THALES
- TOTAL SA...

Academic Partners

University of Vienna Austria (AU), University of Montreal (CA), Concordia University Montréal (CA), Toronto University (CA), MacMaster University Hamilton, TU Dresden (GE) , Pisa University (IT), Milano University (IT), University of Tokyo (JP), Kyoto University (JP), Vrije Universiteit Amsterdam (NL), ETH Zürich Switzerland (CH), Imperial College London (UK), University of Manchester (UK), University of Oxford (UK), University of California at Berkeley (US), Davis (US), San Diego (US), Santa Cruz (US), City College of New-York (US), University of Minnesota Minneapolis (US), Stanford University (US), Universidade Federal do Rio de Janeiro (Brazil), National institute of Informatics (Japan)...

Partnerships & Collaborations

Cap Digital, Medicen, SATT Paris-Saclay

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*CentraleSupélec only

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CentraleSupélec within

LMF, UMR9021

FORMAL METHODS LABORATORY

CentraleSupélec

université PARIS-SACLAY

LMF — Laboratoire Méthodes Formelles

cnrs

université PARIS-SACLAY

école normale supérieure paris—saclay

The *Laboratoire Méthodes Formelles* (LMF) was founded on 1 January 2021 as a joint research centre of University Paris-Saclay, CNRS, ENS Paris-Saclay, Inria, and CentraleSupélec with a main focus on formal methods. The new laboratory combines the expertise of about 100 members from the former *Laboratoire Spécification et Vérification* (LSV) and the VALS team of *Laboratoire de Recherche en Informatique* (LRI).

In our mission to enlighten the digital world through Mathematical Logic, we rely on formal methods as a tool to analyse, model, and reason about computing systems, such as computer programs, security protocols, and hardware designs. Our research targets a wide range of computational paradigms, from classical to emerging ones such as biological and quantum computing.

LMF is structured around three hubs: **Proofs** and **Models**, which lie at the heart of our historical background, and **Interactions**, that is aimed at fostering cross-fertilisation between formal methods and other domains in computing science and beyond.

Research Themes

PROOF AND LANGUAGES

Fundamentals of computing, languages and compilation

Formal Methods for Computer Arithmetic

Proof of programs

- Foundations and spreading of deductive program verification
- Reasoning on mutable memory in program verification

Mechanized evidence

MODELS

Distributed Computing

Model Checking and Synthesis

Formal Modeling of Critical Systems

Formal Testing and Monitoring

INTERACTIONS

Topology and computing applications

Formal methods for security

Formal methods for quantum computing

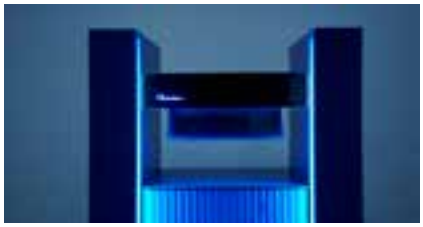
Formal Methods in Biology

Formal Methods for Artificial Intelligence

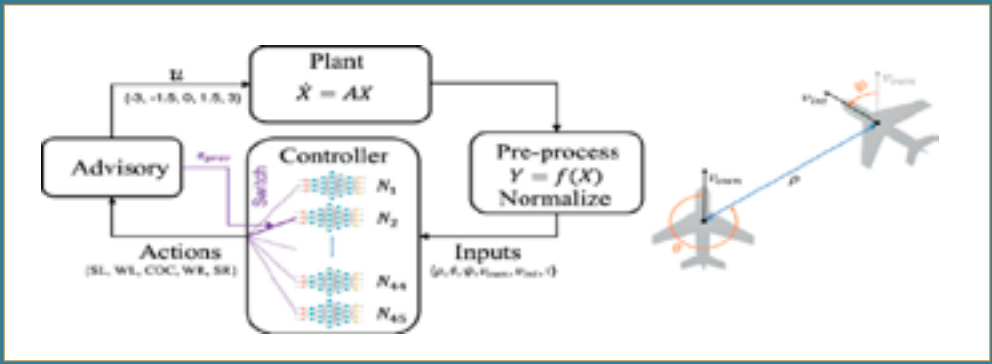
Application Domains

- Safety of software systems in transport
- Quantum computing
- Programming languages
- Toolchain compilation
- Specification/Certification
- Diagnosis of human behavior in accidents
- Proof of correctness of the “Responsibility-Sensitive Safety” strategy of driving autonomous vehicles
- Safety of real-time and hybrid systems: manufacturing processes, transport systems and communication networks
- Safety of dynamic systems controlled by neural networks: transport systems, medical systems
- Emotion identification by neural networks combined with rule-based inference: Therapeutic Chatbot

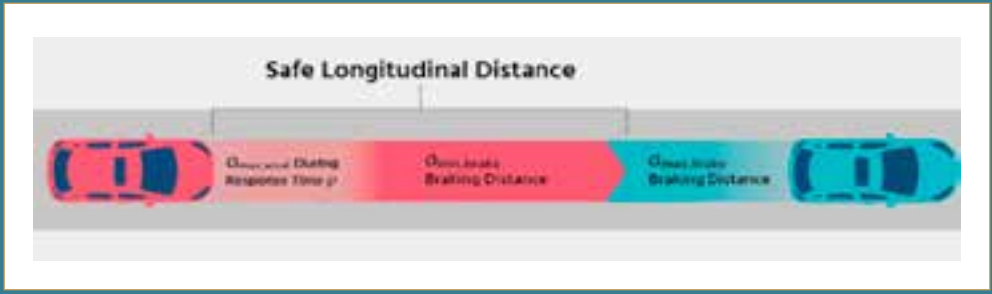
EXAMPLES OF STUDIES



Quantum linear optics is a versatile technology allowing, among other things, to perform quantum calculations. This new calculation model is expected to have applications in varied fields, such as high-performance computing or artificial intelligence. The LMF collaborates with Quandela to define linear optics' graphical languages to code and manipulate quantum algorithms.



Today more and more complex systems are controlled by neural networks, such as autonomous vehicles, a future version of traffic alert and collision avoidance systems, among others. Verification of their behaviour, i.e. the evolution of their outputs according to the variation of their inputs, represents a real challenge. Together with our partners, we are trying to study the formulation of their verification to combine deep learning and formal method techniques.



Modeling and Analyzing Cyber-Physical Systems (CPS) is a challenge for Formal Methods and a field of active research. It is characteristic for CPS that models comprise aspects of Newtonian Physics appearing in system environments, the difficulties of their discretisation, the problems of communication and interaction between actors in this environment, and calculations respecting time bounds. We present a novel approach to address these problems developed within an IRT SystemX project for industrial partners involved in the Autonomous Car Domain.

Modeling human decision errors in critical systems is important to improve the interface of critical systems and to provide better training to operators of critical systems. We developed a formal model of belief revision and an algorithm that relies on SAT solvers to determine minimal knowledge correction sets in order to rebuild the sequence of possible mental states of a human operator that are compatible with the observed trace of his behavior. To filter among the many possibilities, we built a formal model of cognitive biases to prioritize behaviors that match known cognitive biases and are therefore more probable.

Industrial Partners

- AVSimulation
- EDF
- IRT SystemX
- PSA
- Quandela
- Renault
- Valeo

Academic Partners

CEA, INRIA, LORIA, LISN lab of Paris-Saclay University, CRIL, IRIF, IRIT - Toulouse, LACL Lab of UPEC University, Max Planck Institute for Software Systems: MPI SWS - Germany, Institute for Software Engineering and Programming Languages - Germany, AnSyMo group of Antwerp University, MDSL Lab of McGill University, Udela - Universidad de la República - Uruguay, UBA - Buenos Aires University

Key figures*

• Professors, Associate Professors & Researchers	4
• PhD students	7
• Visiting Professor	1
• Publications of the year (WoS)	5

*CentraleSupélec only

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July 2024

LMOPS – UR 4423

LABORATOIRE MATÉRIAUX OPTIQUES PHOTONIQUE & SYSTÈMES

The LMOPS laboratory is composed of 23 faculty members, among which 17 permanent researchers from Lorraine university and 5 from CentraleSupélec, along with 13 PhD students and 2 post-doctoral staff. The laboratory is mainly situated on the Metz Technopole campus, and has two local branches in Thionville-Yutz and Saint-Avold.

OPTICAL MATERIALS, PHOTONICS & SYSTEM

LMOPS is divided in three research groups, respectively devoted to Functional Materials, Photonics and Photovoltaics. It also has a running chair program (Chair in Photonics) and two experimental platforms respectively dedicated to spectroscopy and electrical measurements.

LMOPS also actively participates to the PIA2 IDEX / I-SITE *Lorraine Université d'Excellence* (LUE) project promoted by Lorraine university. The goals of the LUE initiative are to develop the international leadership of the Lorraine site, on engineering viewed from a systemic perspective around major economic and societal challenges.

FUNCTIONAL MATERIALS TEAM

The activities of the Materials team are organized in three major themes : the growing of bulk materials for non linear optics and the study of fire behavior and fire-proofing of polymer materials (*nanocomposite polymers* theme). The bulk material theme is focused on the study of growth and characterization of new materials that are more effective and more resistant allowing the realization of VUV sources (λ<300nm) of high power and stable in the time. For this, two experimental methods are available in the laboratory: the "micro-pulling down" technique (μPD). Concerning the fire retardant research, a booming research topic is the study of flame retardancy of continuous fiber thermoplastic composites. This subject is directly related to the needs of the socio-economic environment of the East-Moselle. The influence of aging on the fire performance of these complexes flame retardant polymer systems is also studied.

Concerning the growth of new photovoltaic materials, the team acquired in 2018 a new spray-pyrolysis equipment (funded by CentraleSupélec) allowing a rapid return of the results of characterizations and modelizations on the growth and structure of the layers and cells. Moreover, the team is also studying photovoltaic cells and modules from other laboratories for specific properties such as aging, effects of thermal and electrical stresses, properties of certain layers (eg transparent conductive layers, absorbent layers) as a function of doping, growth conditions of the gap profile, etc.

PHOTONICS TEAM

The Photonics research team's main theme is nonlinear optics, a domain which is studied using several distinct approaches. Optically induced waveguides and the experimental link they allow between optics and quantum physics using the analogy between optical and quantum behavior equations are studied to provide efficient experimental ways to investigate otherwise unreachable quantum behaviors. Spatio-temporal nonlinear dynamics are also investigated as they lead to an intriguing self-organization property of light itself. The temporal side of these dynamics leads to chaos that could be used for ultra-efficient all optical encryption. Finally, optical neuro-inspired computing based on reservoir computing is a new topic that is rapidly gaining importance in the team. Hybrid, as well as all-optical approaches are investigated for various prediction or recognition tasks. The team has today gained an unchallenged international recognition with paper published in prestigious journals and has a running chair program on photonics with unprecedented funding from both the public and private partners of the laboratory.

Also some researchers have an expertise in spectroscopy to study disturbances and order breaks in various materials (crystals, polymers, solutions) through Raman signatures related to point or extended defects, doping,

phase or phase transformations, domains, components of a mixture, crystallites, etc, but also to perform metrology and control of complex environments by attempting to establish a link between the characteristics of the Raman line (position, width, intensity) and a physical parameter: strain, electrical field, temperature, concentration, size, etc. One of the important topics is the correlation with other techniques (X-Rays measurements, dielectrics, optics) and the coupling with Raman measurement (DSC/Raman, WAXS or SAXS/Raman, Rheology/Raman).

SYSTEMS TEAM

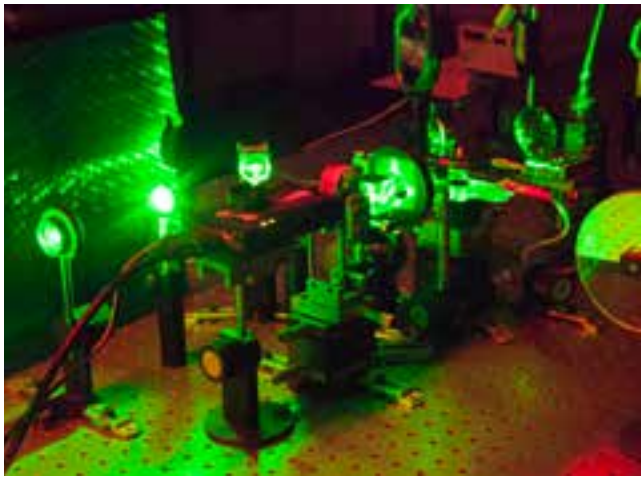
The Systems team main theme concerns the optimization of the various parts of energy production systems starting upstream by the development and modeling of the efficiency of photovoltaic modules – converters – generators – structures. The activities are devoted to photovoltaic systems, which is its mainstream research, but also to more general renewable energy sources. The activities are based on important know-how bringing together various specialties and skills of the different members of the team namely: physics, materials, electronics, optics and systems.

HIGHLIGHTS 2023

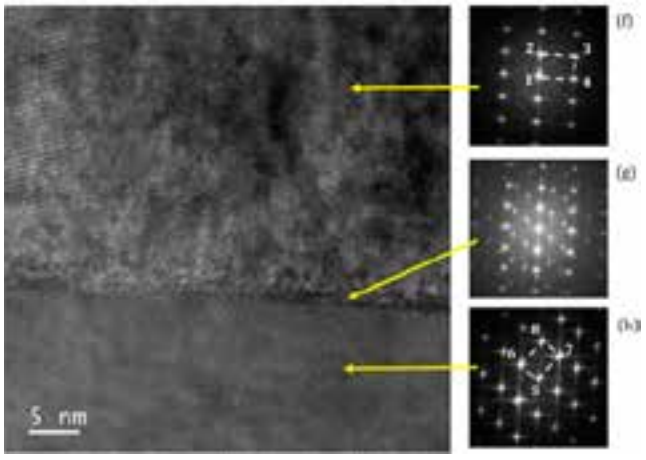
THE INTERNATIONAL SYMPOSIUM ON PHYSICS AND APPLICATIONS OF LASER DYNAMICS 2023 (IS-PALD 2023) took place in Metz from November 19 to 21, 2023. It has been an opportunity to learn advances in physics and applications of laser dynamics through invited talks by renowned scholars and through contributed presentations, both oral and poster, by active researchers. All types of conventional and emerging lasers are covered, such as semiconductor, solid state, fiber, quantum well, quantum dot, quantum cascade, and ring cavity. Meanwhile, the Symposium creates an environment for extensive discussion and potential collaboration with researchers worldwide. Two areas of laser dynamics are covered in the Symposium: Ultrafast Laser Dynamics et Nonlinear Laser Dynamics.

EXAMPLES OF STUDIES

Research team ***Materials***



Research team ***Photonics***



Research team ***Systems***

Industrial Partners

- AIRBUS,
- ArcelorMittal,
- ARKEMA,
- Cristal Laser,
- EDF,
- GDI Simulations,
- Institut de Soudure,
- M-Optics,
- Pôle Matéralia,
- SAFRAN,
- SHASTA CRYSTALS,
- TOTAL.

Academic Partners

Institut Jean Lamour (IJL), Laboratoire d'Etude des Microstructures et de la Mécanique des Matériaux (LEM3), Laboratoire de Chimie et Physique - Approche Multi-échelle des Milieux Complexes (LCP-A2MC), Laboratoire de Cristallographie, Résonance Magnétique et Modélisations (CRM2), UMI2958 Georgia-Tech-CNRS, Institut Lafayette, Laboratoire de Nanotechnologies et d'Instrumentation Optique (LNIO), Université du Luxembourg, Ecole des Mines d'Alès, Luxembourg Institute of Science and Technology, Universités de Bruxelles, Institute for Color Science and Technology (Tehran, Iran). Université de Padoue (Italie), Osbnabrück, Institute for Physical Research (Yerevan, Arménie), Université de l'Oural (Russie), Université de Tlemcen (Algérie), ICube, Laboratoire Charles Coulomb, Laboratoire de Physique des Lasers, Institut des Nanotechnologies de Lyon...

Key figures

• Professors, Associate Professors & Researchers	23
• Engineers & Administrative staff	8
• PhD Students	13
• PostDocs	2
• Visiting Professors	2
• Publications of the year (WoS)	52

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LABORATORY OF MECHANICS PARIS-SACLAY

On January 1, 2022 the Paris-Saclay Mechanics Laboratory (LMPS) was created from the merger of the Mechanics and Technology Laboratory (LMT) and the Mechanics of Soils, Structures and Materials Laboratory (MSSMat). The merger of these two laboratories was all the more natural as they share scientific themes on all facets of solid mechanics: mechanics of materials and structures, civil engineering, fine experimentation and high-performance computing. With nearly 220 members (half permanent members and half doctoral and post-doctoral students), this new research unit, dedicated to experimentation, modeling, and simulation in solid mechanics, aims to contribute to meeting the challenges in the strategic areas of safe and efficient clean energy development, resource management and adaptation to climate change, sustainable transport, and urban systems, reliability of complex systems and industrial renewal. To help overcome the associated scientific challenges, It develops both experimental observation and characterization methods, aims at formulating appropriate models for the physically identified mechanisms, and advanced computational methods and simulation codes able to handle these models efficiently.

With 3 research support resource centers, a management center, an experimentation and development center and a simulation center, the laboratory comprises 4 research teams, plus 2 joint laboratories run by the laboratory and an international partnership with the University of Hanover.

Research Teams

COMMET: Materials Behaviour, Modeling, Experimentation and Theory

The objective is to develop tools for observing and quantifying deformation, damage and failure mechanisms, to propose and formulate reliable mathematical behaviour models for materials and structures, and to implement them numerically. These physically-based models of mechanical behaviour are intended to be adapted to industrial problems and needs and to predict the behaviour of these materials and structures in service and in extreme conditions.

The team pays particular attention to the development of state-of-the-art experiments, from the atomic scale, with transmission electron microscopy (TEM), to the scale of the continuous medium and structures, via intermediate scales with the latest generation tools such as the SEM-FIB, SEM, nanoindenter, tomograph, X-ray diffractometer, etc., within which in situ mechanical tests are carried out. These developments involve complex loadings (uniaxial or multiaxial, under monotonic or non-monotonic conditions, quasi-static or dynamic, fatigue, multiphysics, under environment). This includes aspects from test management to the most modern techniques for identifying and validating models developed in parallel in the team.

STAN: Advanced Science and Techniques in Numerical Mechanics

The core business of the team is modeling and simulation in mechanical engineering sciences and its interactions. Closely blending classical disciplines (material sciences, applied mathematics, etc.) and other more emerging disciplines (such as AI), the team develops modeling approaches and computational strategies that integrate new knowledge and allow to address major societal challenges. These approaches and strategies are focused on the analysis of physics and are largely influenced by the needs of the mechanical engineering sectors and their interactions, so that they are adapted, effective and innovative in an industrial context.

One of the team's objectives is to contribute, through its upstream research productions, to the progress of mechanical sciences in terms of advanced modeling and numerical simulation. This progress is necessary to better understand and apprehend the complex physical systems studied, and to meet current and future challenges in various fields such as health, energy, the environment and mobility.

Another objective of the team is to make a strong and relevant contribution to controlled design in multiple industrial sectors, under increasingly demanding specifications (safety, durability, cost, impact on the environment, compatibility with engineering time, etc.) requiring the elaboration and processing, at the right cost, of increasingly complex problems (multi-scale, multi-physics, stochastic, etc.). The aim is to propose methods and tools to assist in the decision making process in order to imagine, design, characterise, optimise, certify and control the complex materials, structures and systems of today and tomorrow, and thus contribute to the development of the industry of the future.

MILA: Architectural Environments

Some materials, biomaterials or structures, whether manufactured or natural, derive their particular properties from the organization of their internal constituents. The study of the mechanisms and interactions that determine these functional properties at different scales is the focus of our research.

The team is then particularly interested in:

- the different levels of structural organization of organs such as bones and teeth, from their biofabrication in vitro from cells to their repair or regeneration in vivo;
- the synthesis and inclusion of nano-reinforcements in polymeric, ceramic or metallic composite materials in order to couple and optimize multiphysical properties;
- filament assemblies that can constitute composite reinforcements; composite materials for the transport and energy industries;
- non-classical macroscopic behaviour resulting from complex interactions between fibrous components at lower scales.

OMEIR: Structures, Materials, Environment: Interactions and Risks

The upcoming climate transition will significantly increase natural hazards on structures, infrastructures and urban systems. The increasing density of urban environments and the interconnection of systems increase the exposure and vulnerability of societies that want to be increasingly protected. The transition from a prudential society protected by law and regulation to an insurance society requires an assessment of risks and associated uncertainties at increasingly fine scales.

Part of the answer lies in the implementation of numerical twins or even hybrids. Simulation methods, however advanced, are not sufficient, due to lack of data or insufficient validation. Massive data, routinely acquired by monitoring and maintenance systems, must be assimilated and analyzed by these digital twins as they are beginning to exist in other sectors. Finally, advanced experiments on sub-systems but simulating the complete system must be able to be carried out to better control the uncertainties associated with the models.

Thus, the OMEIR team proposes to contribute to the energy, ecological and digital transition of the entire sector related to cities and infrastructures. To do this, it brings together the expertise of research groups specializing in: construction materials and natural materials, the modeling of various physical phenomena (mechanical, thermal, hydric, chemical), fine experimentation, natural risks, complex and large-scale numerical simulations and statistical learning.

RESOURCE CENTERS

Experimentation and Development Center

The Experimentation and Development Center brings together the resources dedicated to experimental research at LMPS. The Experimentation and Development Center (EDC) is a research support department reporting to the laboratory management. It brings together the testing resources and associated skills pooled for the laboratory's experimental research. The EDC is first and foremost a team of twenty engineers and technicians. This team is responsible for the development of original and unique experiments, from design to final measurement. It is also responsible for maintaining the equipment and training researchers in its use. EDC's premises cover an area of 4,000 m². The equipment is dedicated to the analysis of all types of materials: metals, ceramics, concretes, composites, nanomaterials, living tissues, etc. The samples characterized range in scale from the nanometer to the meter: from the arrangement of atoms to structural elements up to three meters long. The material resources of these poles are spread across the two LMPS sites: CentraleSupélec and Ecole Normale Supérieure Paris-Saclay.

Simulation Center

The Simulation Center has a staff of 7 and is organized into 2 divisions: Administration & Networks and Development. The main mission of the LMPS Simulation Center is to provide LMPS members with a hardware, software and service environment that is sufficiently powerful, reliable and secure to enable them to work in optimum comfort and efficiency. It offers an environment based on Linux platforms for the use of industrial software and the production of scientific software incorporating the latest advances in research in the fields of materials and structures, as well as new multiscale, multiphysics and parallel computing strategies. It also ensures the operation of the various servers essential to the various activities.

Management center

The Management center supports and advises LMPS members in their day-to-day scientific and technical activities. It is responsible for the administrative, financial and budgetary management of the laboratory. The center focuses on 5 main axes: Budget - Finance, Human Resources, Communication, Development, Logistics.

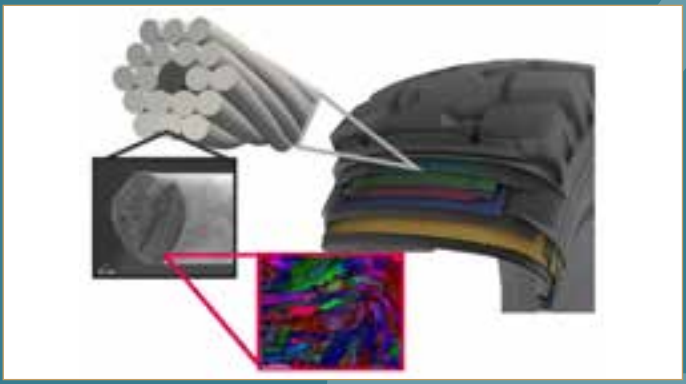
APPLICATION DOMAINS

- Safe and efficient clean energy
- Sustainable transport and urban systems
- Reliability of complex systems
- Industrial renewal
- Sober resource management
- Safe societies - protecting freedom and security.

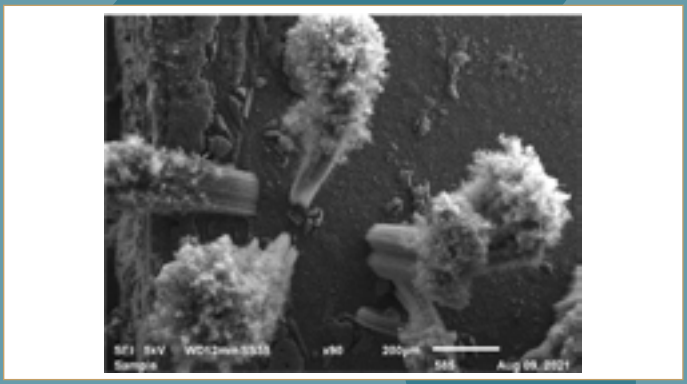
HIGHLIGHTS 2023

- LMPS, Safran Aircraft Engines and SafranTech have set up a joint research programming group (GPRC) on the theme of "Numerical and experimental mechanics for the performance of aeronautical engines and structures".

- The L'Oréal-UNESCO Foundation's *Prix Jeunes Talents France 2023* For Women In Science was awarded to **Amandine Asselin** for her thesis work on chloride diffusion in concrete, carried out at the Laboratoire de Mécanique Paris-Saclay, in co-supervision with Polytechnique Montréal. The prize is awarded each year to 35 young women researchers, and aims to support the involvement of young women in scientific research.

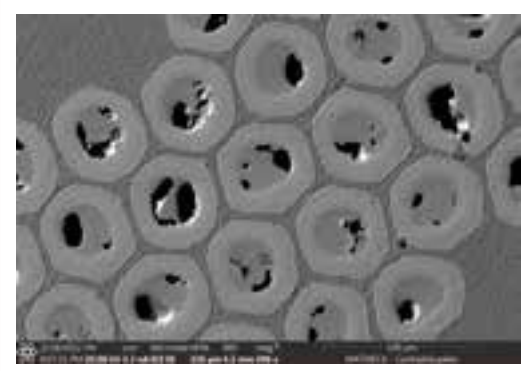


The need for multi-scale approaches to tire design

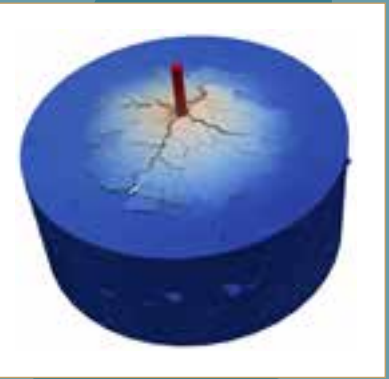


Carbon nanotube NanoCabbages

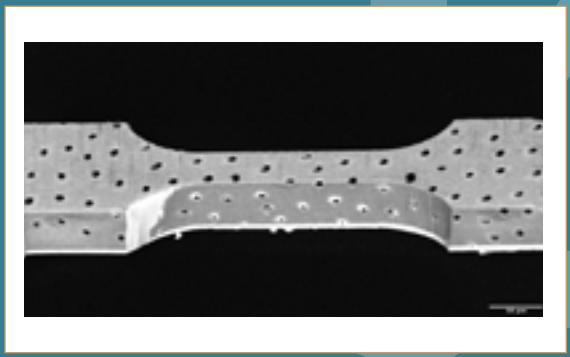
2D multiaxial test with the triaxial testing machine ASTREE



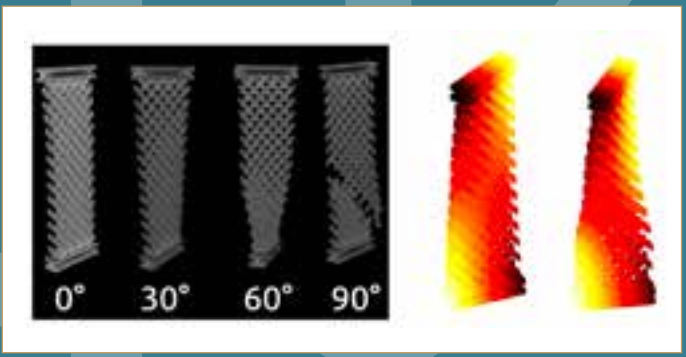
View of a superconducting strand Niobium–tin



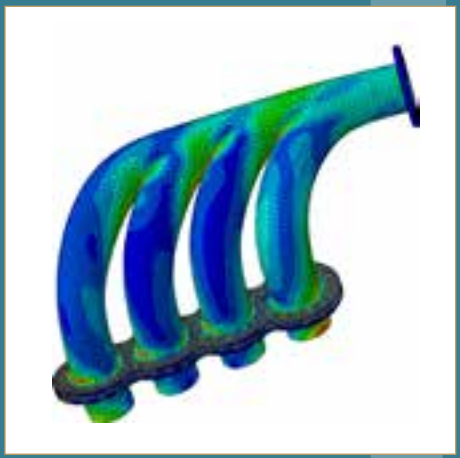
Particle-lattice model simulation of the pull-out of a pegged anchoring system



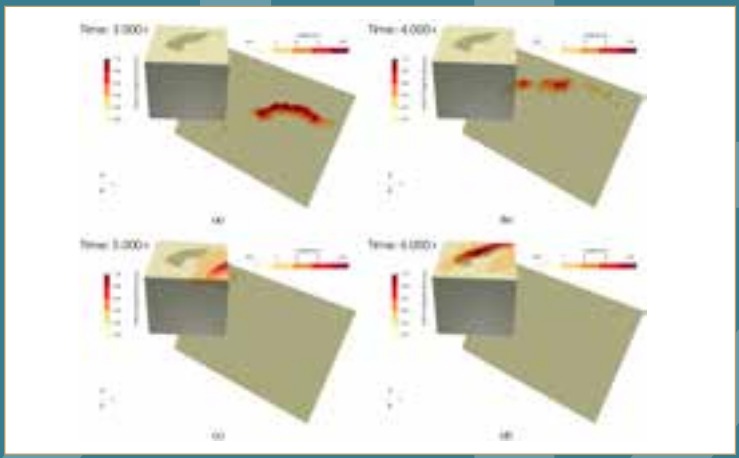
Micro-tensile test piece in dentine



In-situ torsion testing of a 3D printed pantograph under tomography with image correlation



Study of a manifold avatar with connector model for bolted connections



Simulation of the seismic response of the Argostoli basin using SEM3D on HPC facilities (local Paris-Saclay University meso-center and National Occigen)

Industrial Partners

- Airbus, Ariane Group, CNES, Dassault Aviation, MBDA, Safran, Thalès
- Renault, Stellantis, Michelin, RATP, SNCF
- EDF, IRSN, IFP, Mitsubishi Electric, Orano, Saint-Gobain
- ArcelorMittal, Aperam, Tata Steel, Vallourec
- Bouygues construction, Ecocem, sixense, ANDRA, CEMENTYS, IREX
- Altair, Dassault Systèmes, EikoSim, ESI, SIEMENS
- Air Liquide, BIOMODEX, cetim, GE Healthcare, iXblue.

Academic Partners

CEA, DGA, INRIA, ISL, ONERA
Institut Farman, Fédération francilienne F2M-msp, Collège doctoral Franco-Allemand SNTA
ICMMO (Université Paris-Saclay), MATEIS (INSA Lyon), Centre des Matériaux et CEMEF (Mines Paris-Tech), LMS (Polytechnique), SPMS et LGPM (CentraleSupélec), ONERA (DMAS), KTH (Suède), Université de Zagreb (Croatie), UFSCar et USP (Brésil), Université Leibniz de Hanovre (Allemagne), Université Rome Sapienza et l'Aquila (Italie), Université Trondheim (Norvège), Université du Kansas (USA), Université de Talca (ECOS), Université de Sao Paolo, Università di Roma la Sapienza, Laser Institute of Shandong Academy of Science, Ecole Polytechnique de Montréal, MSME(U. Paris-Est Créteil / U. Paris- Est MLV), IJRLDA (Sorbonne U.), PIMM (ENSAM), GeM (EC Nantes/U. Nantes), LVTS et URB2i (U. Paris), G2ELab (U. Grenoble), CRPP (U. Bordeaux), LiPHY (UGA Grenoble).

Key figures

• Professors, Associate Professors & Researchers	65
• Engineers & Administrative staff	31
• PhD Students	90
• PostDocs	10
• Visiting Professors	3
• Publications of the year (WoS)	155

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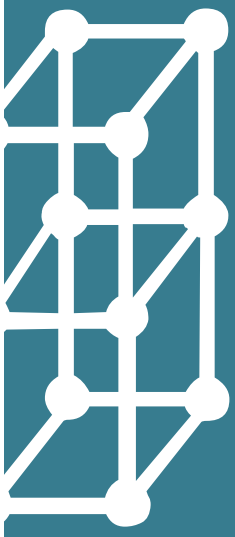

CentraleSupélec within

LORIA UMR 7503

LABORATOIRE LORRAIN DE RECHERCHE EN INFORMATIQUE ET SES APPLICATIONS

Founded in 1997, LORIA is a joint research unit (UMR7503) under the supervisory authority of CNRS, Inria and the Université de Lorraine, located at the Faculty of Sciences and Technologies of Vandoeuvre-lès-Nancy and CentraleSupélec Metz Campus. Since its creation, LORIA has worked on fundamental and applied research in computer science. LORIA belongs to the scientific cluster AM2I (Automatics, Mathematics, Computer Science and Interactions) and is one of the largest laboratories of the Grand Est Region.

Research work is conducted by 5 departments and 28 teams, around 7 cross-cutting axes:

Research departments

- **Algorithms, Computation, Image and Geometry** (ABC, Adagio, Caramba, Gamble, MFX, Pixel, Tangram teams)
- **Formal methods** (Carbone, Mocqua, Mosel-Veridis, Pesto, Types teams): proofs, software validation and certification
- **Networks, Systems and Services** (Coast, Optimist, Resist, Simbiot teams): integrative approach for design, modeling, engineering, and assessment of robust and safe cyberphysic systems
- **Natural Language Processing and knowledge discovery** (K, Multispeech, Orpailleur, Semagramme, SMarT, Synalp teams): data mining, machine learning, visualization, clustering
- **Complex Systems, artificial Intelligence and robotics** (Bird, Biscuit, Capsid, Larsen, NeuroRhythms teams): autonomous systems, machine learning, artificial intelligence.

Cross-cutting axes

- ROBOTICS AND CYBER-PHYSICAL SYSTEMS
- CYBERSECURITY
- HEALTH
- E-EDUCATION
- AUTOMATIC LANGUAGE PROCESSING AND ARTIFICIAL INTELLIGENCE
- ENERGY
- FACTORY AUTOMATION

Application Domains

- Artificial intelligence,
- Cyber-physical systems,
- Cybersecurity,
- Education,
- Energy,
- Factory automation
- Health,
- Natural Language Processing,
- Robotics.

HIGHLIGHTS 2023

- **Charles V's encrypted letter**: a centuries-long riddle-solved. Thanks to the combined efforts of four researchers from Loria (CNRS, Inria, Université de Lorraine) and University of Picardie Jules Verne, an encrypted letter from Charles V has been decrypted and confirmed remarkable historic facts, five centuries after being written. Press release (French): https://bit.ly/49wZost
- A **test of time award for CGAL**: The CGAL (Computational Geometry Algorithms Library) Project has been selected for the *2023 Symposium on Computational Geometry* (SoCG) Test of Time Award. The prestigious award recognizes outstanding papers presented at the SoCG conference from at least 20 years ago that have had a significant impact on the field of computational geometry. Congratulations to the members of the **Gamble team** involved in this project. https://gamble.loria.fr/CGAL_ToT.html
- Two articles were presented at **Siggraph 2023**, the world's largest and most influential conference on computer graphics and interactive techniques: https://www.loria.fr/en/2023/07/the-mfx-team-creating-innovative-uses-for-3d-printing/ https://www.loria.fr/en/2023/08/pcbend-flexible-printed-circuits-for-maximum-creativity/
- A reinforced **French-German partnership** between CISPA and Loria on cybersecurity: https://www.loria.fr/en/2023/05/6th-french-german-day-for-cybersecurity/
- Cybersecurity: Creation of the **CYBI startup**: artificial intelligence to anticipate cyberattacks. https://www.loria.fr/en/2022/06/artificial-intelligence-to-anticipate-cyberattacks-launch-of-the-cybi-startup/
- Participation to the **European project euROBIN**. euROBIN is the Network of Excellence that brings together European expertise on Robotics and AI : https://www.eurobin-project.eu/
- **Dynalips**: speech animation at the frontiers of reality: https://www.loria.fr/fr/2023/06/dynalips-une-animation-de-la-parole-aux-frontieres-du-reel/ Pepite France prize for Dynalips: https://www.pepite-france.fr/10e-edition-du-prix-pepite-decouvrez-les-laureats/
- Science popularization: organization of "**Les Cigognes**" training course in mathematics and computer sciences for 25 high-school girls in the Grand Est Region: https://bit.ly/3U7BBuL

- Publication of the dystopian collection ***Think Before Loading***: These six dystopias were written at the beginning of November 2022 by 23 doctoral students in computer science at the Université de Lorraine, as part of the doctoral course Ethics in computer sciences: write your dystopia. https://thinkbeforeloading.loria.fr/fr

SMART-BIODIV PROJECT - SMART AI TECHNOLOGIES FOR BIODIVERSITY RESEARCH

Marine environments undergo rapid changes and the monitoring of their ecosystem status becomes critical. Such a monitoring requires gathering data, processing them and extracting indicators summarizing the status of the environment. However, the data in environmental sciences are often sparse and imbalanced, which constitute challenges for AI algorithms. This leads to the two directions followed in the SMART-BIODIV proposal:

- Harnessing the power of machine learning algorithms to complete and process sparse and imbalanced data that we often encounter in environmental sciences ;
- Designing indicators to qualify the ecological status of the considered environments. We will also exploit the large image databases collected by the partners on marine plankton and make them available to the challenge participants.

Loria and CentraleSupélec bring their expertise in computer science and more particularly in artificial intelligence applied to the particular theme of biodiversity. The team involved will lead the WP3 on hybrid AI and will also participate in the other WPs. The challenge of WP3 will be to incorporate business knowledge in the form of a relationship graph into predictive models of biodiversity.

CHALLENGE
IA-BIODIV

High Security Laboratory

A Grid5000 node

Creativ'Lab
Crédit photo Inria, D. Betzinger

Industrial Partners

- ALERION,
- Antsway,
- Cyber-Detect,
- Deezer,
- EDF,
- Eviden,
- Linagora,
- Meta,
- Naval Group,
- Orange,
- Scytl,
- Tessael,
- WALLIX.

Academic Partners

Inrae, CHRU de Nancy, Kyutech University, Université de Rabat, JAIST, CISPA, Université Fédérale de Rio Grande Do Norte, Université catholique de Brasilia (UCB)....

Key figures*

• Professors, Associate Professors & Researchers	11
• PhD Students	4
• Publications of the year (WoS)	5

*CentraleSupélec only

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CentraleSupélec within

LUMIN, UMR9024

LIGHT, MATTER AND INTERFACES LABORATORY

LuMIn
Lumière, Matière et Interfaces

cnrs

école normale supérieure paris-saclay

université PARIS-SACLAY

CentraleSupélec

université PARIS-SACLAY

LuMIn is a research laboratory created in 2020 and devoted to light-matter interactions scaling from atoms to materials, devices and living systems at University Paris-Saclay. It aims at proposing novel and original synergies at the frontiers of optical and quantum physics, device technologies, along with the exploration *in vitro* and *in vivo* of fundamental biological processes for a better understanding of cancer and brain disorders pathogenesis.

The core activity of this structure is based on a wide spectrum of competences in optics (lasers, nonlinear optics, quantum physics, plasmonics, optomechanics), with applicative developments to the design and elaboration of micro- and nanophotonic devices (including microfluidic circuits) and to the investigation of biochemical phenomena in cells, tissues and living organisms.

LuMIn operates under the authority of four institutions: CNRS, ENS Paris-Saclay, Université Paris-Saclay and CentraleSupélec. It hosts the Equipex+ eDiamant and shares a common lab. with Thales R&T. It also belongs to the Institut d'Alembert in ENS Paris-Saclay.

Research topics

ULTRAFAST PLASMONICS AND NANOPHOTONICS (IN CENTRALESUPÉLEC SITE)

Metal nano-objects under light irradiation exhibit remarkable optical properties associated with the plasmon resonance phenomenon. We study, by carrying out dedicated experiments and simulations, the interaction of ultrashort light pulses with such plasmonic nanoparticles (NPs). This can lead to the formation of a hot electron gas, whose dynamics is accompanied by interesting phenomena which can be exploited in photonic, chemical or biomedical applications. Further, noble metal NPs are efficient converters of light into heat at small scales when lightened at their plasmon resonance. We study these fundamental mechanisms and exploit them for innovative functional materials and biomedical developments. In addition, we work on optomechanics, which designates the coupling of an electromagnetic wave with the motion or vibration of an object. This interaction is as strong as optical powers are important or as the objects are small. We investigate how optomechanical coupling can be magnified depending on the size of metal NPs and their environment. Besides, while piezoelectric materials change their dimensions when a voltage is applied, a similar effect called photostriction can occur under certain conditions when illuminated by an intense optical beam. We work with the SPMS lab. in CS to investigate this new optomechanical coupling.

DIAMOND-ENABLED MATERIALS AND SENSORS

Our research focuses on applying nitrogen-vacancy (NV) centers in diamond to sensitive magnetic measurements.

LASERS AND OPTICS

Our activities range from very fundamental studies in quantum information to the development of optoelectronic oscillators of high spectral purity, via the physics of lasers and nonlinear optics.

NANOPHOTONICS, MATERIALS AND SPECTROSCOPY

We fabricate and study different kind of nanomaterials and their interaction with light.

STRUCTURATION AND DEVICES

This research theme is focused on the elaboration, physical and technological studies of various kinds of photonic devices, mainly made of molecular and polymeric materials.

NEW OPTICAL METHODS FOR LIFE SCIENCE STUDIES

This theme aims at developing new methods for various applications in life sciences, with a focus on fundamental cellular processes: microscopy setups, optically active nanoprobes, optometry.

BIOPHOTONICS AND PHYSIOPATHOLOGY OF SYNAPSES

We study the synapse biology and circuit physiology in the healthy and diseased brain.

FLUIDIC AND ELECTRIC MICROSYSTEMS FOR LIFE SCIENCE STUDIES

We design and fabricate microfluidic devices for the characterization and treatment of living cells, for medical or environmental applications.

APPLICATION DOMAINS

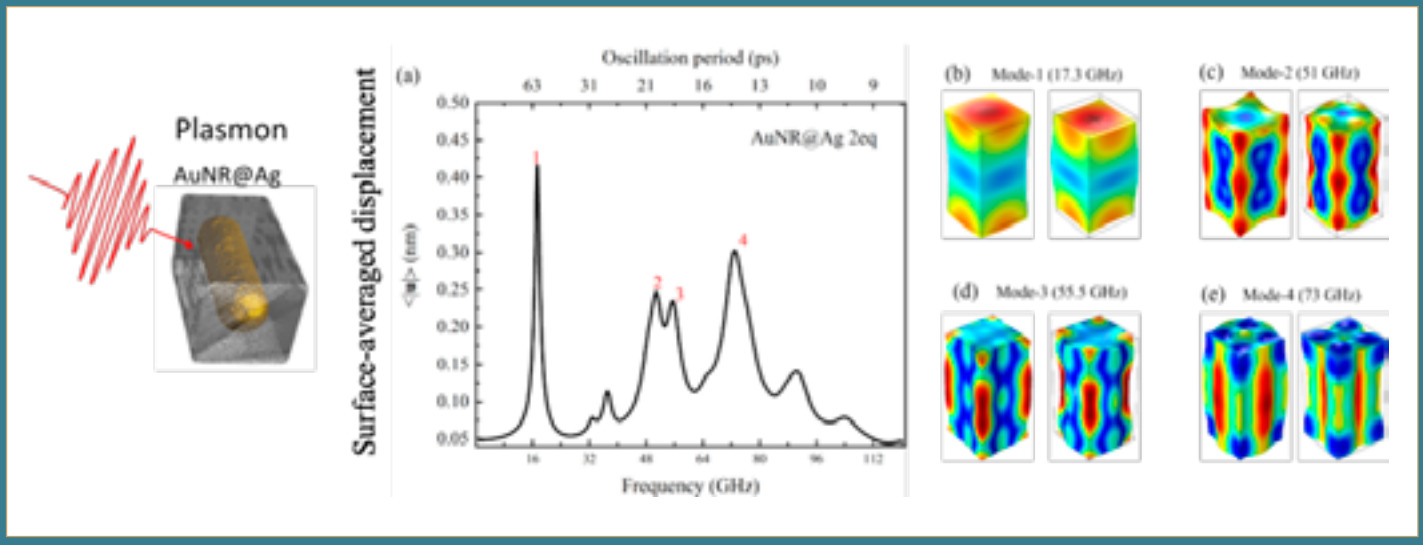
- Optoelectronics,
- Sensors,
- Biomedical imaging,
- Medical diagnosis and targeted therapies,
- Photovoltaics,
- Ultrafast optical processing,
- Quantum information,
- New microscopies,
- Materials for optics, sustainable energies and life science.

HIGHLIGHTS 2023

DECIPHER THE OPTICAL PROPERTIES OF A NEW PLASMONIC MATERIAL: TIN

In collaboration with a team of the Physics Department in Politecnico di Milano, Italy, we have investigated the theoretical description of the stationary and ultrafast optical responses of titanium nitride, a material with remarkable plasmonic properties which could replace noble metals for some applications. Our findings have enable to reproduce with accuracy experimental results already published in the literature. They have been presented in several conferences and should be reported in a regular review in 2024.

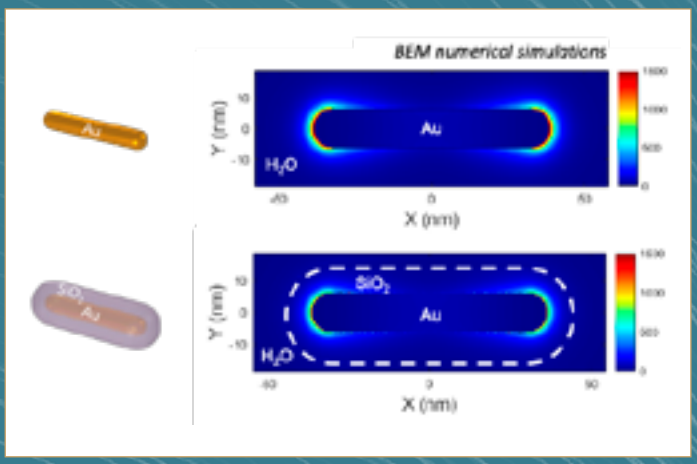
EXAMPLES OF STUDIES



The vibrational landscape of nano-objects revealed by their ultrafast optical response

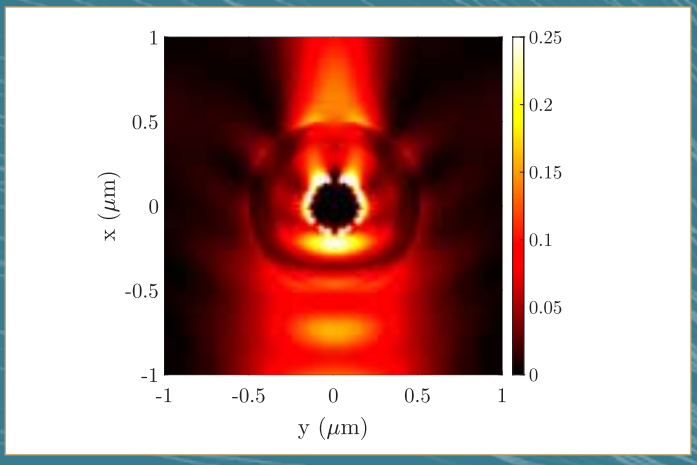
Bimetallic gold-silver core-shell nanoparticles: under pulsed laser illumination tuned to the plasmon resonance mode wavelength (left Fig.), the vibration properties of the nanoparticles can be analyzed by ultrafast transient optical absorption and modeling thanks to opto-mechanical coupling. The vibrational spectrum (middle) reveals different peaks in the sub-THz range, which correspond to specific vibration modes. The main ones are labelled and their origin revealed by acousto-plasmonic modeling (right; colors denote the relative induced displacement).

These results can be exploited for nano-sensing as both the optical and vibrational responses of the nanoparticles are very sensitive to their close environment. Collaboration: LPS, Orsay; ISM-CNR, Rome; IMMM, Le Mans. Published in: T. O. Otomalo et al., Chemosensors 10 (5), 193 (2022). DOI : https://doi.org/10.3390/chemosensors10050193.



Hindering the production of reactive oxygen species in biomedical applications of gold nanoparticles

Gold nanorods are extensively used for biomedical applications thanks to their tunable and effective optical properties. Under ultrashort laser pulses, they can generate reactive oxygen species (ROS) which, while useful for some targeted therapies, must be avoided in other developments like localized gene delivery. We have recently demonstrated that coating such nanoparticles with a thin layer of dense silica (SiO_2) enables us to hinder the production of ROS. This mainly stems from the confinement in the oxide layer of the electromagnetic near-field enhancement occurring at the nanoparticle tips, as illustrated on the figure (color levels: near-field intensity). Collaboration: NIMBE/CEA Saclay. Published in S. Mitiche et al., Journal of Materials Chemistry B 10, 589 - 597 (2022). DOI: https://doi.org/10.1039/D1TB02207E.



Mechanical properties of light at the nanoscale

Optomechanics refers to the coupling of electromagnetic radiation with one or more mechanical degrees of freedom. Indeed, although mass less, photons carry a mechanical momentum. It is intrinsically weak : the typical resulting force is 1nN for a 1W beam. Consequently these phenomena are negligible at the macroscopic scale, but at the nanometric scale objects are much lighter, and therefore much more sensitive to small forces. In addition, at such scales, surface effects are non-negligible since the surface to volume ration increases as the characteristic dimension decreases. In particular evanescent waves have a major contribution to the optical behavior and amplify the mechanical features of photons.

Industrial Partners

- Attocube R&D,
- Christex,
- Essilor,
- IMSTAR,
- Institut Photovoltaique d'Île-de-France,
- Orsay Physics,
- Photonscore GmbH,
- Thales TRT,
- United Visual Researchers.

Academic Partners

In France: Mascot (AP-HP, INSERM, U. Sorbonne Paris Nord); Ecole Polytechnique: Chaire Art & Science; LRS (Sorbonne U., CNRS); UTT: L2n (UTT, CNRS), LBPA (ENS-PS, CNRS), LPS (U. Paris-Saclay, CNRS).

In Europe: Politecnico di Milano (Italy).

Outside Europe: INRS, Montréal (Canada).

Key figures*

• Professors, Associate Professors & Researchers	2
• Engineers & Administrative staff	2
• PhD Student	1
• Post-doc	1
• Publication of the year (WoS)	1

*CentraleSupélec only

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MICS EA4037

LABORATOIRE MATHÉMATIQUES ET INFORMATIQUE POUR LA COMPLEXITÉ ET LES SYSTÈMES

CentraleSupélec

université PARIS-SACLAY

Mathematics in Interaction with Computer Science (MICS)

Founded in the early 2000's, MICS (formerly MAS) is the research laboratory in Mathematics and Computer Science at CentraleSupélec. Research at MICS is concerned with the analysis and modeling of complex systems and data, whether they come from the industry, life or social sciences, financial markets, information technology or networks.

Research Axes

- **Biomathematics**: Data-driven and Knowledge-based Mathematical Modeling, Statistical Inference and Computational to help solve major challenges in life sciences and health. Methods for Biological Systems and Data. Applications to precision medicine, neurosciences, molecular biology, genetics, plant science, epidemiology, decision-aided diagnosis.
- **Quantitative Finance:** Microstructure, high-frequency massive data: auctions, manipulation, market making, reinforcement learning; Covariance matrix filtering and investment; Agent models: cognitive biases and investor behaviour, money markets; Robust transport, mean-field games.
- **Fundamental Mathematics**: Harmonic analysis and geometric measure theory; Analysis of partial differential equations; Harmonic analysis and geometric measure theory; Numerical analysis; Stochastic analysis (rough paths, Fokker-Planck equation); Probabilistic Modeling and Statistics of Stochastic Processes: Regularity of stochastic processes (fractional processes).
- **Scientific Computing**: Massively parallel computing; GPU computing; Algorithmic interface between parallel computing and the numerical analysis of partial differential equations and algebraic differential equations.
- **Computer Science**: formalisms and methods based on logic, probabilities, graphs, category theory, mathematical morphology for software-based systems.
- **Artificial Intelligence and Decision Modeling**: Deep learning; Representation learning; Few shot and continual learning; Explainable artificial intelligence; AI for computer vision; AI for NLP; Multicriteria decision making, preference learning, knowledge representation and reasoning, explaining decisions, multi-objective optimization, collective decisions.

Application Domains

- Industrial systems (aerospace, construction, energy, transportation);
- Environment (plants, hydrology, landscapes, acoustics);
- Information technology and networks (Internet, multimedia, knowledge management);
- Life sciences (medicine, molecular biology, genetics, epidemiology);
- Markets and companies (finance, capital markets, business intelligence).

HIGHLIGHTS 2023

PRIZES

The jury prize for the national MT180 competition was awarded to **Arthur Ledaguenel**, for his thesis "AI neuro-symbolique : apprendre à partir de données et de règles" (*Neuro-symbolic AI: learning from data and rules*). Arthur is a PhD student at the MICS Laboratory, under the supervision of Céline Hudelot.

Javier Maass, a double-degree student from the University of Chile, has published a paper on the work of his *Research Track* at AAMAS, a rank A* conference. Co-authored with **Anaëlle Wilczynski** and **Vincent Mousseau**, researchers at the MICS laboratory, his paper is entitled "A Hotelling-Downs game for strategic candidatures with binary viewpoints", in the field of "computational social choice".

Gurvan Hermange was awarded the 1st Prize *Impact Science 2023* by the Fondation CentraleSupélec for his thesis work in MICS laboratory and Gustave Roussy. His subject is the *Mathematical modeling of myeloproliferative neoplasms, from their development to their treatment with Interferon alpha*.

RESEARCH PROJECTS

As part of the government's France 2030 plan, the **Prism National Center for Precision Medicine** in Oncology becomes one of 5 University Hospital Institutes with a €40 million endowment. Led by Gustave Roussy (Pr. Fabrice André), and involving CentraleSupélec, Université Paris-Saclay, INSERM and Unicancer, the Prism program is based on a transformative, long-term vision of cancer treatment and interception.

Created in 2023 with **Transvalor**, a French specialist in the simulation of materials shaping, the **Artificial Intelligence Chair for the Simulation of Materials Shaping Processes** aims to revolutionise the use of simulation tools in the decision-making process of manufacturing companies and to make Industry 4.0 and the digital twin an operational reality in their day-to-day operations. This could lead to reduced use of raw materials, energy savings and more innovative manufacturing processes.

possibilities offered by artificial intelligence applied to digital simulation. Simulation calculations will become faster and easier to perform and understand thanks to Machine and Deep learning, bringing us closer to real-time calculation, a key factor in the digital twin.

Chair holder: Frédéric Magoulès, MICS laboratory

Chair co-holder: Emmanuel Vasquez, L2S laboratory

A Franco-Quebec research team, comprising Jose Dolz and Pablo Piantanida from the ILLS laboratory, and **Maria Vakalopoulou** and **Stergios Christodoulidis** from the MICS laboratory, has won the second call for projects in the France-Quebec bilateral collaborative research program: artificial intelligence in healthcare, run by the *Fonds de recherche du Québec - Santé* (FRQS) and the Health Data Hub (HDH).

Industrial Partners

- AIR LIQUIDE HEALTHCARE
- BNP PARIBAS
- CYBELETECH
- DASSAULT AVIATION
- DASSAULT SYSTEMS
- EDF
- GE HEALTHCARE
- IBM
- ICON CFD
- ILLUIN TECHNOLOGIES
- INCEPTO MEDICAL
- RANDSTAD
- SAINT-GOBAIN
- SCIENTA LABS
- SERVIER
- SICARA
- SNCF
- SUN ZU LAB
- THALES
- THERAPANACEA,
- TRANSVALOR
- VITADX.

Academic Partners

Institut Gustave Roussy, CEA, INRA, INRIA, INSERM, AgroParisTech, Cambridge, Oxford, Georg-August-Universität Göttingen, Sapienza University of Rome, Polytechnic University of Turin, RUDN University, Bar Ilan, TU München, University of Tokyo, Doshisha University (Japan), Beihang University, (China), Providence University (Taiwan), University of Washington, University of Michigan, Temple University, Berkeley Lab (USA).

Key figures

• Professors, Associate Professors & Researchers	33
• Engineers & Administrative staff	6
• PhD Students	52
• PostDocs	7
• Publications of the year (WoS)	41

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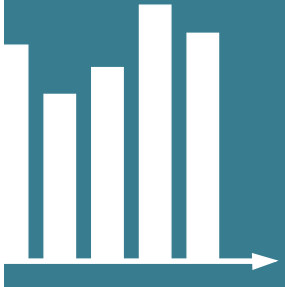


SONDRA

LABORATOIRE SONDRA - CENTRALESUPÉLEC ONERA NUS DSO RESEARCH ALLIANCE

SONDRA (CentraleSupélec ONERA DSO Research Alliance) was officially launched on 28 April 2004 in Supelec. The mission of SONDRA is to conduct unclassified basic research in advanced Electromagnetics and Radar domains.

Catching the invisible with new radar and surveillance concepts

As part of its missions, SONDRA contributes also to a better assessment of new technologies that are of interest to overcome various problems related to maritime surveillance in congested water areas, ground and air surveillance, homeland security especially in urban areas. The characterization of the environment, whether "natural" or anthropogenic is more and more complicated as we aim at augmenting the sensitivity and performances of the surveillance systems in the current context of the new connected world and of increased maritime, air and ground traffics. Radar and EM detection technologies remain of great interest to catch "invisible targets", i.e. target either masked by cloud cover, urban infrastructures, foliage or simply blocked by the horizon line of sight.

The alliance between the 4 parties offers a unique opportunity of development. NUS and CentraleSupelec provide an academic environment, effective at generating new collaborations with academic partners. On the other hand, DSO and ONERA are very attentive to experimental validation and transition to applications. The success of SONDRA is probably due to its capability to carry physics and signal processing research and to systematically register the research projects in a consistent framework leading to concrete actions and real validation, hence taking all attention from overseas stakeholder.

By the association of four high level research establishments in the rich research environment which represents the University of Paris-Saclay, SONDRA represents a world class laboratory for graduate education and research which produces innovative research outcomes for ONERA and DSO.

SONDRA contributes to research through 3 scientific areas, Physics and Modeling, New Concepts and Signal Processing and New Generation Hardware.

- **Physics and Modeling:** to predict the propagation of electromagnetic waves in complex media as forested or urban environments; radar is known to propagate through the foliage and inside urban canyons, hence providing unique capabilities for tracking vehicles that are not visible by optical sensors. Skywave propagation through the ionosphere is also studied to monitor the effects that can affect the medium.
- **New Concepts and Signal Processing:** to maximize the performances of existing or future radar by applying processes based on Artificial Intelligence.
- **New Generation Hardware:** activity focusing on a system approach, applied to the field of electromagnetism by studying new concepts of antennas and specific hardware components for signal conversion.

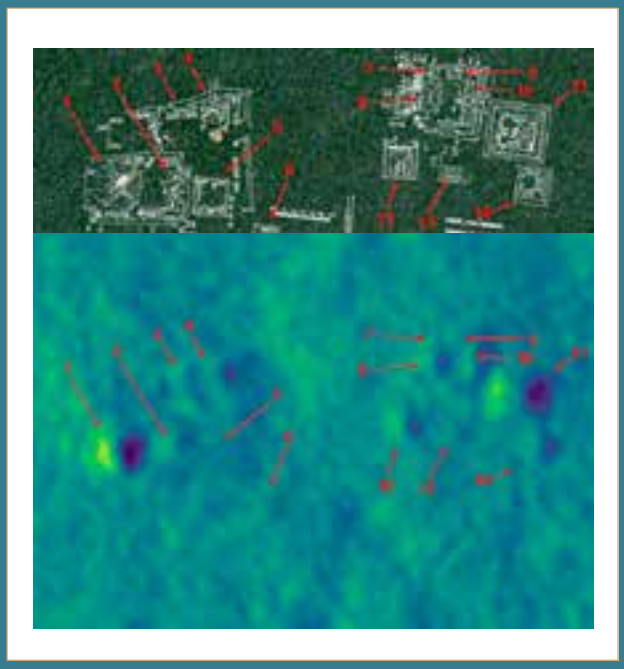
The two first scientific themes are those more developed in SONDRA lab considered a large contribution of Artificial Intelligence for the modeling, analyzing, and processing, whereas the third concerns National University of Singapore, NUS.

HIGHLIGHTS 2023

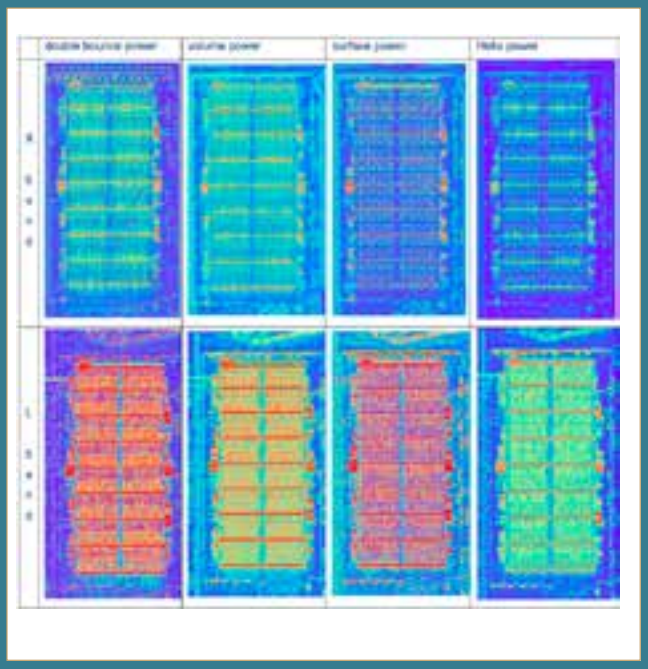
Visit of Singapore Ministry of Defense, Chief Defense Scientist (CDS) Mr. Peng Yam TAN – 22 February 2023.

Visit of Singapore Ambassador, H.E. Mrs Lee Foo TEOW 10 March 2023.

EXAMPLES OF STUDIES

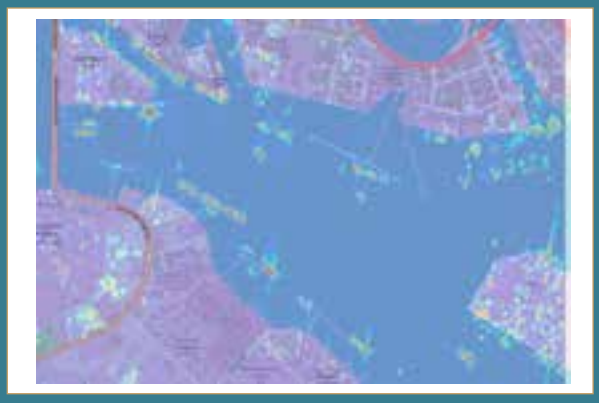


Optical image with map overlaid and markers added (top)
Satellite output SAR image with markers added (bottom).
The large pyramids and several smaller buildings are detected.

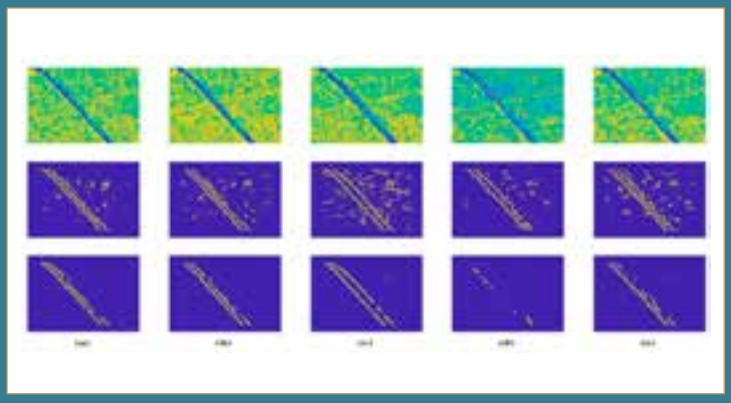


Multiband SAR imaging of one warehouse

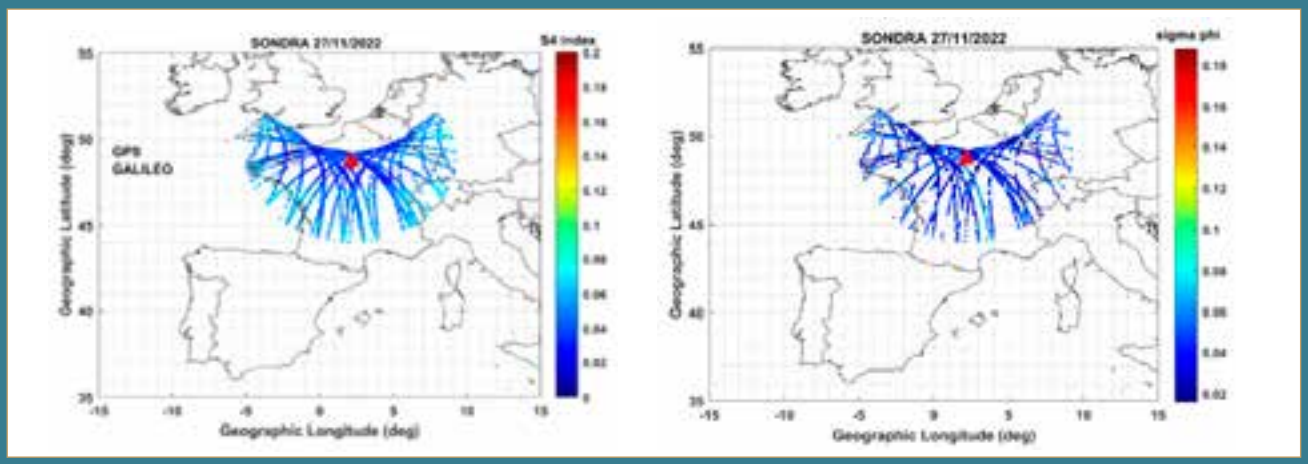
SIERA project (SONDRA Innovative Embedded RAdar Aircraft)



Ships detection results, overlaid on optical imagery using FBR (Frozen Background Reference) technique



Roads deteection from TerraSAR-X and SENTINEL-1 satellite imaging



Day-wise scintillation variation deduced from GALILEO contellation: Right: amplitude scintillation index - Left: Phase scintillation index

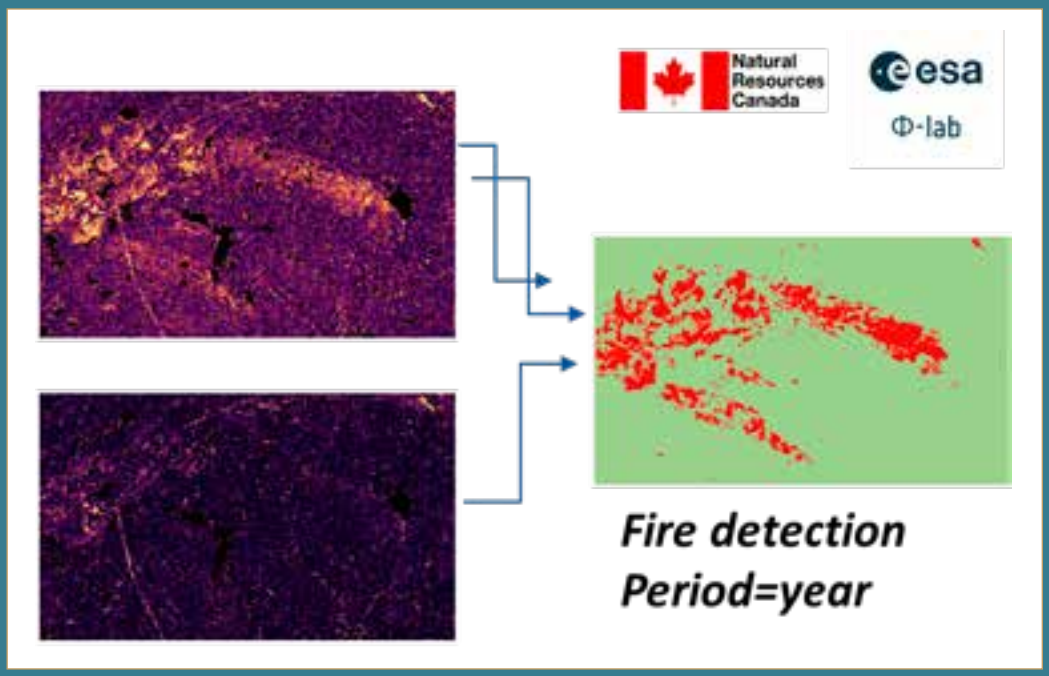


Illustration of the Detection of Forest Fires through Deep Unsupervised Learning Modeling of Sentinel-1 Time Series, ISPRS International Journal of Geo-Information, T. Di Martino, B. Le Saux, R. Guinvarc'h, L. Thirion-Lefevre, and E. Colin

Industrial Partners

- DSO
- ESA
- THALES
- ONERA

Academic Partners

NUS (National University of Singapore), NTU (Nanyang Technological University Singapore), UNIVPM (Università Politecnica Delle Marche, Ancona, Italie), Colorado School of Mines (USA), SATIE (ENS Paris-Saclay), GIPSA (Grenoble), IETR (Rennes).

Key figures

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• PhD Students	9
• Postdoc	1
• Publications of the year (WoS)	16

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LABORATORY STRUCTURES, PROPERTIES AND MODELING OF SOLIDS

Structures
Properties
Modeling *of*
Solids

THEMATIC FIELDS

FERROÏCS FOR TOMORROW'S DEVICES

This research theme revolves around ferroelectric materials, which have an electrical polarization that an electric field can control, and their coupling with mechanical or magnetic commands. This theme has particularly distinguished itself in the following areas of research:

- **Neuromorphic memories and components**: The ability to control polarization using an electric field opens up new possibilities for information storage and processing devices. This work explores ferroelectric relaxor materials for less energy-intensive FE-FET memories, memristor and memcapacitor components for neural networks.
- **Nanostructures and exotic polar states**: New polar states, such as skyrmions and vortices, are being studied for low-energy memories. These topological structures emerge in dimensionally reduced ferroelectric materials (super-lattices and nanoparticles). The SPMS focuses on the characterization and simulation of these systems, with collaborations for developing thin films.
- **Electrocaloric refrigeration**: This research, in collaboration with SATIE at ENS Paris-Saclay and the Josef Stefan Institute, aims to develop lead-free materials and cascade refrigeration devices based on ceramics, polymers, and composites. Particular interest is focused on very low-temperature applications for space and quantum computing.
- **Photo-pyro-piezo-catalysis**: Ferroelectric materials can catalyse oxydation-reduction reactions using ultrasonic, thermal, and optical excitations. Research at the SPMS shows the strong piezo-catalytic and photo-piezo-catalytic potential of ferroelectric nanoparticles for degrading pollutants. Development and industrial collaboration initiatives are underway, supported by local initiatives and proof-of-concept projects.

NEW SUSTAINABLE CONVERSIONS

- **Materials for electro- and opto-mechanical actuators**: Ferroelectrics are crucial in "smart" materials for converting energy types. They enable temperature changes to generate electricity for infrared vision, energy harvesting, and solid-state cooling for quantum computers. They also convert mechanical to electrical energy for self-powered devices in various applications. We aim to find sustainable alternatives to lead-based materials and discover new energy conversion phenomena.
- **Oxides for high-power energy storage**: This research focuses on energy storage in dielectric materials thanks to their polarization hysteresis cycles, particularly in anti-ferroelectric or ferroelectric materials close to their Curie temperature. These materials, ideal for high-power applications and specific environmental conditions, provide rapid discharge and thermal stability. The main materials studied are lead-based multilayers and lead-free alternatives for greener electronics.
- **Oxides for hydrogen technologies**: Hydrogen technologies are at the core of the energy transition, playing an essential role in converting and storing chemical energy into electricity and reciprocally. We focus on the design and test of oxide materials for high-temperature Solid Oxide Cells. We use combinatorial and autonomous research methods to speed up material discovery, focusing on oxide materials for hydrogen tech, sensors, and electronics. We seek to automate material discovery and enhance our understanding of composition-property relationships.
- **Oxides for nuclear energy**: This interdisciplinary research field explores materials and phenomena crucial for nuclear energy applications. Studies focus on understanding structural phase transitions, radiation-induced effects, and electronic properties in materials used in nuclear reactors and fuel cycles. For example, research investigates

the behaviour of materials like uranium oxides and thorium oxides under irradiation, assessing changes in structure, nonstoichiometry, and microstrain.

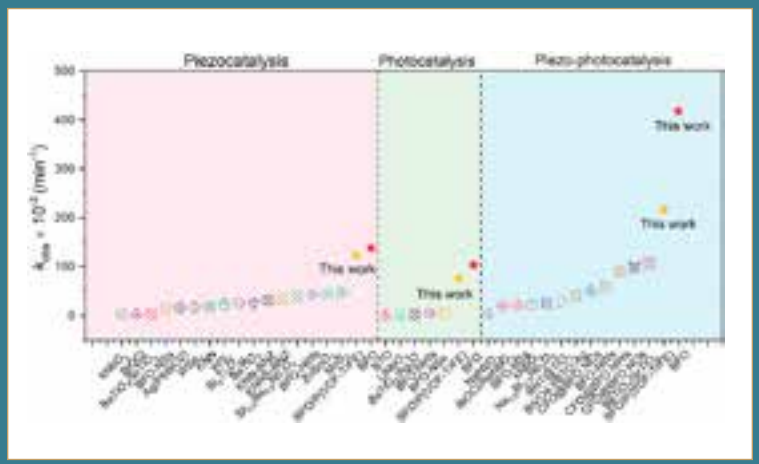
BIO-PHARMA MOLÉCULES AND MACROMOLÉCULES

- **Molecular crystals of pharmaceutical interest**: In the pharmaceutical industries, 80% of the Active Pharmaceutical Ingredients (APIs) are commercialized in solid form: either crystalline or amorphous. The formulation into a medical product of an API strongly depends on its solid form properties. There is an increasing interest in cocrystals by pharmaceutical industries. We have successfully applied the laser-induced nucleation method (NPLIN) to small organic molecules and inorganic compounds in the laboratory. We are currently testing another method using plasma excitations.
- **Physics of macromolecular complexes of biological interest**: This research aims to understand how molecular-level processes govern biological function, focusing on DNA and proteins. Spanning solid-state physics, chemistry, and bioinformatics, it uncovers key relationships between structure, dynamics, and function. Our goal is to reveal how chemical interactions, conformational changes, and atomic fluctuations orchestrate biological functions from disorder.

Application Domains

Electronic, Energy, Environment and Pharmaceutical industries, functional materials, piezoelectric transducers, energy harvesters, solid oxide fuel cells, multilayer capacitors, electrostrictive actuators, memories and artificial synapses, quantum enabling technologies, photovoltaic cells, photo- and piezo-catalysts, photo-sensors and emitters, biomedical field, hydrogen technologies, nanostructured ceramics, nuclear materials.

HIGHLIGHTS 2023



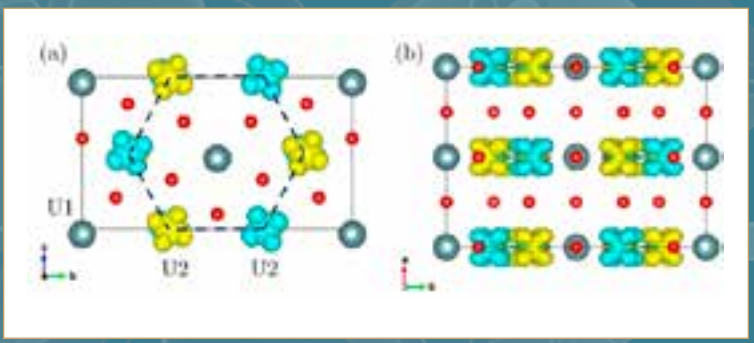
Degradation rate constant kobs for various materials. BFO (red stars) and BFO/P(VDF-TrFE) (orange stars) piezo, photo and piezo-photocatalytic activities compared with other ferro/piezoelectric materials.

$BiFeO_3$ nanoparticles for record efficiency in piezo-photo-catalysis

$BiFeO_3$ nanoparticles synthesized by an innovative method demonstrate exceptional efficiency in piezo-catalysis and piezo-photo-catalysis. As catalysts, they enable rapid degradation of organic pollutants under sunlight and mechanical vibrations, surpassing conventional methods. Integrating these nanoparticles into a polymer film ensures efficient reuse and limits secondary pollution, opening up new avenues for diverse applications, from pollution control to hydrogen production and medical therapy. [W. Amdouni et al., Angew. Chem. Int. Ed. 62,e202215700 (2023); W. Amdouni et al., Adv. Mater. 35, 2301841 (2023)].

Charge order and spin order in U_3O_8

Yellowcake (U_3O_8), a uranium concentrate powder from leaching solutions, is a crucial intermediate in uranium ore processing for nuclear fuel production. Despite its significance, understanding the low-temperature magnetic order and electronic properties of U_3O_8 remained inconclusive. Through the reinterpretation of neutron scattering results and employing group representation theory, we established that its ground state displays collinear magnetic moments, both within and between layers, relieving geometric frustration. This generates a slightly distorted honeycomb lattice with Neel-type antiferromagnetic order. Precise knowledge of this magnetic ground state elucidates the system's band gap characteristics. Spin-orbit coupling (SOC) plays a critical role, significantly altering the electronic structure by reducing the gap by approximately 38%. The predicted electronic structure aligns well with recent optical absorption measurements, highlighting agreement between calculated and experimental properties. [Phys. Rev. Materials 7, 054410 – 2023]



Magnetization density along the direction of the a axis. Gold indicates a positive magnetization and cyan a negative one. (a) Top view of the orthorhombic unit cell. This shows the in-plane honeycomb Néel-type AFM order. (b) Side view of the unit cell, showing the interlayer AFM coupling. This strongly suggests a type of superexchange mechanism mediated by the oxygen atoms between the U2 atoms.

Industrial Partners

- COORSTEK
- EXXELIA
- FERROPERM
- HORIBA-JOBIN YVON
- IMASONIC
- IXSEA (SONAR)
- LETI
- NANOE
- PYTHEAS TECHNOLOGY
- SAINT-GOBAIN
- SCHLUMBERGER
- ST MICROELECTRONICS
- SRT Microcéramique
- THALES & THALES UNDERWATER SYSTEMS

Academic Partners

NATIONAL: CEA-Saclay, CEA-DAM, CEA-Cadarache, Faculty of Pharmacy (Paris-Saclay), ICMCB, ESRF, SOLEIL, LETI, Thiais, Vitry, ENS-Paris-Saclay, C2N-Saclay, UMPhy-Saclay, GEMAC-Versailles, GREMAN-Tours, IMMM-Le Mans, UPJV-Amiens, etc.

INTERNATIONAL: University of Tokyo Waseda, Spring8, University of Arkansas, EPFL, University of Cracaw, University of Belgrade, University of Barcelona, Georgia Tech, JSI-Slovenia, Univ. Duisburg-Essen-Germany, LIST&Univ-Luxembourg, Univ. Liège-Belgium, UCLondon-UK, ISIS-UK, NTNU-Norway, Univ. Tunis El Manar-Tunisia, Xi'an Jiatong Univ-China, East China Normal Univ.-China, SITP-Shanghai-China, UDrexel-USA, UC Berkeley-USA, UConn-USA, etc.

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