INP

INSTITUTE OF PHYSICS RESEARCH NETWORKS (GDR) IN 2021

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Astrid Lambrecht,
Director of the CNRS Institute of physics

The “Groupement de Recherche” (GDR) is a native CNRS entity that brings together and federates a scientific community around an emerging, original research topic. The CNRS’ Institute of Physics regularly initiates new GDRs on subjects relating to current, fundamental scientific or societal issues.

While at the heart of the Institute of Physics’ science, these topics may also interface other scientific fields. Such transdisciplinary GDRs are sponsored by the Institute of Physics, in association with the other CNRS institutes concerned.

GDRs are established for a period of five years, renewable once, and are led by a director. They bring together research teams comprising staff scientists, faculty, PhD students, post-doctoral fellows and engineers from CNRS research units, institutional partners - such as universities, CEA, Inserm, Inra or Ifremer – as well as private companies.

The main missions of a GDR are : to organize a scientific community, often multidisciplinary, around a specific theme, while encouraging new partners (academic, industrial or service providers) to join ; to develop exchanges between scientists within the network of laboratories involved; and finally to set up collaborative projects on a national, European or international level.

In 2020, the activities of GDRs were strongly affected by the Covid pandemic, making in-person meetings difficult or even impossible for much of the year. I wish to extend my most sincere thanks to the GDRs’ directors for their efforts, throughout the year, in keeping the scientific communities alive despite this complicated situation. Unfortunately, this restricted mode of operation will have to be maintained for as long as the pandemic prohibits in-person meetings and exchanges.

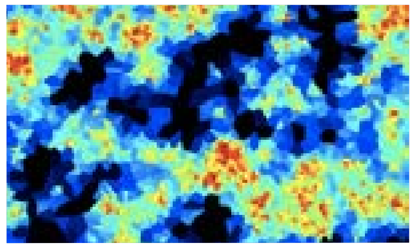
This booklet presents the objectives and prospects of each of the Institute of Physics GDRs in the form of a summary sheet.

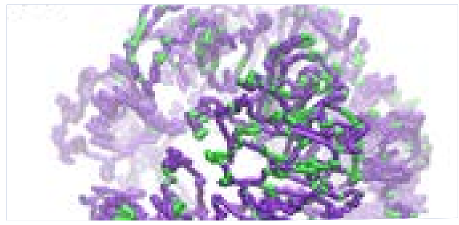
In addition to presenting the research performed on diverse emerging topics, I hope that this booklet will entice new partners from other fields to bring their complementary scientific expertise to these GDRs for the benefit of all parties.

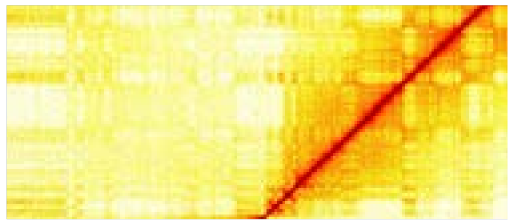
GDR
ADN 2.0*- ARCHITECTURE AND DYNAMICS OF THE NUCLEUS AND GENOMES

The mission of the **Nuclear architecture and dynamics and genomes (ADN 2.0)** research network is to bring together the French community involved in the study of nuclear organisation and interested in physical modelling. At the interface of physics and biology, the GDR ADN 2.0 aims to understand the functional role of the organisation in physiological processes and associated pathologies by encouraging the emergence of a nuclear integrated the architecture of chromosomes and their dynamics on different size and time scales.

* Architecture et dynamique nucléaires et genomes







9 research topics

- Experimental techniques of molecular and cellular biology
- Super-resolution microscopy
- Biotechnologies
- High-speed approaches
- Bioinformatics
- Statistical physics
- Numerical simulation
- 3D visualisation and animation technics
- Physical modelling

200 researchers involved within **50 laboratories**

Coordinator : Cédric Vaillant (LPENSL) | **cedric.vaillant@ens-lyon.fr**
Deputy coordinators : Emanuelle Fabre (GenCellDi) and Jean-Marc Victor (LPTMC)

PROSPECTS

The Architecture and Dynamics of the Nucleus and Genomes research network (CNRS GDR “ADN 2.0”) aims to work in a cooperative and united way, and to strengthen the links between teams working on the 3D organization of genomes. IIt has the dual characteristics of focusing on the entire living world - eukaryotes, but also bacteria and archaea - and concentrating on physical and numerical modelling. This choice of approach opens up the unique possibility of considering nuclear organization in the light of cellular differentiation and development, pathologies (cancers, infectious, chronic and neurodegenerative diseases) and the evolution of species. How are the universal functions fulfilled by the chromosomes of the entire living world implemented by the different types of nuclear organization ? According to which physical principles ? How are certain mechanisms dysregulated and lead to pathologies ? Which mechanisms have started to be set up but have remained at the beginning in some species (so-called “inchoate” processes) while they have ended up in others ?

In addition to the immense scientific challenge of understanding the physiological nuclear organization and its pathologies, there is another challenge - that of supporting the teams concerned in the face of international competition. A collaboration dedicated to the same theme, financially supported by the National Institutes of Health (NIH), began in the United States in 2015 with the launch of the “4D Nucleome” program. Exclusively dedicated to the study of the architecture and dynamics of human cell nuclei, this multi-year program, with an annual budget of $30 million, aims to take the lead in this highly competitive field. In order to have an international impact, we believe it is crucial that a similar initiative be set up in Europe. To this end, we would like to join our forces with other French research groups with related topics (CNRS GDRs Imabio and AQV) as well as other teams in the various European countries. This initiative would be an excellent opportunity to develop the synergy that we have initiated and to highlight the strengths of our approaches. It would also be an excellent opportunity for the CNRS to influence the orientations of future European programs.

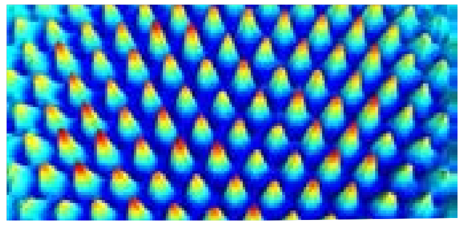
GDR
AF*- COLD ATOMS

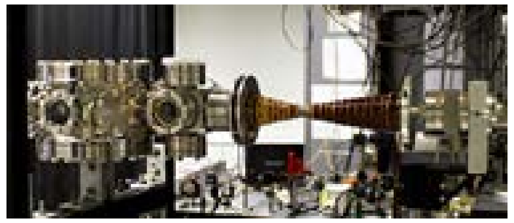
The mission of the **Cold atoms (AF)** research network is to bring together the French community whose research activities focus on cold atoms. Based on experimental and theoretical developments, the scientists address both fundamental and applied questions concerning the problem of cooling, by laser or by evaporation of atoms.

*Atomes froids

6 research topics

- Ultra-cold quantum matter
- Cold molecules and N-body effects
- Waves of matter and light waves, coherence and disorder
- Metrology, fundamental measurements and instrumentation
- Quantum information and optics
- Interface with other domains





200 researchers involved within **22 laboratories**

Coordinator : Robin Kaiser (INPHYNI) | **robin.kaiser@inphyni.cnrs.fr**
Deputy coordinators : Hélène Perrin (LPL), Jacob Reichel (LKB) and Tommaso Roscilde (LPENSL)

PROSPECTS

COLD ATOMS FOR QUANTUM TECHNOLOGIES

This subject is currently very well supported at the European level (with in particular the “Flagship” on quantum technologies) and the French level (with the newly launched Plan Quantique). This is obviously one of the priorities of the field of cold atoms and it is advisable to maintain an important activity in this context, with the recognized potential of cold atom systems for the development of quantum technologies. However, it is necessary to stress that cold atoms have many other applications, both in fundamental research and in applied research. The GDR Cold Atoms is structured into several topics allowing for more specialized meetings in areas that do not benefit from the same visibility as quantum technologies (such as ultra-cold chemistry or disordered systems). The GDR considers that it is important to support these research directions and promote the emergence of new research directions.

NATIONAL STRUCTURE

Most of the group leaders working on cold atoms know each other well and little (if any) of groups seem to be isolated in France. The GDR AF allows in particular to keep a link with and between groups outside the Paris area (with their own “sciences and engineering” structure). The development of new local activities connected to cold atoms sometimes happens without national consultation and the GDR Cold Atoms does not aim to control such research policies. However, as a CNRS structure, it is interesting for the GDR to be aware of such activities in order to support new emerging activities by providing national and international visibility.

INTERNATIONAL LINKS

Among the BRICS countries (Brazil, Russia, India, China and South Africa), China, India and Brazil are in the process of developing their activity on cold atoms. China is particularly active, and it would be important to have a national consultation to plan the exchanges with groups in China. Very fruitful links between France and Brazil have existed for a long time and an International Research Institute (IRN) including cold atoms would be an excellent way to maintain these links. The GDR Cold Atoms is an adequate platform to help to organize meetings and visits for such exchanges.

TRAINING AND DISSEMINATION TO THE GENERAL PUBLIC

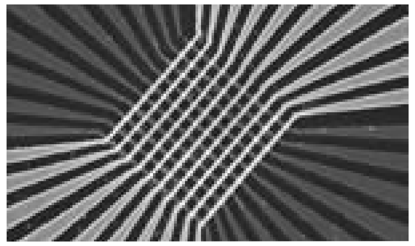
Since its creation, the GDR Cold Atoms has had activities resolutely turned towards young people (before and during the thesis). A yearly predoctoral school in Les Houches is now an internationally well-established event and provides timely and essential training and networking for the next generation of cold atom researchers and engineers. In addition, a book on the applications of cold atoms has been published in 2020 [1] targeting an audience outside of the research laboratories (with a translation into English in progress).

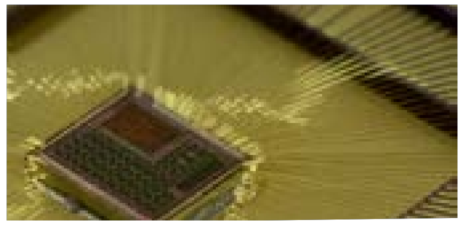
[1] Atomes, ions, molécules ultra-froids et technologies quantiques, R. Kaiser, M. Leduc, H. Perrin, Editors, EDP Sciences, Collection: «Une introduction a ...» (2020), ISBN 2759823776

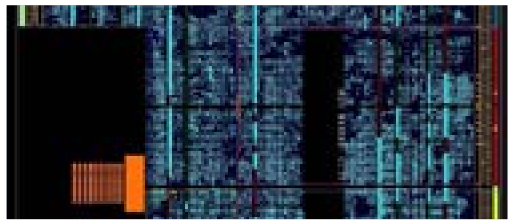
GDR
BIOCOMP*- HARDWARE IMPLEMENTATION OF NATURAL COMPUTATION

The mission of the **Hardware implementations of natural calculation (BioComp)** research network is to bring together and structure the French community working on the realisation of bio-inspired hardware systems. BioComp aims both to understand the mechanisms at work in biological systems in order to create new types of chips based on natural computation, and to build hybrid hardware architectures in order to better understand biology.

* Implémentations matérielles du calcul naturel







6 research topics

- Neuromorphic systems
- Artificial Intelligence
- Bio-inspired computation, cognitive neurosciences and cognitive psychology
- Biologically inspired information processing
- Materials, physics and electronics for bio and neuro-inspired computation
- Neuro-inspired robotics

160 researchers involved within **60 laboratories**

Coordinator : Sylvain Saïghi (IMS) | **sylvain.saighi@ims-bordeaux.fr**
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PROSPECTS

There are many challenges in electronic systems inspired by the brain :

ENVIRONMENTAL

The IT industry already consumes more electricity than India because of the massive use of data centres, especially for running artificial intelligence (AI) algorithms. Neuromorphic systems can drastically reduce this electricity consumption, towards green AI.

ECONOMICAL

The applications of bio-inspired computing systems can be divided into two classes. The first is to accelerate and miniaturise AI for autonomous vehicles, robotics, prostheses, connected networks, etc. The second is to provide supercomputers to enable neuroscientists to run models of the brain.

SOCIETAL

The future development of AI requires changing the hardware on which these algorithms are supported. France is at the forefront of fundamental research in this field.

ETHICS

The development of this new electronics will change the way we interact with machines and raise many ethical questions. From the uses of these technologies, data protection, societal changes to the legal place of these artificial systems, many questions need to be addressed upstream.

SCIENTIFIC

Moving towards the realisation of bio-inspired hardware computing systems will enable scientific advances in all the fields concerned - neurosciences, mathematics, computer science and information processing systems architecture, microelectronics, nanotechnologies and physics.

To achieve this, many challenges must be met :

INTERDISCIPLINARITY

This is a nascent research field, which, to succeed, must bring together researchers from physics to neurosciences via microelectronics and computer science.

HARDWARE IMPLEMENTATIONS

Nanoneurons and nanosynapses with low energy consumption, in tens of millions (10^{11} neurons in the brain) must be produced, modelled, densely connected (10^4 synapses per biological neuron), and adapted algorithms developed (challenge : unsupervised learning).

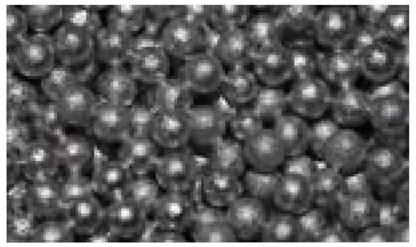
MODELS

Embedded AI systems require new models, less demanding in resources, capable of learning with very little data, tolerant to component imperfections, robust to catastrophic interference, and capable of performing multiple cognitive functions beyond pattern recognition (multisensory fusion, attentional circuits, predictive).

GDR
COMPLEXE* - CONTROL OF WAVES IN COMPLEX MEDIA

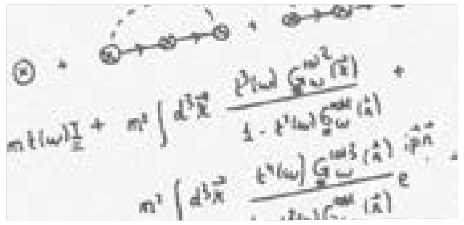
The mission of the **Control of waves in complex media (COMPLEXE)** research network is to bring together the French community involved in both fundamental and applied research in the field of the physics of waves in complex media. COMPLEXE aims to foster exchanges between opticians, acousticians, cold-atom physicists and seismologists, and focuses on fundamental aspects of the propagation of waves as well as on the development of novel methods for control and imaging of waves within complex media.

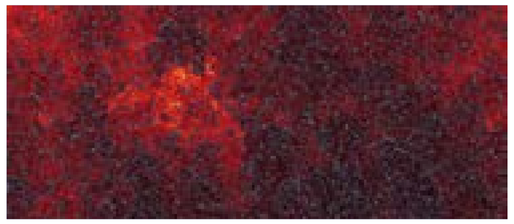
*Contrôle des ondes en milieu complexe



4 research topics

- Methods of control, imaging and characterization of waves in complex media
- Fundamental research on the mesoscopic aspects and the localization of waves in disordered media
- Wave transport in correlated or nonlinear media
- Waves as simulators of quantum or topological systems





146 researchers involved within **31 laboratories**

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Deputy coordinator : Alexandre Aubry (Institut Langevin) | **alexandre.aubry@espci.fr**

PROSPECTS

The GDR COMPLEXE gathers researchers coming from diverse fields but motivated by a common question ; decipher and use the propagation of waves in “complex” media. In our daily environment, complex media are often more the rule than the exception : it is for instance materials that deviate from perfect crystals due to defects, heterogeneous biological tissues, emulsions or dense gases of particles. In these systems, the propagation of waves does not follow a straight line but is erratic. This process is a problem as well as a resource, because it makes imaging difficult but, on the other hand, gives rise to original physical phenomena. The study of waves in complex media raises both fundamental and applied challenges, which lie at the heart of the interdisciplinarity of the GDR COMPLEXE.

CONTROL AND IMAGING

In a complex medium, controlling the propagation of waves or using them for imaging has long been considered hopeless. Major progresses have nevertheless been recently achieved : thanks to wavefront-shaping techniques, or by recording the scattering matrix of a material (its “identity card”), we are now able to force a wave to follow a pre-established trajectory through an opaque medium, and even to image objects through it. Researchers of the GDR COMPLEXE now work to improve the speed of these techniques, to simplify their implementation and to increase their resolution, in particular to make them useable at the industrial level. Imaging directly inside thick complex media remains, in parallel, a major challenge.

MESOSCOPY AND TRANSPORT

The study of wave transport in complex media and of the associated interference phenomena is a core activity of the GDR in a wide variety of areas, such as electron transport in conductors, light propagation in opaque media of the physics of disordered matter waves. In this context, some phenomena that were so far considered well understood have been recently questioned, such as the very existence of Anderson localization of light. In a similar spirit, in disordered media displaying strong correlations concepts as simple as the one of diffusion seem not to hold any more. Developing a theoretical framework allowing us to understand and to systematically characterize these new systems constitute central challenges for the next few years.

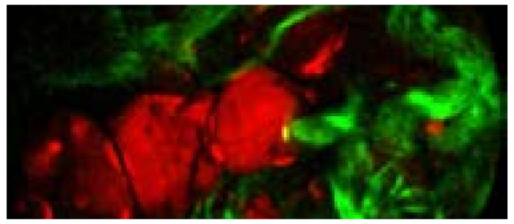
SIMULATING THE QUANTUM WORLD

Exploiting the properties of a wave system to reproduce the physics of the microscopic world has attracted a lot of attention in the past years. Today, the properties of graphene or of topological insulators can thus be simulated by propagating micro-waves or light through properly designed networks. Along the same line, one can achieve analogues of the mechanism of superfluidity of a quantum gas by means of an optical beam in a nonlinear medium. The GDR supports several research teams working on these questions. There is much to do in the next years, in particular to develop the yet rare experimental setups on these questions, and to take advantage of the peculiar properties brought by these wave simulators.

GDR
ELIOS* - NONLINEAR EFFECTS IN OPTICAL FIBERS AND IN INTEGRATED OPTICS

The mission of **Nonlinear effects in optical fibers and in integrated optics (ELIOS)** research network is to bring together the French academic community working on nonlinear effects in waveguides in the broad sense, and to stimulate relations with French manufacturers.

* Effets non-linéaires dans les fibres optiques



7 research topics

- Rogue and shock waves
- Nonlinear effects in multimode and multicore fibers
- Turbulence/thermalisation in fiber optics
- Lasers
- Machine learning
- Frequency combs
- Integrated optics

150 researchers involved within **25 laboratories**

Coordinator : Arnaud Mussot (PhLAM) | **arnaud.mussot@univ-lille.fr**
Deputy coordinators : Hervé Rigneault (Institut Fresnel), Christophe Finot (LICB) and Delphine Marris-Morini (C2N)

PROSPECTS

Nonlinear fiber optics emerged during the 70's within the context of optical telecommunications. This topic rapidly attracted both physicists to investigate fundamental phenomena and eingeneers to control light propagation. As an example, physicists immediately identified these waveguides as fantastic test-beds to explore the richness of complex nonlinear effects predicted by the nonlinear Schrödinger equation. From an applicative point of view, optical fibers are extremely versatile and thus extremely useful to optimize the performances of optical sources with various pulse durations at different wavelengths. In that respect, the nonlinear fiber optics community kept moving forward, tailored to other community needs, and took benefit of new opportunities such as the emergence of micro-structured optical fibers or the recent explosion of spatial light telecommunications. In this very competitive international landscape, the French community has always risen and maintained to the toplevel both in terms of concepts and concrete applications.

Recent top-level publications from the community highlighted the French know-how in the field of nonlinear fiber optics which stimulated the recent development of innovative techniques to characterize the dynamics of complex nonlinear systems with a highresolution for instance.

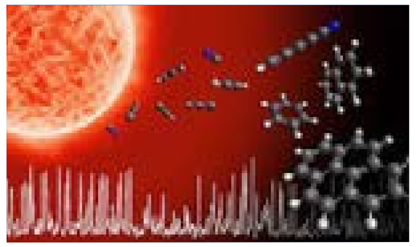
Meanwhile, nonlinear effects investigation on integrated photonic structures is a rapidly expanding field of research. On the one hand, the strong confinement of the field inside these waveguides strongly enhances nonlinear effects. On the other hand, these nonlinear waveguides with standard optical functionalities open the way to many prospects to achieve photonics chips suited to different applications ranging from telecommunications, spectroscopy, or sensors to name a few.

These works meet clearly within the context of fundamental studies such as rogue wave formation for instance, or applied ones such as the development of ultra-stable light sources knwon to have a high societal impact. The aim of ELIOS is to create a synergy between different academic actors of the field and to reinforce the link with companies.

GDR
EMIE*- ISOLATED AND INTERACTING MOLECULAR ASSEMBLIES

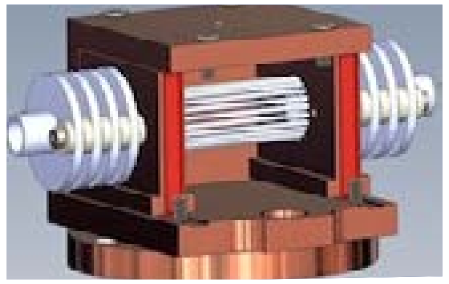
The mission of **Isolated and interacting molecular assemblies (EMIE)** research network is to bring together the French community of physicists and chemists working on molecular systems, and covering a wide range of size and complexity. The objects under scrutiny are either isolated in the gas phase or surrounded by a controlled environment. Building upon fundamental aspects of experimental and theoretical molecular physics, our community is naturally inclined to benefit from interactions with other disciplines (chemistry, biology) and to extend its fields of applications to other scientific domains with timely societal impacts (biology, atmosphere).

* Édifices moléculaires isolés et environnés



6 research topics

- Experimental methods and instrumentation
- Theoretical approaches
- Atmospheric and Universe sciences
- Excited states and energy
- Biomolecules
- Environment effects



250 researchers involved within **40 laboratories**

Coordinator : Pierre Çarçabal (ISMO) | **pierre.carcabal@universite-paris-saclay.fr**
Deputy coordinator : Aude Simon (LCPQ) | **aude.simon@irsamc.ups-tlse.fr**

PROSPECTS

The main goal of the studies undertaken by EMIE members is to better describe and understand matter at the atomic and molecular scales.

Researchers from the EMIE network contribute to experimental and theoretical methodological developments to characterize molecular assemblies over a wide range of sizes, often by means of frequency and time-resolved spectroscopic methods.

In the frequency domain, vibrational and electronic spectroscopy are our main source of information on large systems. These skills will be completed in the near future with high-resolution spectroscopy methods, which enable investigating rotational and rovibrational signatures which are particularly robust for studying small and mid-size systems.

We study molecular transformations such as short timescale electronic and nuclear dynamics induced by fast and intense excitations (atto/pico-seconds), and also much slower processes occurring at macroscopic timescales, for instance for slow relaxation mechanisms that can be studied in traps or storage rings.

In terms of spatial environment, our community also covers a wide range of processes including heterogeneous reactivity, systems that are deposited, solvated or embedded in solid matrices, as well as nanoparticles, with the aim of disentangling the contributions of the environment and of the object itself.

While being structured around fundamental molecular physics and chemistry, our community also explores the application of its specific expertise beyond its own frontiers.

In the field of Universe sciences, we contribute to the characterization of molecular assemblies relevant in astrophysics, and to the study of mechanisms involved in atmospheric physics and chemistry. We can apply our expertise to aerosols formation, growth and reactivity, to environment effects, including solid/gas interfaces, and to the formation and evolution of molecular pollutants.

In life sciences, our contribution is based on a strong history of developments in analytical sciences, instrumentation and theoretical approaches, which led to the creation of strong connections at the biology-chemistry interface. Studies including environment influence, such as hydration effects on biomolecules, will be further developed in this field too.

In the domain of energy, our studies on excited molecular states can be applied to the dynamics of photoreactive molecules, and we also foresee addressing issues related to the stability of gas hydrates or solvated asphaltenes.

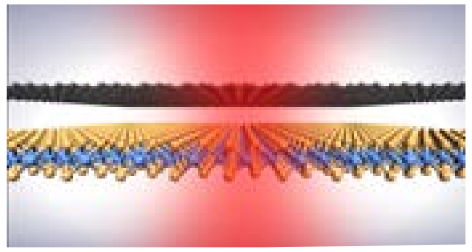
GDR
HoWDi*- VAN DER WAALS HETEROSTRUCTURES OF LOW DIMENSIONAL MATERIALS

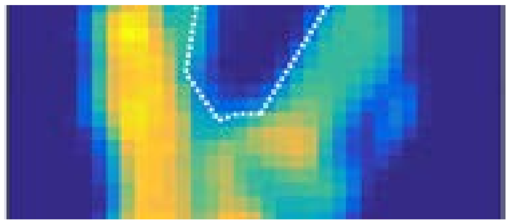
The mission of the **van der Waals heterostructures of low dimensional materials (HoWDi)** research network is to bring together the French community concerned by the development of heterostructures. Indeed, the van der Waals interaction now makes it possible to assemble materials of different nature and dimension, 2D (2D materials), 1D (nanotubes, nanowires), 3D (more or less thin films) or 0D (quantum dots, molecules). Such heterostructures show new physical properties, inherited from the constituent materials or generated by interface or proximity effects.

*Hétérostructures de van der Waals de matériaux de basse dimensionnalité

4 reseach topics

- Synthesis, nanofabrication, characterization
- Electronic transport and devices
- Optical and excitonic properties, photonics
- Magnetism, spintronics, electronic correlations





300 researchers involved within **90 laboratories**

Coordinator : Christophe Voisin (LPENS) | **christophe.voisin@ens.fr**
Deputy coordinators : Stéphane Berciaud (IPCMS), Johann Coraux (NEEL) and Annick Loiseau (LEM)

PROSPECTS

A major evolution in low-dimensional physics arises from the possibility to assemble crystalline materials at the macroscopic scale but with atomic precision, yielding 2D, 1D and mixed dimensional (2D-1D, 2D-0D or 2D-3D) heterostructures. The cohesion of these delicate assemblies stems from van der Waals interactions, which led to the now popular name of "van der Waals heterostructures". These artificial materials can be fabricated at the laboratory scale by inexpensive means, and have revealed remarkable properties, which have had a strong impact in recent years (moiré effects on superconductivity and light emission, proximity effects on the emergence of exotic electronic phases). Our network addresses theoretical, numerical and experimental aspects associated with van der Waals heterostructures.

AN EXTENDED FAMILY

Van der Waals materials have attracted major scientific interest over the past 15 years, first with graphene, then with boron nitride (BN) and later with semiconducting transition metal dichalcogenides. During the last five years, new quantum phases (spin, charge order, electronic correlations, electronic and photonic band structure of non-trivial topologies) have been experimentally observed in the 2D limit. Individually, these materials stimulate dedicated fundamental studies and their integration in van der Waals heterostructures gives access to a multitude of new physical phenomena.

CONTROLLED ELABORATION, CHARACTERIZATION AND MODELING

Increasingly sophisticated "top-down" approaches allow stacking of micrometric sheets by controlling their sequence and relative orientations. These approaches offer almost unlimited possibilities and alongside, access to a whole range of original properties. Albeit conveniently implemented at the laboratory scale, such approaches preclude the obtention large-area, scalable heterostructures. Our GDR aims to promote a national effort on bottom-up approaches in a field where almost everything remains to be done : mastering the quality, crystalline phase and stoichiometry of van der Waals materials, as well as epitaxy relationships and proximity effects within heterostructures.

This research is accompanied by advanced characterizations (optical and electronic microscopies and spectroscopies, local probe measurements). These efforts can rely on numerical and modeling efforts to predict the existence and properties of new families of materials and heterostructures.

TWISTRONICS AND PROXIMITY EFFECTS

Controlling the distance between van der Waals materials at the angström scale as well as the angular degree of freedom (chiral angle in nanotubes, angular mismatch ("twist") between atomic lattices of 2D layers) offers the possibility to truly engineer band structures and to discover new electronic and photonic phases or new coupling phenomena in the near field. In this context, the emergence of van der Waals materials with a magnetic order makes it possible to reinvent the physics of magnetic proximity effects, for example at the interface between semiconductor and 2D ferromagnetic materials.

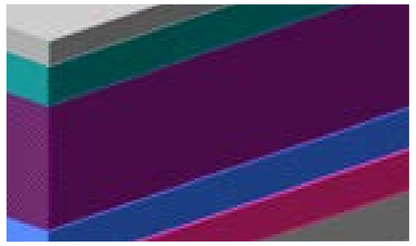
METROLOGY AND INNOVATIVE DEVICES

Van der Waals heterostructures can be integrated into photonic, electronic, magnetic, mechanical nanostructures. It is then possible to optimize and control their light emission and/or electronic transport characteristics up to metrological accuracy. More generally, van der Waals heterostructures allow the design of numerous model devices (single photon sources, light-emitting diodes, photodetectors, magnetic tunnel junctions, ect.), whose microscopic operation is controllable by an external parameter (mechanical stress, electric field, ect.). One of the major challenges of this field is to exploit the specificities of van der Waals materials (absence of dangling bonds, lattice mismatch, various electronic and magnetic phases, enhanced Coulomb interactions, valley pseudospin) to obtain new functionalities that cannot be achieved with more established materials.

GDR
HPERO* - HALIDE PEROVSKITES

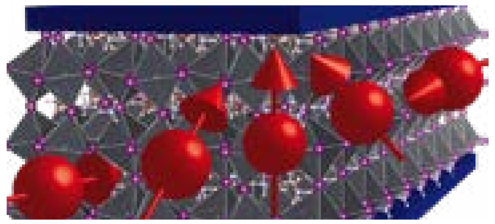
The mission of **Halide perovskites (HPERO)** research netwotk is to bring together the French community working on halide perovskites. It offers a multidisciplinary approach mixing fundamental and applied aspects, so as to create a synergy capable of developing new concepts as well as opening new potentials in terms of applications.

* Pérovskites Halogénées



3 research topics

- Chemical engineering of the material
- Characterization of the structural, electronic and optical properties of the material
- The material and its interfaces



150 researchers involved within **42 laboratories** (including 4 foreign laboratories)

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Deputy coordinators : Jacky Even (FOTON), Claudine Katan (ISCR) and Nicolas Mercier (MOLTECH-ANJOU)

PROSPECTS

Hybrid halide perovskites marked a breakthrough for photovoltaics in the early 2010s, with a first record efficiency certified in the NREL diagram at 14.1% in 2013. In 2020, the certified record efficiency reaches 25.5%, exceeding those of the thin films or multicrystalline silicon sector, as well as those of the CIGS one. The use of halide perovskites in tandem solar cells, especially with silicon, should permit to reach efficiency records of more than 30% in the next years (29.15% reached in December 2020 with a silicon / perovskite tandem cell).

These record efficiencies being obtained on small areas, up-scaling (successful up-scaling in 2019 by CEA-INES to reach 20.3% on a module of surface 11.2 cm2) is an important issue, especially since the solution–processed technology at ambiant temperature of the halide perovskites layers is particularly well suited.

Stability problems (of chemical origin or under illumination) of the perovskite cells represent a critical issue that has to be overcome. Adressing the stability issue opens several fields of research, with works aiming to (i) understand the underlying mechanisms from both the experimental and theroretical points of view, (ii) develop new interfaces including buffer layers of organic or inorganic materials and search for more relevant hole/electron transporting layers, (iii) tune the composition of the perovskite layer.

This last topic resulted recently in a renewed interest in layered perovskites, well known since the beginning of the 1990s for their remarkable optical properties. Moreover, low dimensional materials such as nanometric quantum dots and platelets have also emerged as potential avenue of exploration.

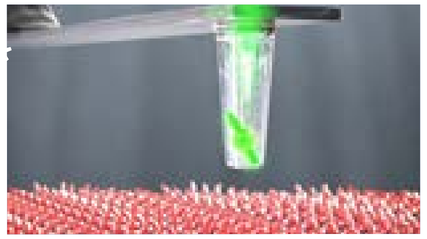
In turn, the number of perspectives for halide perovskites has grown considerably with :

- a wide field of exploration for chemical engineering : shaping (crystals, thin films, nanostructures), doping, new cations, lead substitution, encapsulation, interface layers in devices ;
- a growing number of potential applications: LEDs, laser diodes, photodetection, field effect transistors, spintronics/ spinorbitronics, catalysis and photocatalysis (hydrogen production), ect ;
- increasing efforts to understand the physical properties : structural information, nature and role of defects, optical properties (excitons, biexcitons), electronic, spin, transport and mechanical properties, physical and chemical mechanisms at interfaces. These fundamental studies are based on both experimental and theoretical investigations, largely benefiting from tools and concepts developed for “conventional” semiconductors including the use of major research infrastructures (neutrons, synchrotron, intense magnetic fields, NMR, GENCI).

GDR
IQFA*- QUANTUM ENGINEERING, FROM FUNDAMENTAL SCIENCE TO APPLICATIONS

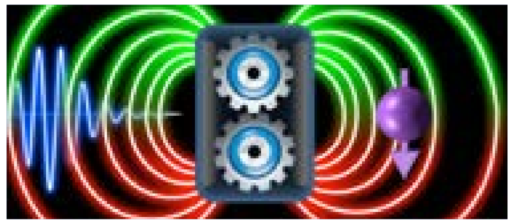
The mission of **Quantum engineering, from fundamental science to applications (IQFA)** research network is to bring together the French community whose research activities relate to quantum technologies. All quantum information applications are concerned, i.e. communication, processing, simulation, and metrology. Moreover, all quantum information holders are considered, encompassing quantum light, condensed matter, quantum gases, etc., where photons, atoms, electrons, trapped ions, superconductor circuits, etc., play a major role. Also, quantum science and technology applications are investigated regardless of coding strategy, e.g. individual or collective states, and the very nature of the observables.

* Ingénierie quantique, des aspects fondamentaux aux applications



5 research topics

- Fundamental quantum science
- Quantum communication and cryptography
- Quantum computing, hardware and algorithms
- Quantum simulation
- Quantum metrology and sensors



400 researchers involved within **50 laboratories**

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PROSPECTS

ORGANIZATION OF THE COLLOQUIUM IQFA'12 AT ENS LYON

In the perspective of enlarging the organization sites from the Paris-Grenoble-Nice axis, the IQFA committee has decided to locate its next colloquium, IQFA'12, at ENS Lyon in November 2021, and to entrust its management to Pascal Degiovanni of the Physics Laboratory of the ENS Lyon (LP-ENS-Lyon). IQFA'12 will be open to all the themes that fall within the scope of the GDR, with, as usual, tutorial-type interventions and a call for poster-type contributions and the selection of about fifteen of them for oral presentations, a methodology that has already proven its worth, particularly among young researchers, as well as doctoral and post-doctoral students.

STRENGTHEN INTERDISCIPLINARITY

There is now a strong interest in organizing hybrid colloquia between IQFA and the GDRs Mathematics and Computer Science (IM) as well as Mesoscopic Quantum Physics (MESO). These hybrid colloquia should target on the one hand quantum engineering aspects developed from systems derived from condensed matter, and on the other hand on quantum algorithms resulting from research in computer science and theoretical mathematics. Experimental perspectives will of course be considered.

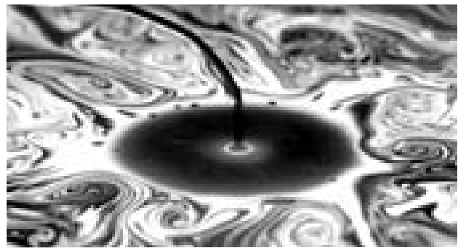
TRAINING ACTIONS IN QUANTUM ENGINEERING

Given the multidisciplinary nature of quantum technology research (physics, mathematics, chemistry, information theory, condensed matter, materials, nanosciences, marketing, etc.), major French research organizations such as the CNRS, Universities, and higher education institutions, must now adapt their training programs to offer courses that will train future generations of "quantum engineers". This type of training must be truly transdisciplinary. IQFA, with the help of the Institute of Physics of the CNRS, intends to be strongly involved in the implementation of a training offer, which could take the form of a CNRS thematic school or a national training action. The objectives are twofold. On the one hand, it is to answer a growing need in CNRS laboratories, both for researchers and engineers. On the other hand, it aims at efficiently answering and upstreaming to Europe's vision regarding the training of future generations of "quantum engineers and researchers".

GDR
ISM*- INTERFACIAL SOFT MATTER

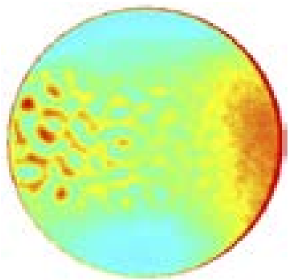
The mission of the **Interfacial Soft Matter (ISM)** research network is to emphasize and understand structure and dynamics of thermally dominated systems near the boundary between a liquid and another phase. ISM provides a forum for the French and international communities - from physics, chemistry and engineering backgrounds and using a diverse set of experimental, theoretical and computational tools - studying the domain to congregate and exchange ideas.

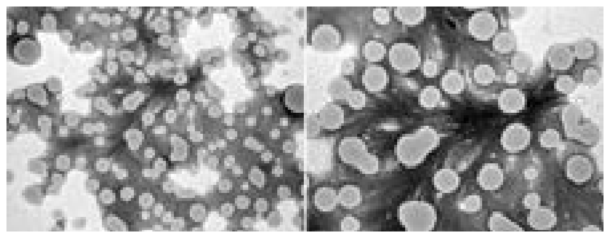
* In english originally



5 research topics

- Mechanics of soft interfaces
- Surfaces in contact with electrolytes
- Active matter
- Soft functional layers
- Structure-property relations





200 researchers involved within **40 laboratories**

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Deputy coordinators : Lionel Bureau (LiPhy), Cécile Cottin-Bizonne (ILM), Benjamin Cross (LiPhy) and Vincent Ladmiral (ICGM)

PROSPECTS

The organization and dynamics of soft materials can be deeply altered in the vicinity of an interface since the interaction energies there are typically of the same order of magnitude as those involved in the bulk material. Similarly for the bulk, many soft materials and biological entities can be pictured as “made of interfaces” : systems such as suspensions of particles or droplets are formed of mesoscale objects interacting via intermolecular and surface forces, the details of which control the macroscopic material properties.

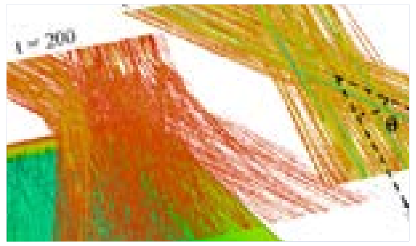
Interfaces are indeed at the heart of a wealth of challenging problems in today’s soft matter science, from DNA transcription, to friction and lubrication, charge regulation, and “smart” functional layers requiring novel syntheses. Additionally, many non-equilibrium systems give rise to spontaneous mobility of particles without the need for an external action. All of these systems, by virtue of their grouping under the heading of “soft”, typically bear the signatures of thermal agitation. Combining all of these ingredients, the GDR Interfacial Soft Matter (ISM) was created.

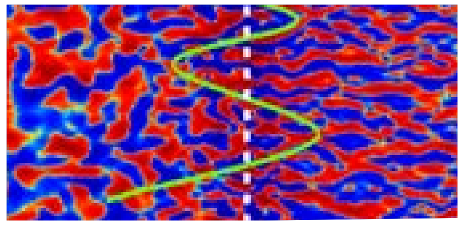
The principal themes considered by ISM constitute an emergent field. Those themes concerning mechanics and electrolytes, describing equilibrium as well as structural and dynamical aspect of soft matter, are the most fundamental axes of the ISM domain. These fundamental axes are strongly linked to active matter along with the practical, societal and industrial applications of soft functional layers and the theme of structure-property relations. In this last theme, the questions linked to synthesis and innovative applications of interfacial soft matter are also of great interest to our industrial partners.

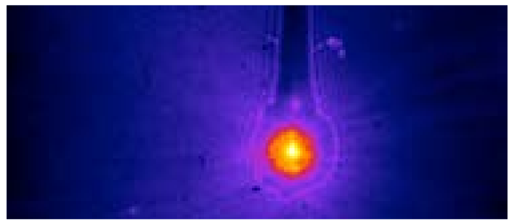
GDR
LEPICE HDE*- HIGH-ENERGY LASERS AND PLASMAS UNDER EXTREME CONDITIONS

The mission of the **High-energy lasers and plasmas under extreme conditions (LEPICE HDE)** research network is to bring together the French community working on High Energy Density (HED) physics related to high energy lasers. Its role is to strenghten the exchange between the numerous research teams with the aim of developping new experimental and diagnostic tools, as well as improving the modelling capabilities for HED physics in the frame of laser-generated plasmas.

*Lasers énergétiques et intenses et plasmas sous conditions extrêmes







7 research topics

- Laser generated shocks, matter under extreme conditions, planetology, geophysics
- Hydrodynamics and transport in the context of inertial confinement fusion (ICF)
- Laser-plasma interaction : laser beam propagation in warm plasmas, anomalous absorption
- Atomic physics in warm and dense plasmas, atomic physics in presence of intense fields
- Laboratory astrophysics in laser plasma experiments
- Laser generated radiation sources and their application to High Energy Density physics and nuclear physics
- "Avenir et ouverture" for innovative approaches, such as ultra-high intensity lasers

150 researchers involved within **16 laboratories**

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Deputy coordinators : Sylvie Depierreux (CEA-DAM) and Patrick Renaudin (CEA-DAM)

PROSPECTS

The research topics of GDR LEPICE (standing for "Lasers énergétiques et intenses et plasmas sous conditions extrêmes" = "High-energy lasers and plasmas under extreme conditions") cover the whole range of High-Energy-Density (HED) physics that can be accessed with high-energy and high-power lasers, like the physics around Inertial Confinement Fusion (ICF) projects as well as laboratory astrophysics and geophysics.

The research on matter under extreme conditions is of fundamental interest due to its implications with the physics of dense matter, in particular in the context of geophysics and astrophysics. High-energy lasers, such as those developed for the different steps on the way to achieve ICF, as well laser-generated short-wavelength radiation sources allow nowadays to access and/or to diagnose matter under poorly known conditions what concern density and temperature. This allows us to advance considerably in our understanding with respect to what has yet been accessible with "conventional" methods.

The radiation energy that is delivered with the available facilities allows researchers to reproduce in laboratory experiments extreme conditions that are encountered in the Universe (e.g. supernovae, accretion disks, jets, etc.) and, upon that, to realize dynamic studies, impossible to obtain via studies with astronomical techniques.

The studies on plasma hydrodynamics within this GDR are carried out in close coordination between experimental teams and specialists in theoretical-numerical modelling. The results obtained from French and international laser facilities, together with the modelling, provide major advances in the understanding of the dynamics of plasmas under extreme conditions.

The research on Laser-Plasma Interaction presents a key activity in the frame of the GDR for the physics of laser fusion, for the laser-plasma coupling of ultra-high intensity (UHI) lasers, as well as for generation of secondary radiation sources. The complementary competences unified in this GDE allow us to advance in the understanding and modelling of propagation, absorption, diffusion, and pulse amplification of intense coherent light beams in plasmas.

Secondary radiation sources due to laser-driven collective electron motion have an important potential of application in HED physics. Proton- and electron beams generated via UHI lasers, nowadays available on every major laser facility, are extremely important elements in HED experiments, in particular for diagnostic purposes.

Atomic physics in dense plasmas plays an important role for several of the research axes of this GDR, in particular for radiative transport in plasma hydrodynamics. Studies on opacities of strongly correlated plasmas play an important role in ICF and astrophysical plasmas for the understanding of hydrodynamic (Rayleigh-Taylor) instabilities and of radiative shocks.

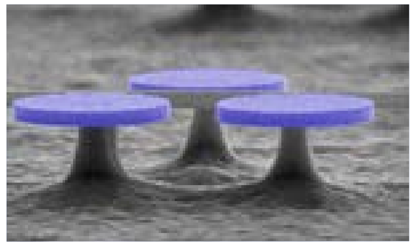
The activities on laser-driven nuclear excitation within this GDR are at the interfaces between nuclear and atomic physics, as well as physics of warm plasmas. These very innovative studies have the goal to explore the modifications on nuclear states by external (laser) fields in ionized matter.

Several recent UHI laser facilities, now accessible in France (Cilex-Apollon) in Europe (ELI), will soon give access to laser intensities that can expose the vacuum and matter (plasmas !) to extreme electromagnetic fields. By successively increasing the field strength by improving the performance of such lasers, it will be more and more likely to provoke phenomena of Quantum Electrodynamics (QED), e.g. e- e+ pair production, that have not yet been observed with other facilities (colliders etc.). Several groups within the GDR have started studies to explore the way to access this exciting QED regime with the actual and forthcoming conditions of laser facilities.

GDR
MECAQ*- QUANTUM OPTOMECHANICS AND NANOMECHANICS

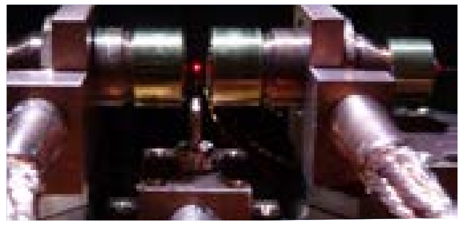
The mission of the **Quantum optomechanics and nanomechanics (MecaQ)** research network is to bring is to bring together the French research community in the fields of nanoechanics and optomechanics, in particular in the regime where quantum fluctuations matter. Metrology, ultrasensitive measurements and quantum information are among the research topics covered by GDR MecaQ.

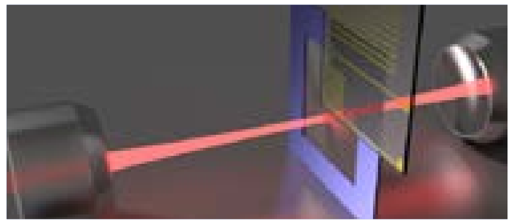
* Optomécanique et nanomécanique quantiques



11 research topics

- Quantum Thermodynamics
- Nanomechanics and nonlinear optics
- Theory of nanomechanical systems
- Optomechanical sensors
- Quantum Optomechanics
- Hybrid systems
- Optomechanics and Fundamental Physics
- Electro-optomechanics
- Nano-fabrication & nanomechanical engineering
- Micro-/Nano-optomechanics in industry
- Nanophononics and phonon transport





120 researchers involved in **32 laboratories**

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Deputy coordinators : Daniel Lanzillotti-Kimura (C2N) and Pierre Verlot (LuMIn)

PROSPECTS

An important research topic of the 2010's decade has been "quantum" mechanical systems, mechanical resonators so sensitive that a full description of their dynamics requires a quantum treatment. GDR Quantum Optomechanics and Nanomechanics fosters research activities on these topics, related to quantum measurement and control, with new stakes and very ambitious challenges.

TECHNOLOGICAL STAKES AND CHALLENGES

The main technological stakes in developing quantum mechanical systems are similar to those encountered in emerging quantum technologies, with the recent perspective of a new generation of ultrasensitive sensors and communication systems, possibly embedded in compact packages for wide application. To name a few, development of coherent opto-electromechanical transducers between the optical and the microwave bands, hybrid mechanical systems (where a mechanical degree of freedom is strongly coupled to another quantum system), nanooptomechanical crystals (possibly used as topological insulators), nanooptomechanical probes, definition of new metrological standards, ect. The associated technological challenges are related to the effects of decoherence, which have to be strongly minimized. Tremendous progress have been recently performed in this direction, with nanomechanical systems with quality factors above one billion at room temperature. Designing fabrication processes that allow simultaneous very low optical and mechanical losses however remains a huge technical challenge, that still requires an important research effort.

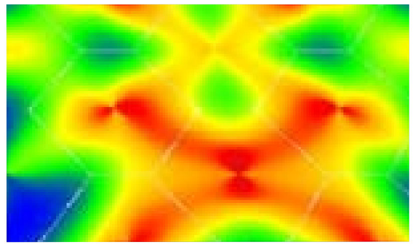
FUNDAMENTAL STAKES AND CHALLENGES

Technological progress in ultrasensitive mechanical systems are also motivated by fundamental physics issues, in what is commonly called the second quantum revolution. These include demonstration of displacement measurement experiments at or below fundamental sensitivity limits, macroscopic demonstration of mechanical energy quantization, back-action evading measurements, creation of non-classical mechanical states, or the impact of gravitation on the decoherence of macroscopic systems. These issues are at the heart of an important research effort to understand their impact at the macroscopic scale and to design measurement protocols that lower or evade quantum bounds.

GDR MEETICC*- UNCONVENTIONAL MATERIALS, ELECTRONIC STATES, INTERACTIONS AND COUPLINGS

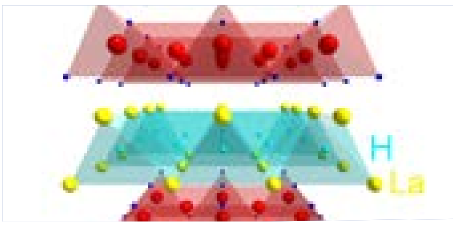
The mission **Materials, electronic states, interactions and unconventional couplings (MEETICC)** research group is to bring together the French community of experimental and theoretical scientists, chemists and physicists, who study materials with unconventional electronic states and couplings. Once under control, the remarkable properties of systems such as multiferroics or topological insulators could lead to breakthroughs in the field of energy and information technology.

*Matériaux, états électroniques, interactions et couplages non-conventionnels



3 research topics

- Remarkable properties in highly correlated systems (magnetism, superconductivity)
- Unconventional electronic states in topological phases and confined systems
- Unconventional electronic materials and properties



350 researchers involved within **45 laboratories**

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Deputy coordinator : Etienne Janod (IMN)

PROSPECTS

The scientific prospects of the GDR MEETICC are presented according to its three axes of research.

AXIS "HIGH-CORRELATION SYSTEMS"

Recent advances involve chiral interactions (Dzyaloshinskii-Moriya), at the origin of original magnetic mesostructures (skyrmions, hopfions). As far as superconductivity is concerned, a strong activity is developing around pnictures, chalcogenides and iron silicides (discovered in France). The understanding of their phase diagram, mixing exotic phases and unconventional superconductivity, could allow the identification of superconductivity mechanisms. Note the emergence of themes related to electronic surface states, out of equilibrium, or associating electronic correlations and spin-orbit coupling as in iridates.

AXIS "UNCONVENTIONAL ELECTRONIC STATES OF TOPOLOGICAL PHASES"

We foresee developments concerning the topological properties of correlated systems (Mott insulators ; heavy fermion supra), or Weyl semimetals. Moreover, 2D metallic or even superconducting electron gases open the way to emerging electronics and topologically protected quantum computing (Majorana quasiparticles).

AXIS "EMERGING MATERIALS"

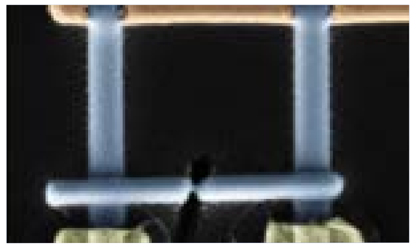
We can note the development of oxyhydrides inducing atypical valence states (Ni+, Ru2+, etc.) that can lead to new phases, and the global prediction of topological properties, based on space group and band theory. Finally, the control of properties at interfaces – such as multiferroicity, spin/charge current conversion - is strongly emerging and could lead to new heterostructures, associating topological insulators or ferromagnetism with novel physical properties.

Our research will benefit from impressive advances in experimental techniques using extreme conditions of pressure, temperature and electric/magnetic field, giving access to unexplored regions of phase diagrams. Let us underline the considerable development of ultrafast techniques (femtosecond or even attosecond ; European XFEL sources, HHD sources, etc.), giving access to new exotic out-of-equilibrium states and allowing the decoupling of interactions simultaneously at work in our systems.

GDR
MESO*- MESOSCOPIC QUANTUM PHYSICS

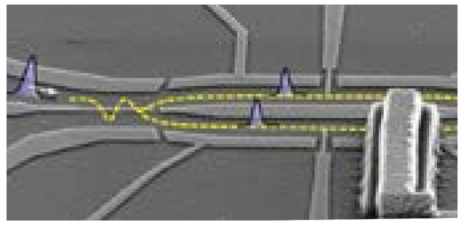
The mission of the **Mesoscopic quantum physics (MESO)** research network is to bring together the French community whose activities are focused on coherent electronic transport in conductors of all sizes and types (hybrid systems, topological insulators, graphene, ect.). Recent theoretical and experimental developments focus on the manipulation of the quantum states of such systems, and on very large bandwidth experiments.

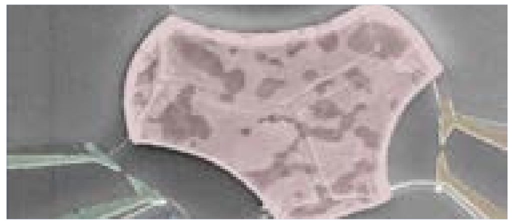
*Physique quantique mésoscopique



4 research topics

- Coherent manipulation of charge and spin degrees of freedom
- Hybrid systems, Dirac and topological matter
- Open quantum systems
- Mesoscopic thermodynamics





320 researchers involved

within **35 laboratories**

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Deputy coordinators : Hugues Pothier (SPEC) and Xavier Waintal (CEA-Grenoble)

PROSPECTS

WHAT IS AT STAKE ?

The general theme of the GDR MESO is the study of the quantum properties of conductors, mainly through transport measurements that provide information on the wave nature of the charge carriers, but also through current noise measurements that provide information on the corpuscular nature and thus the statistics of the carriers. Recent years have seen the emergence of local probe techniques (capacitive measurements, tunnel transport measurements, ect.), finite frequency measurements (to reach the regime where the excitation frequency is comparable to the characteristic frequencies of the circuit) and hybrid experiments combining optics and transport. Most of the experiments are performed at low energies (below 100 µeV and at very low temperature 10 - 100 mK).

The GDR remains very focused on fundamental “physics”, even if we keep potential applications in mind. In particular, our work can have direct impacts on quantum information science. Indeed, if the miniaturization of electronic components continues, the electronics of the future could enter fields where quantum effects play an important role. All research on quantum bits justified by the prospect of a possible quantum computer has led to the understanding of many underlying mechanisms responsible for the loss of quantum coherence. Another very important point is the emergence of new types of materials or topological matter. Graphene is an obvious example where advances in the fabrication of high mobility samples have made it possible to realize resistance standards for metrology based on the quantum Hall effect that do not require liquid helium cooling.

The fundamental challenges are divided into 4 axes :

- Coherent manipulation of charge and spin degrees of freedom
- Hybrid systems, Dirac and topological matter
- Open quantum systems
- Mesoscopic thermodynamics

New theoretical and experimental means allow probing systems in limits never explored before, beyond simple perturbative approach. One of the challenges of our GDR is to promote a scientific culture that allows us to approach quantum systems with a transversal vision, combining approaches from other communities.

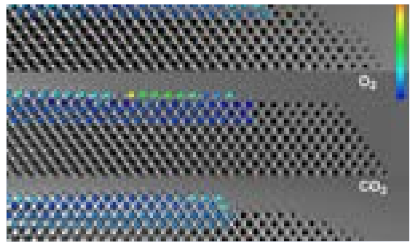
CHALLENGES

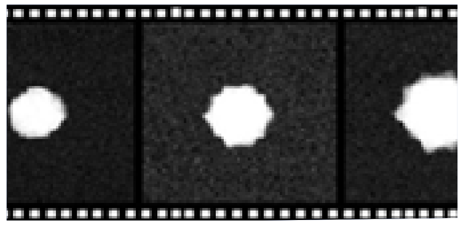
The systems we study naturally contain many interacting particles. Thus, one of the challenges is to solve the N-body problem, regardless of the type of Hamiltonian, time-dependent or not. This challenge is both theoretical and experimental, since to deal with such problems, new theoretical tools must be combined with experiments to probe ever more complex quantities.

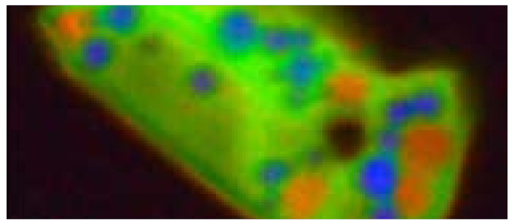
GDR NANOPERANDO*- STRUCTURE AND DYNAMICS OF MATERIALS IN REAL ENVIRONMENT

The mission of the **Structure and dynamics of materials in real environment (NANOPERANDO)** research network is to bring together the French community studyingthe structural dynamics of materials in their formation or application media. Although *in situ* or *in operando* analysis have been developed on all the techniques that allow investigating matter at the atomic scale, it remains nevertheless a very young science and its future progress requires the emergence of interdisciplinary synergies that could open new fields of research in material sciences, but also in Earth and life sciences.

* Structure et dynamique des matériaux dans leur environnement « réel »







5 research topics

- Synthesis, and self-assembling of nanomaterials
- Reactivity of nanocatalysts
- Electrochemical reactions
- Structure and dynamics of biomaterials in their native environments
- Life cycle of (nano)materials in natural and biological media

260 researchers involved within **50 laboratories**

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PROSPECTS

Here are the goals of the actions and events organized by the GDR Nanoperando :

Stimulating collaboration between experimenters (developers) of environmental techniques and potential users specialized in materials, by confronting the current possibilities and limits of environmental analysis techniques with the needs of users.

Bring together three communities of experimenters (electron microscopy, near-field microscopy and synchrotron techniques), which despite their common goals, strategies and problems still collaborate too little. This diversity of technical skills within the GDR will be an essential asset to effectively cover its thematic plurality.

Exploiting the complementarity of environmental techniques and initiate the development of correlative multi-scale approaches. Confronting the results obtained with different techniques will allow a better understanding of the *in situ* phenomena under study and the artifacts inherent to each technique (electron beam effects, tip effects, interpretation of synchrotron data, ect.). This approach will also facilitate the transfer of ideas and even technologies between techniques. It is also important to establish common data acquisition and processing protocols, including machine learning approaches that can be applied to different techniques and experiments.

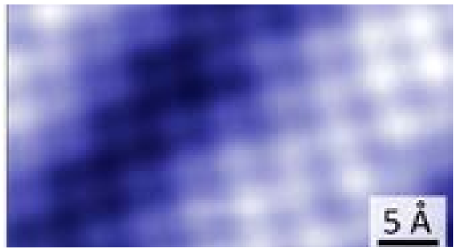
Identify and remove the technical barriers preventing the use of environmental techniques on certain types of samples. Given the diversity and complexity of observable phenomena, it is essential to set up interdisciplinary working groups that are aware of the instrumental constraints and specific requirements related to the nature of the samples and their environment.

Coupling experience and theory. In parallel with the recent progress of *in situ* analysis, theoretical approaches are being developed to understand the thermodynamic properties of nanomaterials in interaction with their environment. By bringing together experimentalists and theoreticians, the GDR will generate new synergies and establish a unique pole of expertise that is essential for quantitatively interpreting dynamic and complex phenomena.

GDR
NS-CPU*- NANOSCIENCES WITH NEAR-FIELD MICROSCOPY UNDER ULTRA-HIGH VACUUM

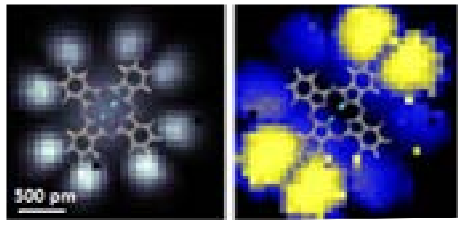
The mission of the **Nanosciences with near-field microscopy under ultra-high vacuum (NS-CPU)** research network is to bring together the French community whose "nanoscience" research activities are based on scanning probe microscopy (SPM) techniques operating under ultra-high vacuum (UHV). Indeed, a typical phenomenon in nanoscience results from a physical, chemical, magnetic, mechanical or optical fact that must be measured by individual and direct observations with spatial precision of the order of a picometre.

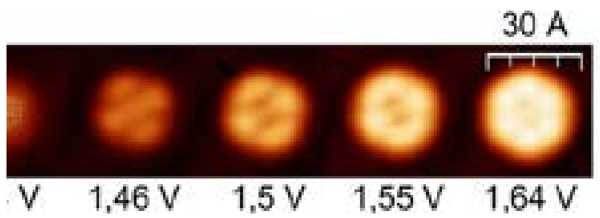
* Nanosciences en champ proche sous ultra vide



5 reseach topics

- Electronic and vibrational structure of individual nanostructures and nano-objects
- Nanometer-scale light-matter interactions
- Study of local magnetism and quantum states
- Electronic, electrostatic properties and charge transfer
- Theoretical concepts and computational tools





125 researchers involved within **20 laboratories**

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Deputy coordinators : Jérôme Lagoute (MPQ), Muriel Sicot (IJL), Guillaume Schull (IPCMS), Christophe Brun (INSP), Clemens Barth (CINaM), Sylvie Godey (IEMN), Christian Joachim (CEMES)

PROSPECTS

Backed by surface sciences, nanosciences intersect many scientific and technical fields: nanoelectronics, electronics and molecular mechanics, nanomagnetism, the physics of semiconductors and superconductors, the physics and chemistry of individual nano-objects, heterogeneous catalysis, metallurgy, ect. The techniques of choice for the study of nanosciences are near-field microscopies (STM, STM-photon, STM + magnetic field, STS, NC-AFM, KPFM) operating under ultra-vacuum (UHV), and at different temperatures (4 K, 77 K, 300 K, ect.). They provide direct access to the topography of the support surface, but above all to the electronic, optical or magnetic properties of a single nano-object, a molecule, an atom or a surface state.

ELECTRONIC AND VIBRATIONAL STRUCTURE

Tunnel spectroscopy (STS) provides access to the electronic structure of matter down to the atomic scale through I (V), I (Z) and differential conductance measurements. This technique allows to measure the electronic spectrum of individual nano-objects (a molecule, a nanostructure), and also to probe the electronic properties of low-dimensional materials (nanotubes, graphene and other two-dimensional materials). Vibrational states can be probed by inelastic spectroscopy both on an individual nano-object and on nanomaterials.

LIGHT-MATTER INTERACTIONS

The optical properties of a single nano-object, such as a quantum dot, a fluorescent molecule or an atom, critically depend on their interactions with their nearby environment (<10 nm). Various mechanisms such as a transfer of charge or energy between the tip and the nano-object can be used to probe, modify or exacerbate the properties of these nano-objects. Experiments combining, under ultra-vacuum, tunneling and optical microscopies, allow direct observation of these mechanisms. The development of approaches combining STM and pulsed lasers opens a path towards pump-probe experiments combining atomic-scale spatial resolution and femtosecond time resolution.

LOCAL MAGNETISM AND QUANTUM STATES

The study of the electronic properties of bulk materials, low-dimensional materials or individual nano-objects presenting a non-trivial quantum state (magnetic, superconducting, charge or spin-density-wave, Mott insulator, topological insulator or topological superconductor, etc.) has grown significantly with the development of (very) low temperature UHV STM techniques, including those coupled to an external magnetic field. These techniques enable observing the quantum order parameters, the charge or spin local orders at the atomic scale. Recent instrumental developments aim at probing time-resolved and/or frequency-resolved (up to few dozens of GHz) elementary electronic excitations.

ELECTROSTATIC AND CHARGE TRANSFER

The study of electrostatic phenomena at the elementary charge scale is observed in non-contact mode atomic force microscopy (nc-AFM) coupled with Kelvin probe microscopy (KPFM). We measure both the topography with atomic resolution and the surface potential linked to the electrostatic (dipoles, charges) and electronic (work function, doping, etc.) properties of the surface or of the single nano-object studied (a nanoparticle, a nano-island, a molecule, an atom, surface defects, etc.).

THEORETICAL CONCEPTS AND COMPUTATIONAL TOOLS

The description of the "tip-surface" interactions (alone or with the nano-object) such as exchange, electrostatic, Van der Waals and magnetic is the basis of all the calculations making it possible to predict and reproduce the different experiments that can be carried out in the near field: topography (STM, NC-AFM), dnI/dVn, dI/dZ, dZ/dV (STS), Δf/dZ, Δf/dV (NC-AFM/KPFM) spectroscopies, atomic or molecular manipulations. The interpretation of the experimental data will support the development and provision of calculation codes based on the quantum and/or semi-classical description of these interactions.

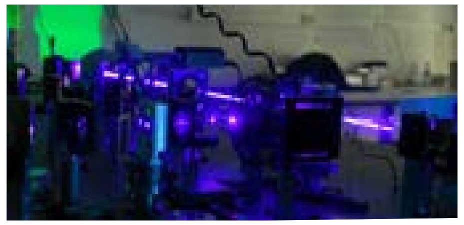
GDR
OR-NANO*- GOLD NANOPARTICLES

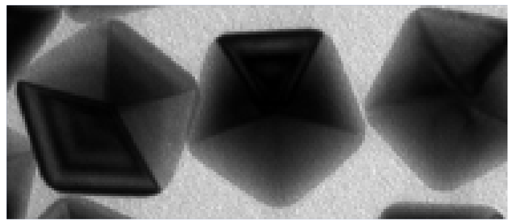
The mission of the **Gold nanoparticles (Or-nano)** research network is to bring together the French community whose research deals with gold nanoparticles, nanometric gold films or alloy nanoparticles containing gold. Gold plays a special role at the nano scale because of its metallic character, optical properties, reactivity and biocompatibility. The GDR Or-nano enables highly multidisciplinary exchanges on nanophotonics, plasmonics, nanoelectronics, catalysis, chemical synthesis, chemical functionalization, simulation methods and novel therapies.

*L'Or nanométrique

6 research topics

- Advanced plasmonics and nanoelectronics
- Gold nanoparticles for health, radiotherapy and theranostics
- Nanoparticles for the environment: coupling plasmonics and catalysis
- Theoretical and computational approaches of gold nanoparticles
- Synthesis, functionalization and reactivity
- Social responsibility, reach-out and ethical responsability





400 researchers involved within **64 laboratories**

Coordinator : Olivier Pluchery (INSP) | **olivier.pluchery@insp.jussieu.fr**
Deputy coordinators : Catherine Louis (LRS), Hazar Guesmi (ICGM), Julien Burgin (LOMA), Nathalie Tarrat (CEMES), Magali Gary-Bobo (IBMM) and Fabienne Testard (NIMBE)

PROSPECTS

The thematic positioning of the GDR Or-Nano is special because of the very specific status of gold nanoparticles, which belong to various disciplinary fields such as fundamental nanophotonics, plasmonics, reactivity, biochemical functionalization, new chemical synthesis processes, advanced therapies, numerical simulations, etc.

THE HOT ELECTRON PHYSICS

Hot electrons are electrons that are strongly excited above the Fermi level : either via an STM, or by an optical wave or electron beams, etc. Hot electrons correspond to excited states whose lifetime is finite, of the order of a few tens of femtoseconds. They are very much in the minority in front of undisturbed electrons and become quickly thermalized. They are therefore difficult to detect. Plasmonics is a way to amplify the effect of hot electrons and opens a new field of physics where the optical and physical properties of condensed matter are combined. Hybrid nanosystems (metal/semiconductor) involving gold nanoparticles are also of great interest at present since they are at the origin of "plexitonics" which mixes plasmon and excitons. The study and use of their optical properties are only at their beginnings, and this new type of object also has strong links with the hot electrons mentioned above, since they allow the injection of hot electrons from the metal (excited by plasmon resonance) into the semiconductor region of the nanosystem to be studied.

PLASMONICS, NANOTHERMICS AND QUANTUM PLASMONICS

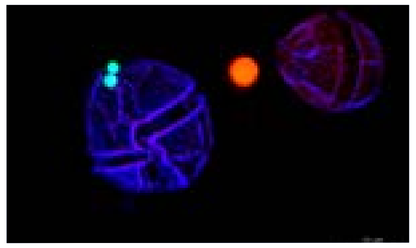
Plasmonics allows to manipulate the optical near field by adjusting the antenna effect and to concentrate the field on dimensions much smaller than the wavelength. Gold nanoparticles are also increasingly used as optically controllable nanosources of heat. In particular, they allow the study of thermal phenomena on small scales. Quantum plasmonics is largely a continuation of the work carried out so far in nonlinear plasmonics, but makes possible relatively integrated quantum optics in the long term. From the point of view of classical nonlinear plasmonics, efforts are focused on multipolar nonlinear optics and its applications, especially for sensing.

In addition, the links between laboratories and entrepreneurship are gradually being forged, particularly due to the aspiration of many PhDs to create start-ups, increasingly supported by permanent researchers. In 2017-2020, Or-nano has worked with around ten start-ups such as Cybernano, SmartForce, Ugiel, WatchLive, NanoLike, Daumet and Bichromatics in a wide variety of fields where nanometric gold plays a key role. This is a very profound renewal of possible public-private partnerships that will certainly help to overcome the reluctance of large companies to establish a dialogue with the academic world. This aspiration must be further supported.

GDR
P&O*- POLYMERS AND OCEANS

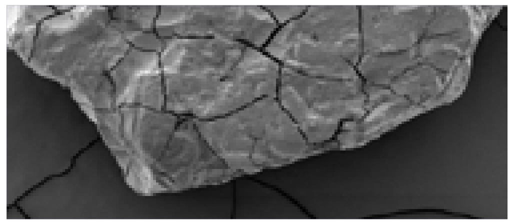
The mission of the **Polymers and Oceans (P&O)** research network is to bring together the French community working on the future of plastics in aquatic environments with the aim of promoting the emergence of new interdisciplinary research on this subject. The major asset of the GDR P&O is to mobilize all the scientific communities concerned : chemists, physicists, biologists, ecologists, ecotoxicologists, oceanographers, economists and sociologists in order to support the development of multi-scale and transdisciplinary approaches.

* Polymères et Océans



3 research topics

- Plastics : from their entry into the environment to their ultimate fate
- Impacts of plastics and long-term risks
- The tracks for the future



240 researchers involved within **50 laboratories**

Coordinator : Pascale Fabre (L2C) | **pascale.fabre@umontpellier.fr**
Deputy coordinators : Matthieu George (L2C), Fabienne Lagarde (IMMM), Ika Paul-Pont (LEMAR)

PROSPECTS

PLASTICS : FROM THEIR ENTRY INTO THE ENVIRONMENT TO THEIR ULTIMATE FATE

What are the quantities contributed by each of the sources of contamination (rivers, coasts, sea), what is the true level of contamination of the oceans (surface, water column, seabed, sediment) and how to model the plastic cycle taking into account the land-sea continuum to the abyss ? New scientific protocols must be developed to take into account all scales ranging from macro-, to micro and nano-plastics. Much fundamental knowledge about the behavior and ultimate fate of plastics in the environment remains to be acquired. In order to assess the degradation times of polymers in a medium as complex as the environment, it is more than ever necessary to understand the links between their structural and/or morphological properties and their (bio) degradation and fragmentation processes.

IMPACTS OF PLASTICS AND LONG-TERM RISKS

What are the impacts of the accumulation of plastics in the aquatic environment on organisms and the functioning of ecosystems ? How do micro- and nano-plastics and associated contaminants interact with cell envelopes and what are their transfer capacities within tissues and cells ? The toxicity of microplastics is that they consist of a complex and dynamic mixture of polymers and additives, to which organic matter as well as chemical and biological contaminants can additionally bind.

The mechanisms of colonization and biofilm formation, the role of plastics in the vectorization of species, the biodegradability of polymers are all topics that need to be deepened. Taking into account the great diversity of plastics and the complexity of the natural environment, laboratory research must also acquire an ecosystem dimension.

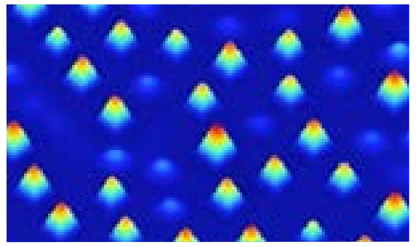
THE TRACKS FOR THE FUTURE

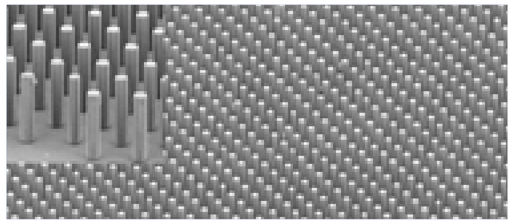
What are the preferred solutions for the future ? How can an interdisciplinary scientific community respond to this societal, environmental, economic and political demand ? In the years to come, it is necessary to be able to offer alternative innovative polymers, whose biodegradability can be controlled by playing on their physico-chemistry, and whose future and potential impacts at the end of their life will be anticipated at the stage of their design. To take into account the social and economic dimension of the problem of plastic pollution in the oceans, questions pertaining to the implementation of new economic models and the perception of environmental issues by society will also be raised.

GDR
PULSE*- ULTIMATE PROCESSES IN THE EPITAXY

The mission of the **Ultimate processes in the epitaxy of semi-conductors (PULSE)** research network is to bring together the French community working on the epitaxy of systems made of semi-conductors, in order to grasp the difficulties related to growth processes, the innovative properties, the new research directions and open questions, both theoretically and experimentally.

* Processus ultimes en épitaxie de semi-conducteurs





8 research topics

- Modelization and coupling between theory and experiments
- Monolithic and heterogeneous integration and heteroepitaxy on Silicon
- Organization on functionalized and nanostructured substrates, selective growth and lateral epitaxy
- Ultimate characterization : local, microscopic and global
- New instrumental technics related to epitaxy and new systems
- Properties (optical, electronic, ect.) of epitaxial systems and applications
- New semi-conducting materials (oxides, organics) and new systems (1D, 2D, core-shell, ect.)
- Nanowire

315 researchers involved within **33 laboratories**

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Deputy coordinators : Isabelle Berbezier (IM2NP) and Chantal Fontaine (LAAS)

PROSPECTS

Epitaxy has continued for decades to produce tremendous discoveries associated with different Nobel prices : development of the molecular beam epitaxy (MBE), invention of the transistor, tunnel effect, Hall effect, spintronics, giant magnetoresistance, blue LEDs, topological insulators etc. Nowadays, new needs emerge both in fundamental and industrial research, for different applications and applications, in nanoelectronics, photonics, information technology, photovoltaics, etc. Challenges are related to the control of growth and properties of objects at the ultimate atomic scale. If the synthesis by epitaxy of high-quality materials is achieved for nanoscale layers, new applications are related to more complex geometries, nanowires, quantum dots, nanomembranes, 2D materials, ect.

The issues related to epitaxy are multiple. The development of *in situ* and real time techniques or in the same vacuum chain, is a real breakthrough on the elaboration front. *In situ* transmission electron microscopy should thus allow live observation of growth at the atomic scale, when chemical analysis techniques should provide maps at these same scales. The new lines of synchrotrons and “extremely bright” sources open up the prospect of fine characterization of nano-objects, and analysis of the coupling of structures/properties (optics and electronics) that can lead to new systems.

The stakes related to growth mechanisms concern the understanding and control of the physico-chemical material/substrate interaction, as well as the selectivity and localization of growth with important perspectives of monolithic integration. One objective is to access the direct fabrication of nano-objects on nanostructured or nanofunctionalized substrates.

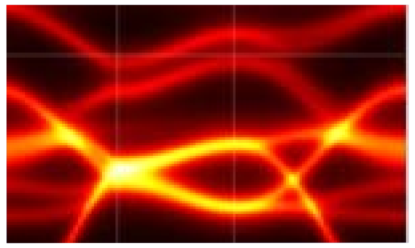
The control of epitaxy also supposes a reinforcement of the link between theory and experience, by considering sufficient complexity. The modeling of out-of-equilibrium mechanisms, the calculation by density functional theory (DFT) of optical, electronic or transport properties, or the development of new multi-scale approaches, reveal the need for a realistic description that takes into account the complexity of the phenomena.

Finally, real opportunities are opening up with the interaction with other communities, such as that of 2D materials (graphene, silicene, etc.). While their topdown production is well known, it results in systems that are too limited. Van der Waals epitaxy of 2D materials by molecular beam epitaxy (MBE) or chemical vapor deposition (CVD) opens the possibility of growing full-plate films and heterostructures, opening the field of applications for these unique materials.

GDR
REST*- THEORETICAL SPECTROSCOPY MEETINGS

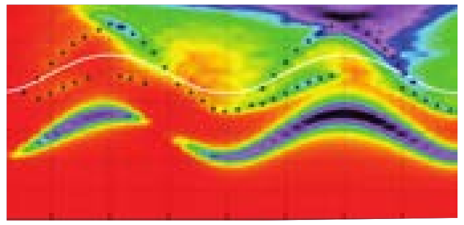
The mission of the **Theoretical spectroscopy meetings (REST)** research network is to bring together the French communities of theoreticians and numerical simulators of electronic excited states. The objective for the researchers is to exchange and compare with a twofold objective (and common denominator) : i) to develop "new" theory for electronic excited states ; ii) to model real materials (bulk, surfaces, molecules and nanostructures) with a strong technological interest.

* Rencontres de spectroscopie théorique



6 research topics

- Fundamental development : going beyond perturbation theory
- From screening to spectroscopy
- Effective approaches for a wide range of spectroscopies
- Quantum chemistry and solid state physics
- Valence and core excitations
- Strong vs weak correlation



150 researchers involved within **52 laboratories**

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PROSPECTS

REAL-TIME AND BEYOND EQUILIBRIUM

The development of real-time techniques (as opposed to linear response frequency domain), especially in the framework of Green's function and Density functional polarization theories was one of the mayor recent outcomes of the electronic excitations community. Members of the GDR REST have also been involved in these important developments, and are strongly contributing in explaining recent exciting experiments, going much beyond previous theoretical approaches.

BEYOND PERTURBATIVE APPROACHES

Perturbative approaches (like the GW approximations or the linear response TDDFT) have been very successful in describing photoemission spectroscopy or electron energy loss spectra. Today's developments however permit to go beyond the first order perturbation theory (being first order in the external potential, or in the screening, etc.), so to tackle more complicate systems (strongly correlated) or new features (like double plasmons, or satellites in photoemission). The researchers of our network greatly benefited from the gathering action "Strong *versus* weak correlation". So a completely new scenario opens in the domain of electronic excitations, that require profound theoretical investigation, at the fundamental level ("how to solve an integro-differential equation, without going towards perturbation theory or Dyson equations ?", for instance). The REST community is deeply involved in this new strategy.

TOWARDS NEW SPECTROSCOPIES

The development of the *ab initio* screening beyond dipole approximation and with the inclusion of excitonic effects opened the way to new features (excitonic satellites in photo-emission), to new spectroscopies (Coherent Inelastic X-ray Scattering, Resonant Inelastic X-ray scattering, X-ray absorption beyond dipole approximation, etc.) and to new ideas (like Bose-Einstein condensation of excitons) to be exploited in the near future by the REST community.

NEW CHALLENGES FROM EXPERIMENTS

The last four years have witnessed an enormous progress and new directions and investments are being made as we write. New directions, strategies and investments strongly influence the development of theory.

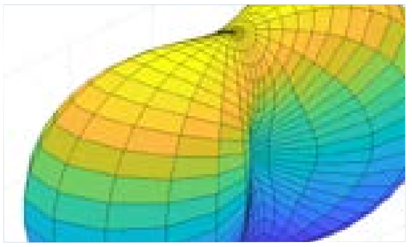
The interaction between matter and strong laser fields has been extensively studied in the last decades, particularly in atoms and molecules. This is however not the case for a crystal. Up to very recently, it was not possible to let a solid interact with a strong laser field (in order to generate higher harmonics, for instance) without destroying the sample. It was only in 2011, in fact, that it was shown the high harmonic generation in a solid of ZnO, opening completely new possibilities, in particular for what are considered table-top synchrotrons. This exciting field needs to be tackled from many sides, for the interaction solid-strong laser field involves many degrees of freedom (surface effects, lattice-electron interactions, quantum nature of photons) and requires a community rather than a group to be efficient.

The need of the theoretical counterpart to new and more challenging experiments will soon have a new meaning, with a new generation of synchrotrons that are seeing the light all over the world. Many among important synchrotrons in fact have shut down for upgrade. The objective: is to acquire unprecedented resolution, coherence and, by consequence, the capability to carry out new and exciting discoveries and analysis.

GDR
THEMS*- QUANTUM DYNAMICS INSIDE MOLECULAR SYSTEMS

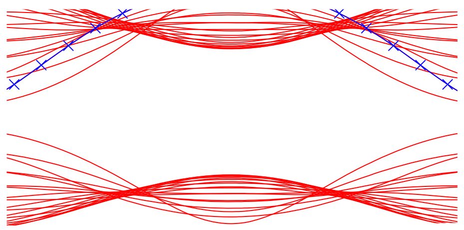
The mission of **Quantum dynamics inside molecular systems (THEMS)** research group is to bring together the French community whose activities are to develop refined and performing theoretical approaches in order to respond to the scientific challenges posed by physical chemistry in cold and ultra-cold environments, interaction with intense fields, quantum information, nanophysics, system environment, and biophysics. THEMS also strives to foster training initiatives for young researchers, to strengthen and stimulate collaborations between theoretical physicists, and to maintain the indispensable link with experimental developments.

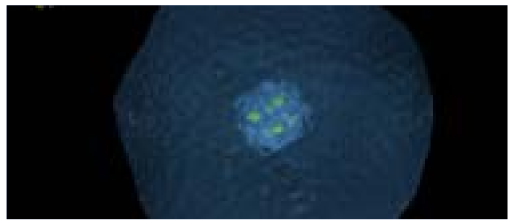
* Dynamique quantique dans les systèmes moléculaires



3 research topics

- Isolated molecular systems
- Molecular systems in the presence of intense electromagnetic fields
- Molecular systems submitted to their environments





75 researchers involved within **25 laboratories**

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Deputy coordinators : Nadine Halberstadt (LCAR) and Olivier Dulieu (LAC)

PROSPECTS

The theoretical methods of atomic and molecular physics and chemical physics are used in a wide variety of contexts that involve knowledge of the structure and dynamics of quantum systems with a finite number (from two to several dozen) of bodies isolated in the gas phase, subjected to external electromagnetic fields, or influenced by their environment.

The development of theories and models, and the continuous increase in computing resources that accompanies it, make it possible to deal more and more precisely with the dynamics of complex N-body system (typically composed of a few nuclei and electrons) that constitutes an isolated molecular edifice. But the environment in which these molecules are immersed induces an additional complexity that is often beyond the reach of these methods. The complexity of such systems lies not only in the number of particles involved, but also in the diversity of interactions involved, the presence of quantum effects, the effect of an environment and the specificity of the system's response to excitation by external light pulses.

The treatment of these problems requires the implementation of theoretical methods and the development of original and very varied models, as well as original software and the use of commercial programs. This is the scientific challenge that brings together the actors of GDR THEMS, which can be summarized through several questions :

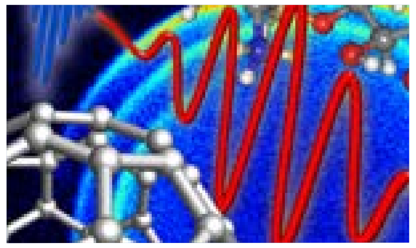
- To what extent can the precise knowledge of few-body quantum systems be transferred to N-body problems ?
- What balance must be found between «all-quantum» approaches and classical or semi-classical approaches? To what extent is this paradigm shift associated with a particular size of the system under study ?
- What renewal can we expect from methodologies that have sometimes been established for many years, and which have continuously benefited from the development of computing capacities ?

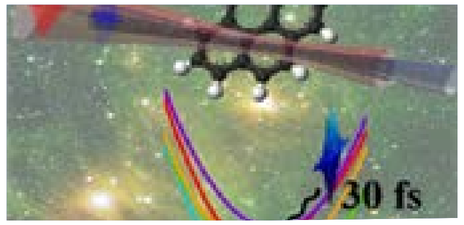
Finally, our entire field of research is starting to explore the paradigm shift in programming resulting from the extension of parallel computers based on GPUs or located in computing centers. In particular, there is no guarantee that the computing resources currently required for the theme (methods that are difficult to parallelize, shared memory, etc.) will remain perennial in computing centers. The GDR will be able to take up this technical challenge in the long term, by offering appropriate training courses for the translation and porting of current codes. The development of artificial intelligence and the expected appearance of a quantum computer are two other sources of future evolution of our disciplines that we will accompany in particular by offering appropriate training in each of our themes.

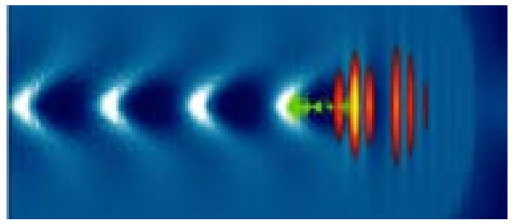
GDR
UP*- ULTRAFAST PHENOMENA

The mission **Ultrafast phenomena (UP)** research network is to bring together French experimentalists experimentalists and theoreticians interested in the study of processes occurring on the ultrafast timescale that is attosecond, femtosecond or picosecond, in all phases of matter.

* In english originally







7 research topics

- Attosecond Science
- Gas phase, from atom to complex molecule
- Femtochemistry and Femtobiology in the condensed phase
- Ultrafast Dynamics in Materials and Nanostructures
- Secondary Sources : photons, electrons, protons
- Instrumentation & Data
- Communication

500 researchers involved within **50 laboratories**

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PROSPECTS

COMPACT ULTRASHORT PULSE RADIATION SOURCES

The ultrafast science community strongly evolves due to the emergence of new laser and secondary sources. These sources are very compact and deliver striking performances that renovate our ways to probe matter and allow to envision complex experiments on laboratory scale. Laser-matter interaction allows the development of large variety of ultrashort secondary sources including : (i) femtosecond sources of particles (electrons, protons) for medical (radiobiology) and ultrafast imaging applications, as well as (ii) UV-X attosecond or X-ray femtosecond sources, to study dense and hot matter for instance. In parallel, the emergence of high repetition rate sources (kHz et MHz) that can explore a large spectral range from THz to X-ray, will be crucial for many applications. With many world leading research groups and companies, France is in excellent position to lead future breakthroughs and play a major role in that field.

ATTOSECOND SCIENCE : THE ACCESS TO ULTIMATE TIMESCALES

France is one of the pioneer and leading country in the field of attosecond physics. One of the current challenge is to understand dynamics of small quantum systems on the sub-fs timescale. This will require the development of experiments in which all the particles are measured in coincidence. This will provide a direct access to highly accurate information (coherent dynamics, quantum electron scattering phases). The field also evolves towards the investigation of more complex systems (biomolecules, molecular complexes). After major progresses made in gas phase experiments, attosecond physics is now dealing with condensed phase and the study of solids (topology), or liquids (solvatation) is now considered. The future of the field is clearly interdisciplinary and first explicit links to other research fields already appear in the case of astrochemistry (HAP stability in interstellar media) or biochemistry (charge transfer, chirality). The recent possibility to generate attosecond pulses at FELs (FERMI, LCLS, XFEL) also opens new opportunities for our community. With the increasing complexity of the experimental technics and systems of interest, new theoretical methods are under development both to help the interpretation of the experiments and to guide future research lines.

MULTISCALE AND HETEROGENEOUS SYSTEMS IN PHOTOCHEMISTRY ET PHOTOBIOLOGY

Here, the challenge is to understand molecular photoactive structures of increasing complexity implying sequential multiple elementary photoinduced processes on multiple spatio-temporal scales (commutation of fluorescent protein, ligand transfer in hemoproteins, photo-actuation and supramolecular photo-active assembly, etc.). New approaches related to the interaction between molecules and metallic and semi-conductor surfaces are under development, in relation with photocatalysis, chemical plasmonic or photovoltaic. The development of reliable ultrafast multidimensional (2D) spectroscopy (IR, UV) opens new perspectives to study chemically or biologically relevant systems.

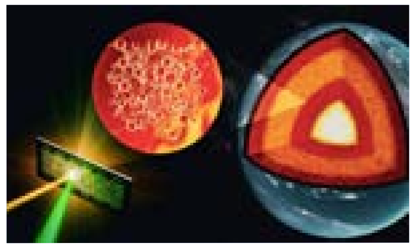
MATERIALS, HYBRIDE OBJECTS AND NON-LINEAR NANOPHYSICS

The combination of traditional optical femtosecond sources, THz and X-ray sources allow to investigate new out-of-equilibrium and non-linear physical phenomena. New materials exhibit ultrafast dynamics and non-linear processes involving electrons, spins and phonons. Some remarkable examples are the striking properties of multiferroïcs, Van der Waals heterostructures (2D materials) or spin-charge conversion in nano-hybrid structures. These new phenomena guide progresses in electronics and spintronics, plasmonic or photovoltaic. These striking advances are made possible thanks to the development of new technics such as electron sources triggered by ultrafast ionization of nanotips, photoemission and time-resolved electron microscopy experiments developed in French laboratories.

GDR
XFEL*- SCIENCE AROUND THE XFELs

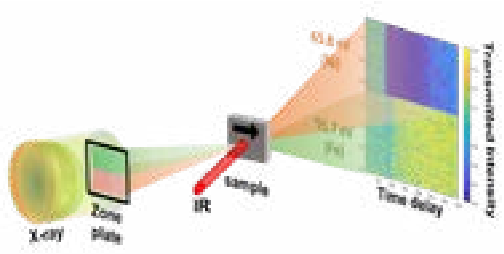
The mission of **Science around the XFELs (XFELs)** research network is to bring the French community of involved researchers in studies using X-ray free electron lasers (FELs) emitting in the x-ray domain. At the interface of physics, chemistry and biology, the XFEL GDR aims at sharing know-how and at maintaining the community aware on the fast evolution of the possibilities provided by this kind of installation.

* Science autour des XFEL



5 research topics

- Condensed Mater Physics
- Atoms and Molecules in diluted samples
- High Energy Density
- Photochemistry
- Structural Biology



120 researchers involved within **35 laboratories**

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PROSPECTS

XFELs are large facilities producing ultrashort light pulses (UV or X) characterized by a brilliance 9 orders of magnitude higher than 4th generation synchrotron facilities. This kind of installations are running in Germany, United States, Japan, Italy, Switzerland, South-Korea and soon in China. The short pulse duration (5-100 fs), the intensity (10^{10}-10^{12} photon/pulse) and the pulse focus dimension (0.1-20 µm), combined with the extended x-ray energy range (from XUV to hard x-rays X) allow to perform innovative experiments not feasible with other types of light sources. The involved scientific topics are condensed matter physics, geoscience, laboratory astrophysics, plasmas, photochemistry, atomic and molecular physics and structural biology. Unique characteristics of light pulses allow, in each domain, to perform time-resolved experiments and to study ultrafast dynamics.

We observe a growing number of members of the French XFEL users' community, with international projects lead by CNRS, CEA and universities. The XFEL community is specific because it brings together – and sometime for a beamtime – physicists, chemists, geoscientists, astrophysicists, materials engineers and biologists, all motivated by conducting experiments at the limits of feasible in order to answer questions unsolved so far.

Although the scientific topics are diverse, experimental bottle necks are often similar, explaining the development of common culture, founded on scientific exchange on the data acquisition or data treatment. The first goal of the XFEL GDR is to create a privileged space for exchange of know-how in order to allow access to a larger number of scientists. This actors-partners federation is essential to reinforce the competitiveness of French teams.

The GDR will meet in plenary sessions once every 2 years. One school will be organized every two years and thematic workshops will be regularly organized.

Cover photo: Prototype Cat-Qubits chip developed by the start-up Alice & Bob, which is developing a self-correcting Qubits quantum computer (called Cat-Qubits). The qubit is the unit of information storage that indicates the computational strength of quantum computers. Alice & Bob was co-founded in February 2020 by Théau Peronnin, president, from the Physics Laboratory of ENS Lyon and Raphaël Lescanne, technical director, from the Physics Laboratory of ENS Paris. It aims to significantly increase computing power with Cat-Qubits that enable fault-tolerant quantum computing and can execute any quantum algorithm. The quantum computer will indeed be able to perform parallel calculations, simultaneously, and with extreme speed, unattainable with current classical computers. They could revolutionize many industrial sectors, from health to chemistry, including industry, computer security and energy.

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