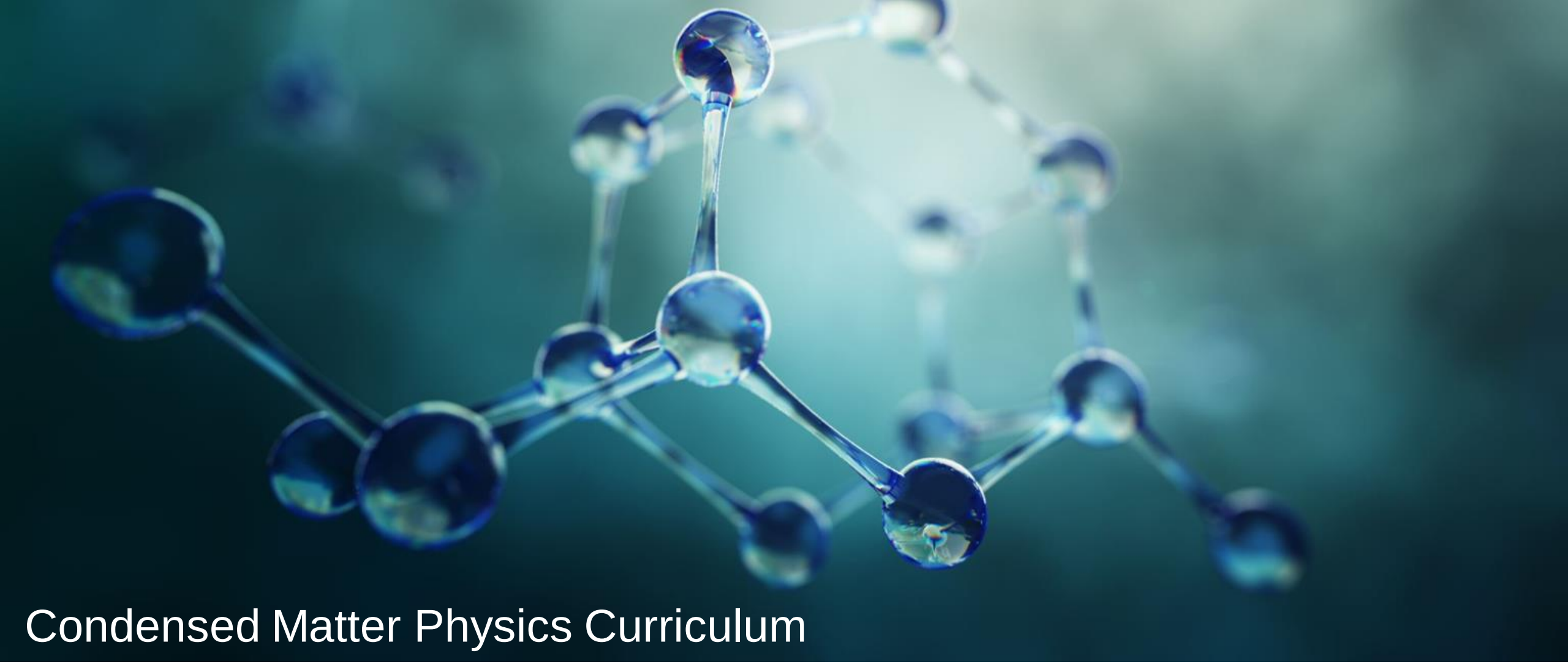


Condensed Matter Physics Curriculum

Porte Aperte Sapienza
12 Luglio 2023

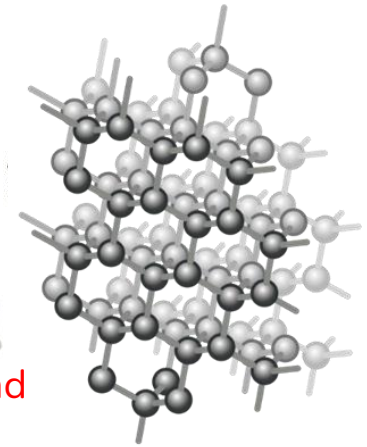
Marta De Luca (EXP)
Bernard van Heck (TH)

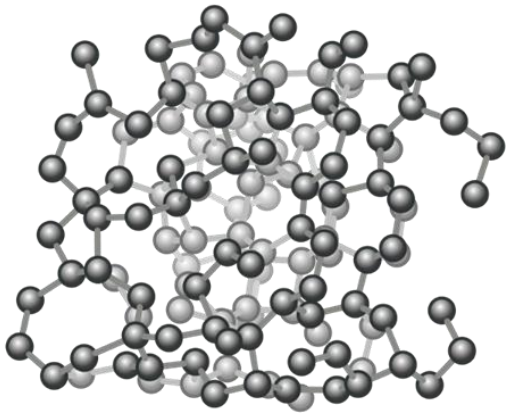
What is condensed matter physics?

It deals with macroscopic and microscopic physical properties of matter, primarily **solids and liquids**.

- Necessity to **understand systems of many interacting particles or components.**
- Realization that "**more is different**": **new properties emerge** that are not attributes of individual constituents, leading to a huge variety of phenomena and applications.

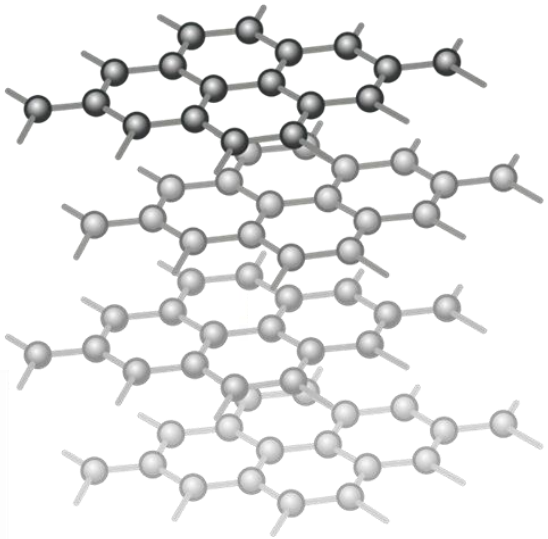
Diamond

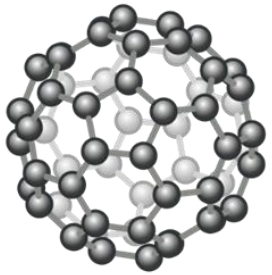




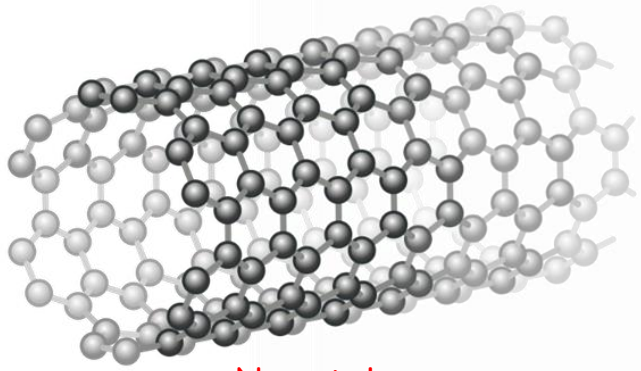
Amorphous carbon

Graphite / graphene





Fullerenes



Nanotubes

C

All these systems are made only of carbon atoms,
differing only in structure and dimensionality.
Yet, their physical properties are completely different.

The variety of condensed matter physics

NOBEL PRIZES IN THE LAST 15 YEARS

2022, "*for experiments with **entangled photons**, establishing the violation of Bell inequalities and pioneering **quantum information science***", Alain Aspect, John F. Clauser and Anton Zeilinger

2018, "*For groundbreaking inventions in the field of **laser physics***", A. Ashkin, G. Mourou, D. Strickland

2016 "*For theoretical discoveries of **topological phase transitions** and **topological phases of matter***", D. J. Thouless, F.M.D. Haldane, J.M. Kosterlitz

2014 "*For the invention of efficient blue **light-emitting diodes** which has enabled bright and energy-saving white light sources*", I. Akasaki, H. Amano and S. Nakamura

2012 "*For ground-breaking **experimental methods** that enable measuring and manipulation of **individual quantum systems***", S. Haroche and D. J. Wineland

2010 "*For groundbreaking experiments regarding the **two-dimensional material graphene***", A. Geim, K. Novoselov

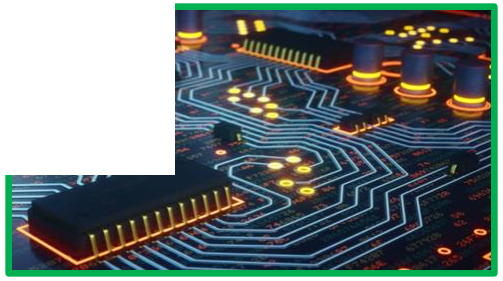
2009 "*For the invention of an **imaging semiconductor circuit – the CCD sensor***", W.S. Boyle and G.E. Smith

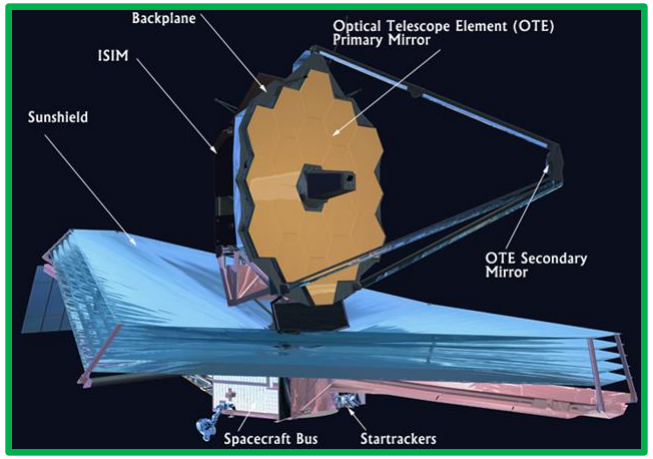
Why is it important?

Condensed matter is **the largest subfield of physics** (~1/3 physicists are in Condensed Matter): ***why?***

- **It is all around us.** We spend most of our day interacting with “condensed matter”. It gives the answers to simple questions, *e.g.*: why do we like coffee in ceramic cups? Why is a piece of gold shiny?

- It provides the ideal **laboratory to study, apply and develop quantum mechanics and statistical physics**





…which are in turn enabling new discoveries in other fields

EXPERIMENTAL CONDENSED MATTER: HOW DO WE DO IT?

sakkmesterke/stock.adobe.com

Micro/Nano

Manipulation

Understanding

(Spectroscopy)

Experimental facilites

Electrons, neutrons, ions and photons are the main probes in condensed matter experiments

OUR LABS IN THE DEPARTMENT

LARGE SCALE FACILITIES

- Synchrotron sources

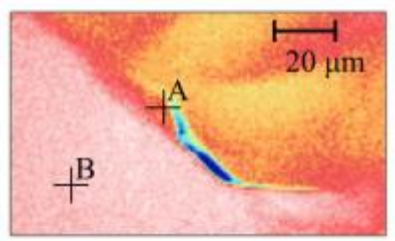
  Free electron lasers

- Neutron sources
- European magnetic field laboratories
- Micro/nano fabrication labs

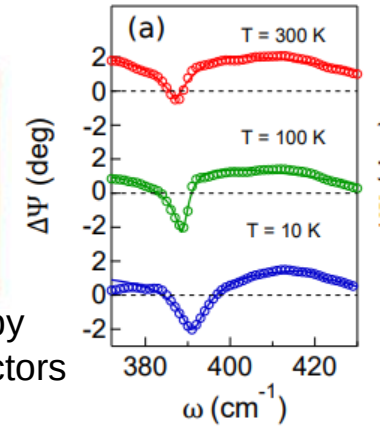
Fields of research

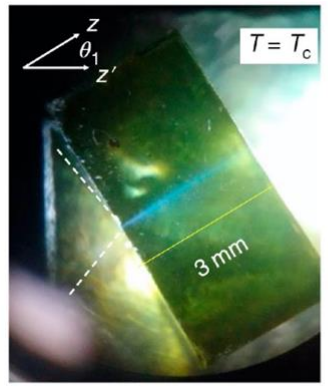
Hard Condensed Matter

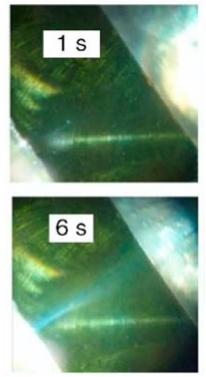
- Superconductivity, highly-correlated systems, and topological states



Photoelectron microscopy of BiS_2-based superconductors



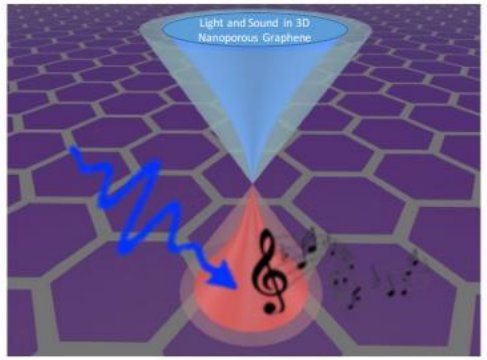




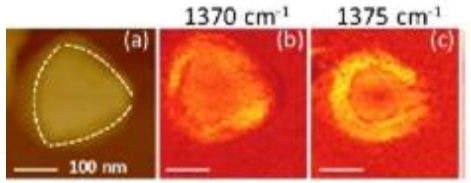
Topological surface states at the Bi_2Se_3/sapphire interface

Giant refraction in nano-disordered ferroelectric super-crystal

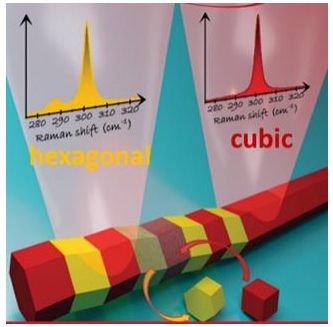
- Surface physics, nanostructures



Light transduced in sound in nanoporous graphene

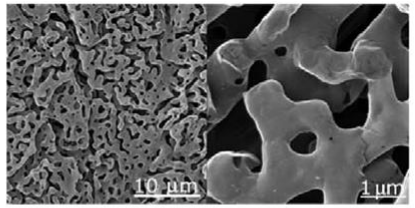


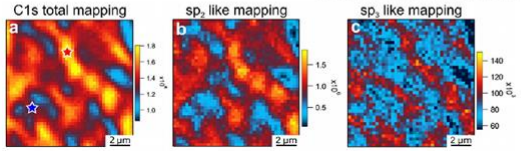
Polaritons in IR absorption maps of hBN flake



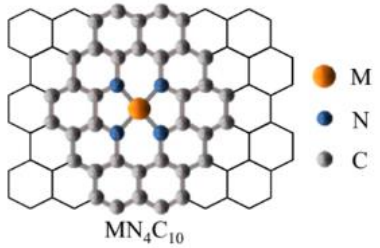
Superlattices in nanowires

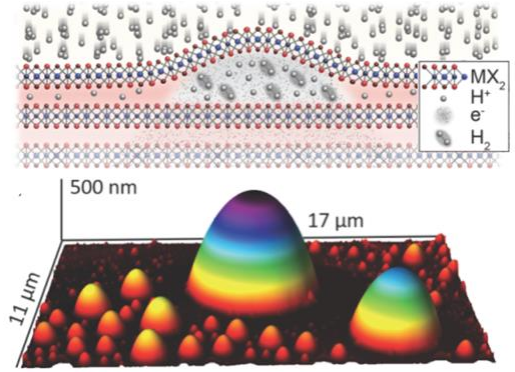
Photoemission in nanoporous graphene





Carbon-based electrocatalysts for energy applications

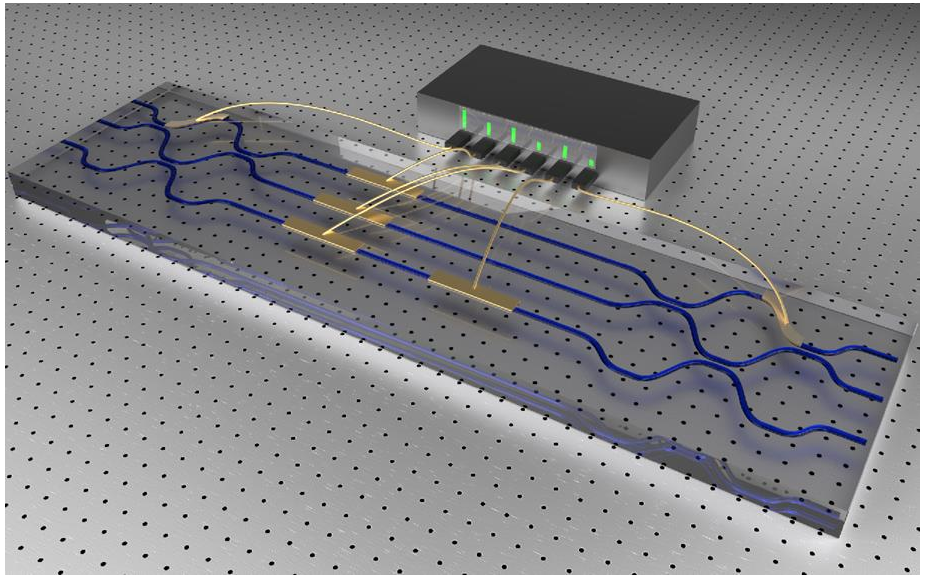




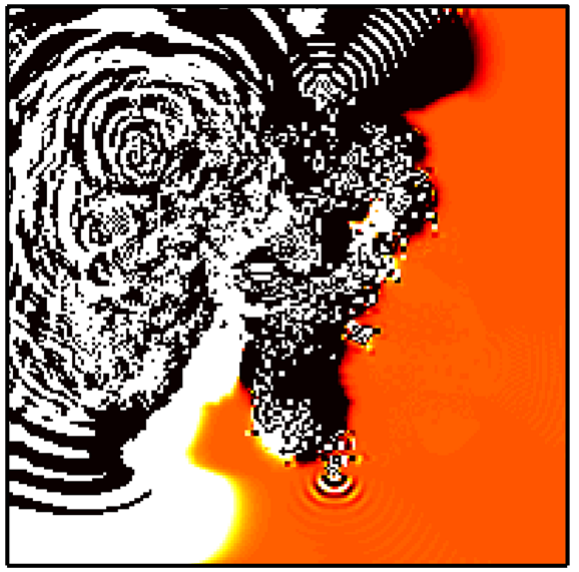
WS_2 domes caging highly pressurized hydrogen

Fields of research

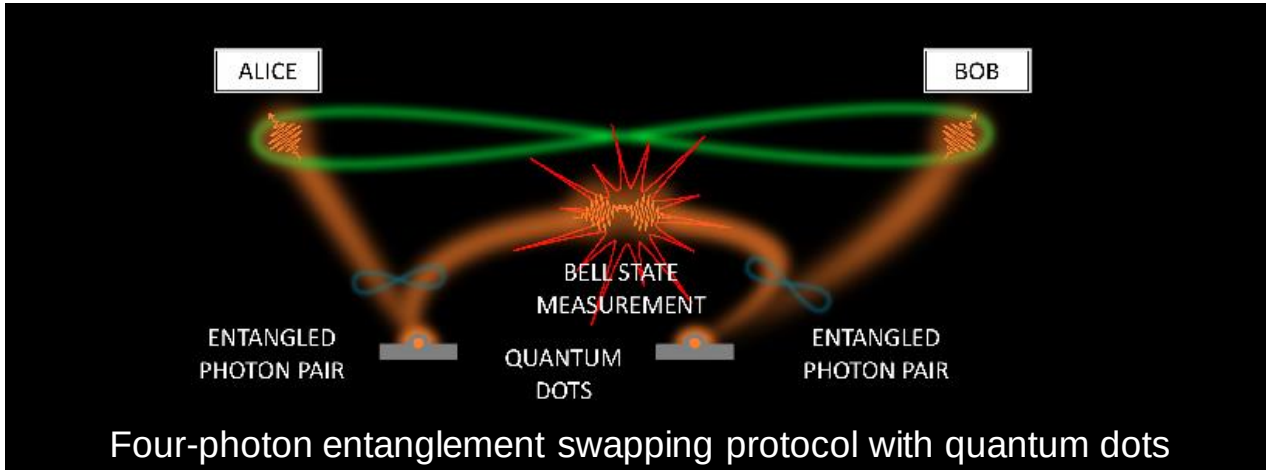
Photonics and Quantum Technologies



Multiarm interferometer in a femtosecond laser-written circuit



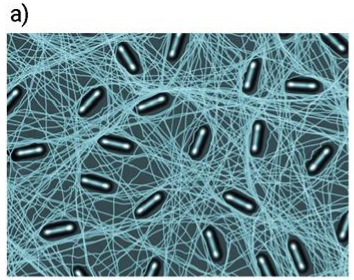
Simulations of a light-driven cellular automata



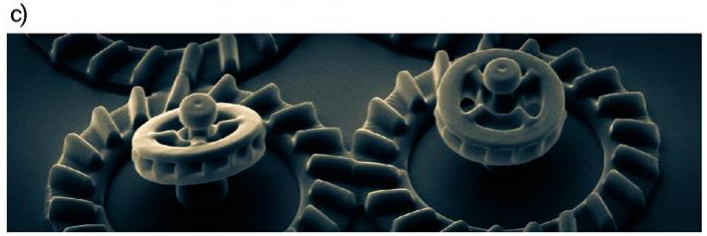
Four-photon entanglement swapping protocol with quantum dots

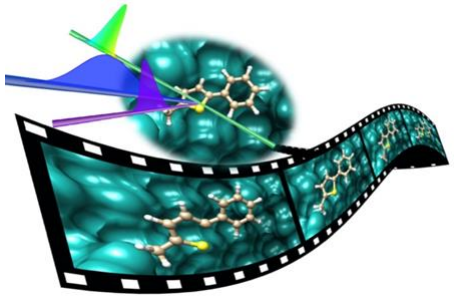
Fields of research

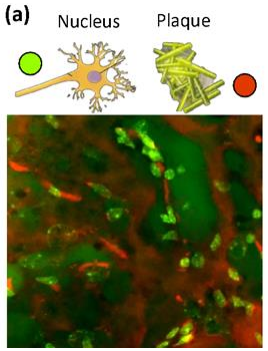
Active Matter, Soft Matter and Biosystems



Bacteria swimming
and
3D printed
micromachines

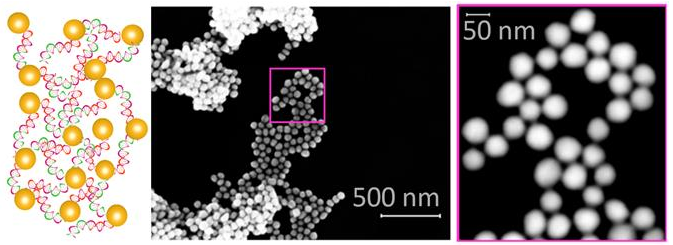


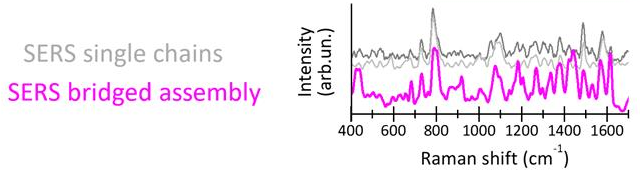




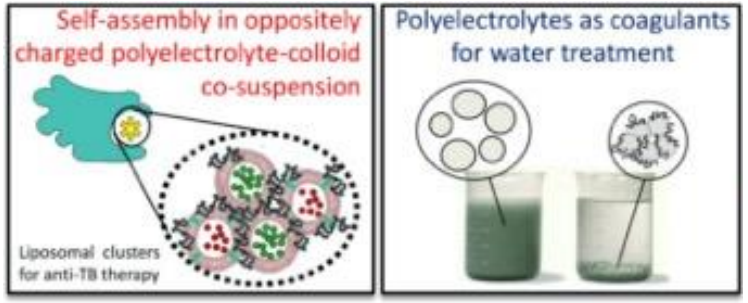
Pump and probe
spectroscopy of
cells and tissues

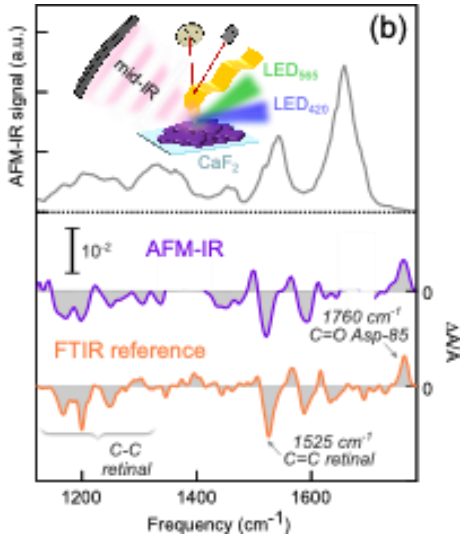
DNA-mediated assembly of gold nanoparticles for biosensing





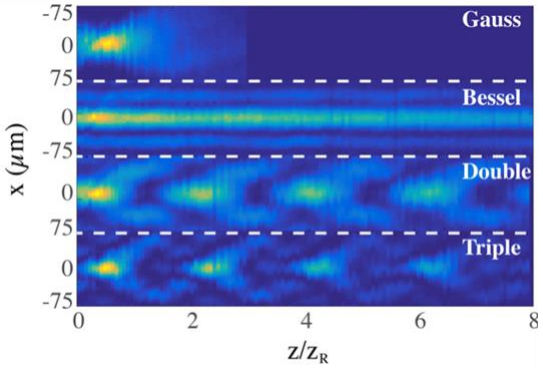
Colloids for biotechnological
and environmental applications





AFM-IR photo-expansion
spectrum of a purple-membrane

light confinement in disordered media



Experimental Condensed Matter: who are we?

Hard Condensed Matter

- Superconductivity, highly-correlated systems, and topological states

→ Saini, Nucara, Ortolani, Del Re, Conti, Postorino

- Surface physics, nanostructures

→ Baldassarre, Ortolani, Nucara, Lupi, Betti, Mariani, Frisenda, Postorino, Felici, Polimeni, De Luca M., Trotta, Placidi, Scopigno, Trequattrini

Photonics and Quantum Technologies

→ Sciarrino, Spagnolo, Mataloni, Conti, Del Re, Trotta

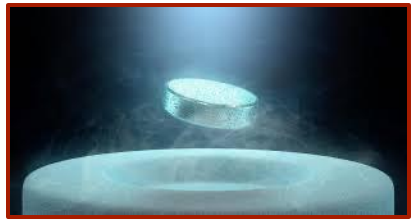
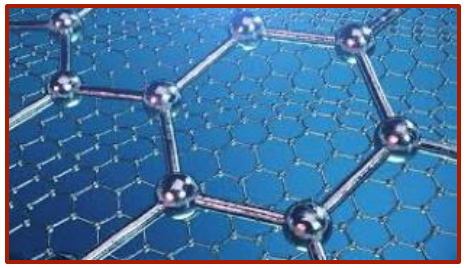
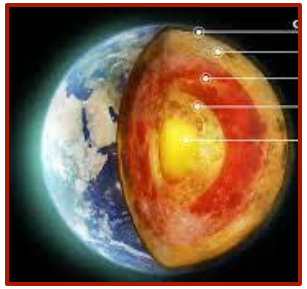
Active Matter, Soft Matter and Biosystems

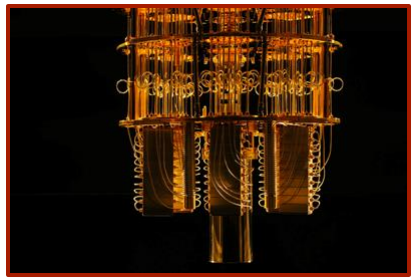
→ Postorino, Baldassarre, Ortolani, Ruocco, Conti, Del Re, Di Leonardo, Scopigno, Sarti, Bordi, Bove, Trequattrini

Theoretical Condensed Matter

QUANTUM MATTER

[Lara Benfatto, Lilia Boeri, Sergio Caprara, Marco Grilli, Francesco Mauri, Riccardo Mazzarello, Bernard van Heck]

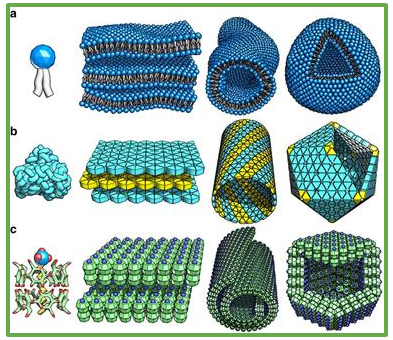
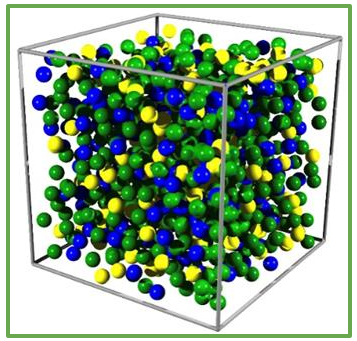
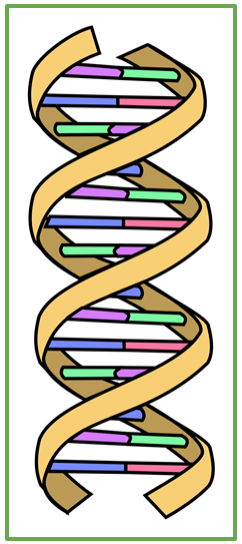






- Superconductivity
- Magnetism
- 2D Materials
- Matter @ Extreme conditions
- Topological Matter
- Quantum Devices

SOFT MATTER

[Andrea Crisanti, Cristiano De Michele, Lorenzo Rovigatti, John Russo, Francesco Sciortino]

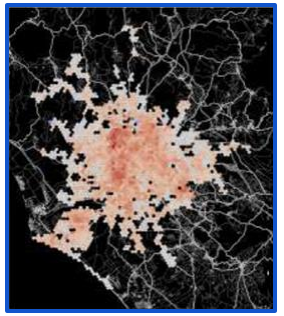




- Complex liquids
- Self-assembly
- Biopolymers
- Phase-Change Materials
- Active Matter

COMPLEXITY

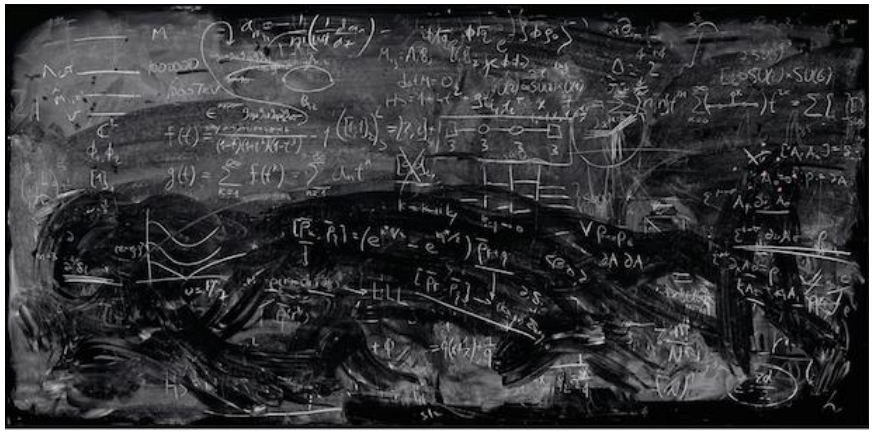
[Vittorio Loreto, Francesca Tria]



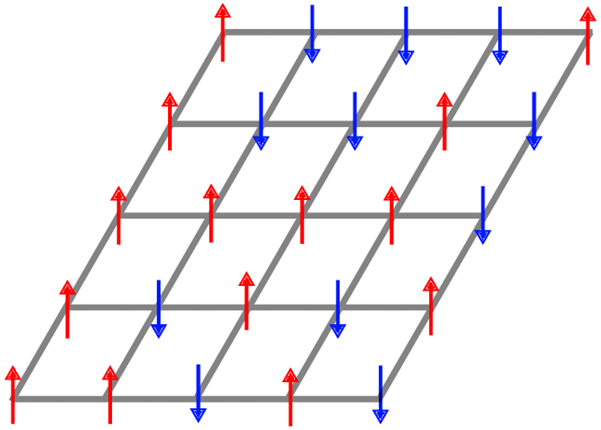


- Networks
- Human Dynamics
- Innovation dynamics
- Sustainable Cities

Research in condensed matter theory requires to learn, use and develop advanced methods in theoretical physics, both analytical and numerical.

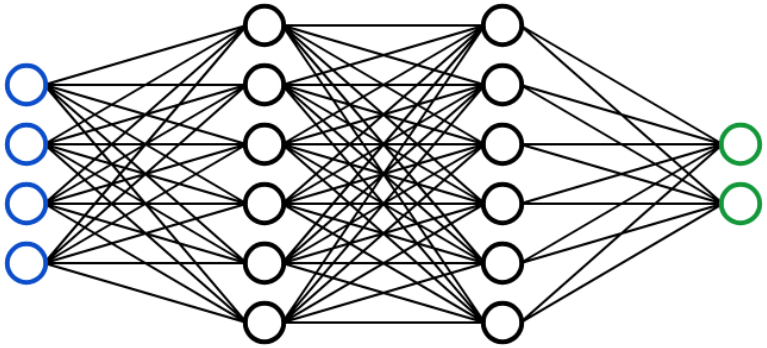


Many-Body Theory



Statistical Mechanics

Computer Simulations (Quantum & Classical)



Machine Learning & AI

Curriculum Condensed Matter: Theory and Experiment

To guide your choice, we formulated five **sub-curricula** corresponding to **five research areas*** active in the department:

- **Complexity Science**
- **Disordered Systems: liquid, glassy and soft matter**
- **Photonics and Quantum Technologies**
- **Superconductivity, Strongly Correlated Systems and Functional Materials**
- **Surface Physics and Nanostructures**

Each of these:

- can be tailored to **theory or experiment**
- optimally prepares for research in the corresponding area
- is planned to avoid scheduling conflicts

*see: https://www.phys.uniroma1.it/fisica/ricerca/aree-tematiche-e-gruppi-di-ricerca

SUB-CURRICOLA CONDENSED MATTER
[indicativi - in corso di aggiornamento per A.A. 23/24]

COMPLEXITY SCIENCE

Primo Anno, Primo Semestre [30 crediti]	
Introduction to Quantum Field Theory	6
Condensed Matter Physics	6
Physics Laboratory I	6
Computing Methods for Physics [INF/01]	6
Statistical Mechanics and Critical Phenomena	6
Primo Anno, Secondo Semestre [31 crediti]	
Physics Laboratory II	9
Condensed Matter Physics II	6
Meccanica Statistica del Non Equilibrio	6
English Language	4
ONE AMONG Advanced Machine Learning for Physics Deep Learning and Applied Artificial Intelligence [INF/01]	6
Secondo Anno, Primo Semestre [21 crediti]	
Statistical Physics and Machine Learning	6
Physics of Complex Systems	6
ONE AMONG Superconductivity and Superfluidity Statistical Mechanics of Disordered Systems Theory of Stochastic Processes	6
Internship	3
Secondo Anno, Secondo Semestre	
Thesis Project	38

DISORDERED SYSTEMS: LIQUID, GLASSY AND SOFT MATTER

Primo Anno, Primo Semestre [30 crediti]	
Introduction to Quantum Field Theory	6
Condensed Matter Physics	6
Physics Laboratory I	6
Computing Methods for Physics [INF/01]	6
Soft and Biological Matter	6
Primo Anno, Secondo Semestre [37 crediti]	
Physics Laboratory II	9
Condensed Matter Physics II	6
Physics of Liquids	6
Biophysics	6
English Language	4
ONE AMONG Advanced Machine Learning for Physics Deep Learning and Applied Artificial Intelligence [INF/01]	6
Secondo Anno, Primo Semestre [15 crediti]	
TWO AMONG Statistical Mechanics and Critical Phenomena Statistical Mechanics of Disordered Systems Theory of Stochastic Processes	12
Internship	3
Secondo Anno, Secondo Semestre	
Thesis Project	38

PHOTONICS AND QUANTUM TECHNOLOGIES

Primo Anno, Primo Semestre [30 crediti]	
Introduction to Quantum Field Theory	6
Condensed Matter Physics	6
Physics Laboratory I	6
Nonlinear and Quantum Optics	6
Computing Methods for Physics [INF/01]	6
Primo Anno, Secondo Semestre [31 crediti]	
Physics Laboratory II	9
Condensed Matter Physics II	6
Photonics	6
English Language	4
ONE AMONG Spectroscopy Methods and Nanophotonics Nonlinear waves and solitons	6
Secondo Anno, Primo Semestre [21 crediti]	
Physics of Solids	6
Quantum Information and Computation	6
ONE AMONG Solid State Sensors Surface Physics and Nanostructures	6
Internship	3
Secondo Anno, Secondo Semestre	
Thesis Project	38

SUPERCONDUCTIVITY, STRONGLY CORRELATED SYSTEMS, AND FUNCTIONAL MATERIALS

Primo Anno, Primo Semestre [30 crediti]	
Introduction to Quantum Field Theory	6
Condensed Matter Physics	6
Physics Laboratory I	6
Computing Methods for Physics	6
ONE AMONG Statistical Mechanics and Critical Phenomena Nonlinear and Quantum Optics	6
Primo Anno, Secondo Semestre [25 crediti]	
Physics Laboratory II	9
Condensed Matter Physics II	6
English Language	4
ONE AMONG Mathematical Physics, Advanced Machine Learning for Physics, Spectroscopy methods and nanophotonics, Photonics, Physics of Liquids	6
Secondo Anno, Primo Semestre [27 crediti]	
Physics of Solids	6
Many-Body Physics	6
Superconductivity and Superfluidity	6
ONE AMONG Many-Body Physics, Solid State Sensors, Surface Physics and Nanostructures, Quantum Information and Computation	6
Internship	3
Secondo Anno, Secondo Semestre	
Thesis Project	38

SURFACE PHYSICS AND NANOSTRUCTURES

Primo Anno, Primo Semestre [30 crediti]	
Introduction to Quantum Field Theory	6
Condensed Matter Physics	6
Physics Laboratory I	6
Computing Methods for Physics	6
ONE AMONG Nonlinear and Quantum Optics, Statistical Mechanics and Critical Phenomena	6
Primo Anno, Secondo Semestre [31 o 37 crediti]	
Physics Laboratory II	9
Condensed Matter Physics II	6
Spectroscopy Methods and Nanophotonics	6
English Language	4
ONE OR TWO AMONG Photonics, Physics of Liquids, Mathematical Physics [MAT/07]	6 (12)
Secondo Anno, Primo Semestre [15 o 21 crediti]	
Physics of Solids	6
Surface Physics and Nanostructures	6
ONE OR ZERO AMONG Many Body Physics, Solid State Sensors, Superconductivity and Superfluidity, Quantum Information and Computation, Statistical Physics and Machine Learning	6 (0)
Internship	3
Secondo Anno, Secondo Semestre	
Thesis Project	38

WHY CHOOSE IT?

- **Challenging problems** tackled in **small research groups** (experiments are “cheap”)
    - Continuous **feedback between theory and experiment.**
- **Always full of scientific surprises:** quantum Hall effect, high-Tc superconductors, graphene, topological insulators, twisted materials… what next?
- **Combines applied and fundamental research**, with many connections to other disciplines:
    - Materials science, chemistry, engineering, biology, computer science, economics, sociology, …
- **Many career opportunities in Italy and abroad:** R&D (semiconductor electronics, automotive, micro electronics, quantum …), data science, …
- **International atmosphere:** the curriculum is in English, many international collaborations.

LAZIO INNOVA

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If you have any questions, just ask! bernard.vanheck@uniroma1.it (TH) marta.deluca@uniroma1.it (EXP)