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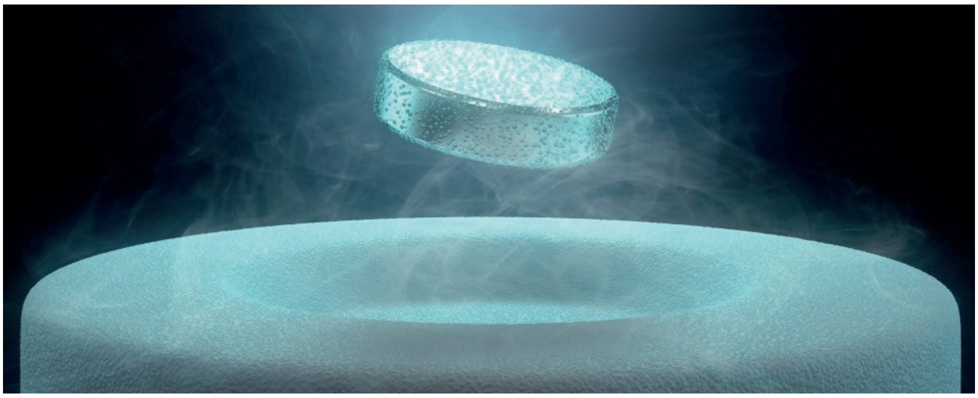
The Rise and Fall of a Room-Temperature Superconductivity Claim

Claudio Cazorla

> In recent years, the scientific world was rocked by what seemed to be a monumental breakthrough: the discovery of superconductivity at room temperature. Long considered a holy grail in condensed matter physics, room-temperature superconductivity –if achieved– would revolutionize energy transmission, computing, and many other technologies. But the claims, initially celebrated, have since unraveled under the weight of scrutiny, revealing deep issues related to data integrity, reproducibility, and scientific ethics. The Nature article "Superconductivity scandal: the inside story of deception in a rising star's physics lab" (nature.com/articles/d41586-024-00716-2) provides a good overview of the claims.

The saga began in 2020 when Dr. Ranga P. Dias, a physicist at the University of Rochester, and his team published a paper in Nature titled "Room-temperature superconductivity in a carbonaceous sulfur hydride." The study claimed that a specific hydrogen-rich material exhibited superconductivity at 15°C under a pressure of about 267 GPa –conditions achievable with diamond anvil cells. This was not the team's first controversial claim; in 2019, Dias and co-authors had published another high-profile superconductivity study in Physical Review Letters on lanthanum hydride, which was also met with skepticism.



Representation of Meissner effect for superconductors.

The 2020 Nature article generated global headlines. Superconductivity without the need for extreme cooling would represent a massive leap forward for science and industry. However, this claim came from a field notorious for irreproducible results, and the community was immediately cautious. Several groups attempted to replicate the results but failed to observe the same phenomena.

Scrutiny and retraction ensued. The controversy escalated in 2022 when independent researchers began questioning the data analysis methods used by Dias and colleagues. Physicist Jorge E. Hirsch from the University of California, San Diego, was among the most vocal critics, raising alarms about potential inconsistencies in the reported magnetic susceptibility data –a key measurement for confirming superconductivity.

An in-depth investigation by Nature, prompted by these concerns and the lack of reproducibility, eventually led to the paper's retraction in September 2022. The editors cited doubts about the reliability of the magnetic data and the inability to

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Dr. Claudio Cazorla earned his Ph.D. in Computational Physics from the Universitat Politècnica de Catalunya (Barcelona, Spain) in 2006. From 2006 to 2010, he worked as a postdoctoral researcher in the Department of Physics & Astronomy at University College London (United Kingdom). In 2010, he joined the Institute of Materials Science of Barcelona (Spain) as a JAE-DOC Research Fellow.

provide raw data for independent verification. A subsequent 2023 paper by Dias's group, again claiming room-temperature superconductivity in a nitrogen-doped lutetium hydride, was published in Nature and received similar fanfare. But just months later, this paper, too, came under fire. Nature retracted it in November 2023, citing irregularities and concerns about data validity.

Was it a fabrication or an error? This is key question haunting the scientific community is: whether these flawed results were due to honest mistakes or deliberate fabrication. While investigations by the University of Rochester and funding agencies are ongoing, some allegations point toward intentional data manipulation. For example, critics claim that portions of the magnetic susceptibility data may have been copied or altered to fit the desired outcome. Dias has denied these allegations and maintains the validity of his group's research.

In August 2023, Physical Review Letters retracted the 2019 paper by Dias and colleagues due to concerns over data manipulation, specifically regarding the reuse of noise patterns across different datasets. The accumulation of retractions and irregularities has severely impacted the credibility of Dias's group, although conclusive findings on intent have yet to be publicly released.

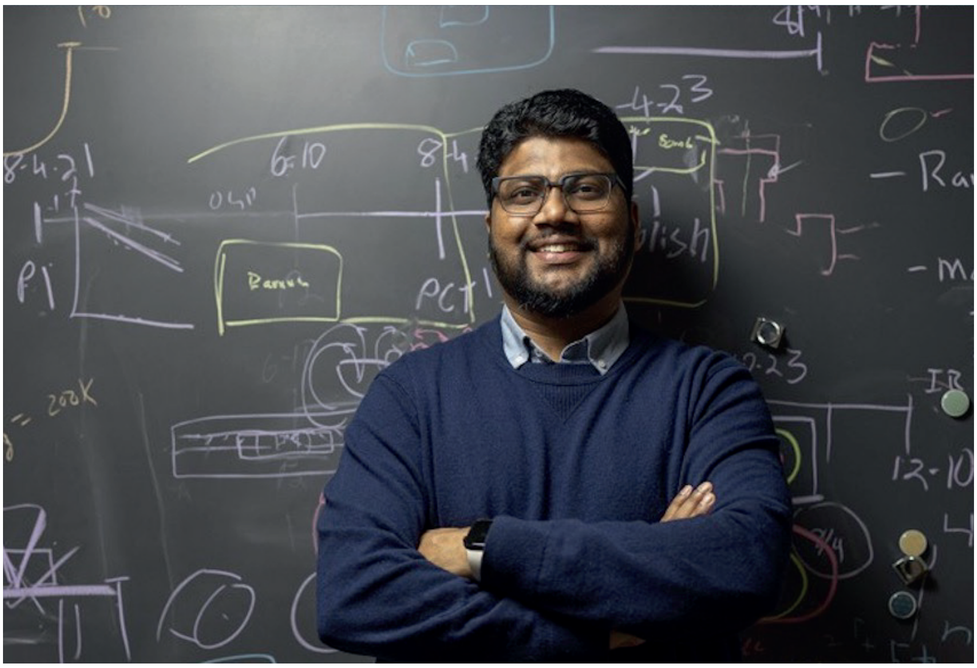
Let me put forward some ethical reflections on this series of events since they raise profound ethical questions about scientific publishing and the peer review process. The initial papers were published in some of the most prestigious scientific journals, suggesting that the editorial and peer-review systems were either insufficiently rigorous or flawed. Moreover, the high stakes associated with room-temperature superconductivity likely intensified the desire for rapid publication, potentially compromising thorough scrutiny.

The case also highlights the importance of data transparency and reproducibility. Increasingly, journals are being urged to mandate the sharing of raw data and computational methods to enable external validation. This episode highlights the importance of such practices –not only to maintain scientific integrity but also to safeguard public trust in science.

In the wake of the controversy, discussions are ongoing in the scientific community about how to improve research culture, especially in high-impact fields where the rewards of breakthrough discoveries may tempt some to cut corners.

A hopeful conclusion to this history: The now-retracted claims of room-temperature superconductivity by Ranga Dias and his collaborators serve as a cautionary tale. While the dream of a truly practical superconductor remains alive, this episode reminds us that the path to scientific truth is paved not only with brilliance and ambition but also with rigor, humility, and accountability. Until these values are consistently upheld, even the most promising discoveries must be met with cautious skepticism. ❑

Photograph of
Dr. Ranga P. Dias.



PhyTracer: A teaching innovation project on Physics

> The Physics Department received internal funding from the UPC for the project PhyTracer: Physics as Tracer of Teaching Innovation Actions, under the Galàxia Aprenentatge call for innovative teaching projects in 2024.

Physics plays a fundamental role in engineering education, providing key principles that support nearly all engineering fields—from mechanics and thermodynamics to electromagnetism and modern materials science. Teaching physics effectively in engineering programs is essential for developing students' problem-solving abilities, analytical thinking, and deep conceptual understanding needed for innovative and practical engineering solutions.

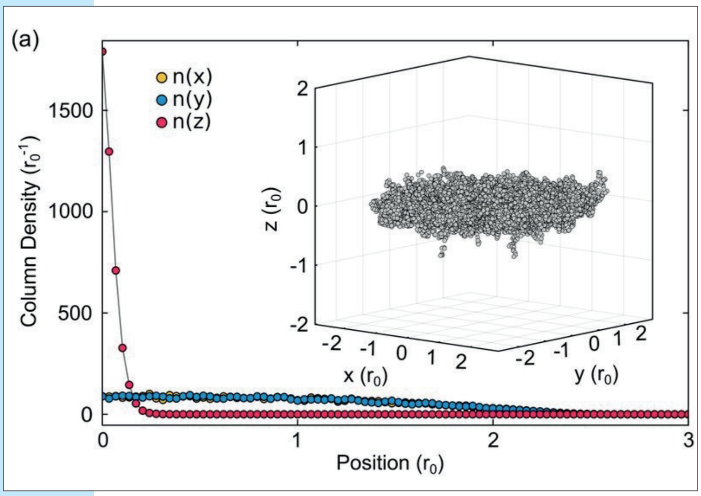
To enhance physics instruction, Physics Education Research (PER) has become a vital area of scholarly study. PER explores how students learn physics, how instructors teach it, and how educational environments and tools can be improved. PhyTracer, led by principal investigators Claudia Grossi and Muriel Botey, aims to use first-year physics education as a catalyst for pedagogical transformation across the university. It also seeks to establish a new research line in PER within the same Physics department. Specifically, the PhD project led by Marina Ristol, supervised by Claudia Grossi and David Pino, will focus on 'Identifying and Addressing Physics Misconceptions in Final-Year High School and First-Year Engineering Students'. □

First theoretical study of Bose-Einstein condensate of a system of polar molecules

> In June 2024, the first experimental observation of a Bose-Einstein condensate in a system of polar sodium-cesium molecules was reported in Nature, achieved by the team of Prof. Sebastian Will from Columbia University in the United States. Although Bose condensation of atoms at ultracold temperatures is routinely carried out in several laboratories worldwide, the equivalent process with molecules has been elusive, as these tend to react chemically when cooled.

Members of the Barcelona Quantum Monte Carlo group, together with a team formed by several European universities, have recently published the first theoretical study of these types of condensates. This has been achieved using Path Integral Monte Carlo simulation methods, which are capable of accurately sampling the exact wave function of the ground state of the many-body system. Starting from a potential that contains both the dipolar interaction terms and an anisotropic core produced by the screening potential created by the interaction with the microwave field, it has been possible to obtain an accurate description of the most relevant static properties of the system, showing that it has a natural tendency to form particularly dense droplets compared to what is found in similar situations with atomic species.

An example of a drop of polar molecules in the strong interaction regime is shown in the image. The high lack of symmetry is due to the anisotropy of the interaction the red and blue curves represent the densities integrated in the XY plane and the XZ plane, respectively.The work concludes by establishing the phase diagram, where the critical number of molecules required to form these droplets is determined, based on the characteristic parameter that measures the relationship between the characteristic dipolar distance and the diffusion length of the total interaction. □

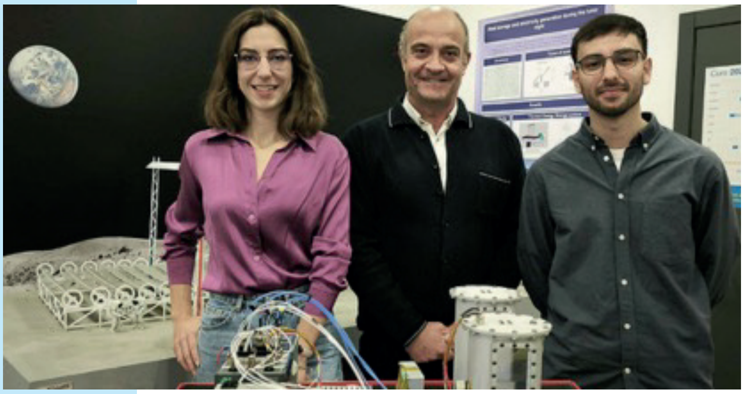


Reference:
Langen, T., Boronat, J., Sánchez-Baena, J., Bombín, R., Karman, T., and Mazzanti, F., "Dipolar Droplets of Strongly Interacting Molecules", Phys. Rev. Lett. 134, 053001 (2025).

Pioneering experiment for fuel management in space

> Professor Ricard González-Cinca, head of the Space Exploration Laboratory, linked to the group BIOCOM-SC at the Physics department, is participating in a pioneering experiment for the management of cryogenic fuels in space. The research is being carried out within the framework of the CRYSALIS project, a consortium formed by the Universitat Politècnica de Catalunya–Barcelona Tech (UPC), the companies Absolut System and The Exploration Company, and the Centre Spatial de Liège.

The objective of the project is to develop a system capable of transferring and storing cryogenic propellant in the long term in microgravity conditions. Cryogenic propellants are a type of propellant that are stored and used at extremely low temperatures. They are fuels and oxidizers such as liquid hydrogen and liquid oxygen, which offer very high performance and efficiency for rocket engines, and which still pose challenges in terms of their handling and storage in space.



The CRYSALIS project addresses this challenge by developing technologies that will be tested, over a six-month period, with a small-scale orbital demonstration, planned for 2027. This experimental system will allow the validation of propellant storage and transfer systems in a real space environment, opening the door to new exploration opportunities, including inorbit transport, long-duration missions and in-orbit storage.

The contribution of the UPC Space Exploration Laboratory to the project focuses on the development of an experimental acoustic propellant management system, which includes techniques for boiling control and fuel measurement. In this laboratory, subsys-tems are designed to test the implemented techniques and tests are carried out to validate the experimental system. ☐

Pilot project to measure radon concentration in different catalan schools

> Professors Claudia Grossi and David Pino from the Physics department of the Polytechnic University of Catalonia (UPC) are participating in a pilot project on air quality and radon exposure in different schools in Catalonia.

RASCLET
RADON AWARENESS IN SCHOOLS
COMMUNITY LEARNING
EXPOSURE TESTING

The project of citizen science, air quality and health RASCLET (Radon Awareness in Schools Community Learning Exposure Testing) has been promoted by David Pino, professor of the Department of Physics of the Polytechnic University of Catalonia (UPC), and Claudia Grossi, lecturer in the same department, in collaboration with Roser Sala, researcher at CIEMAT, expert in environmental risk perception, and pediatricians from the Pediatric Environmental Health Network of Catalonia coordinated by Dr. Ferran Campillo (Hospital d'Olot).

The RASCLET project, funded with an ALECTOR23 grant from the UPC, aims to carry out, thanks to the collaboration between academia, educational centers and health leaders, measurements of radon concentration in different schools in Catalonia that are located in areas classified as at risk on the map of the Nuclear Safety Council.

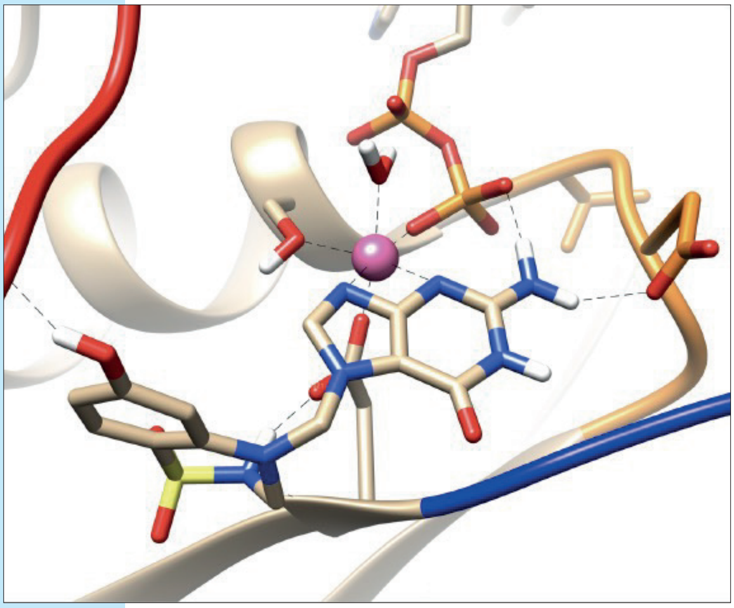
For 3 months, measurements of the average concentration of radon will be carried out in different schools in Catalonia and both the levels of knowledge of the students before and after the experience will be evaluated, as well as the possible changes in the perception of the risk of radon and its effect on the implementation of protective behaviors.

The results of the average concentrations found in the different schools in Catalonia will be analyzed together with meteorological data from the Meteorological Service of Catalonia and radon exhalation maps. The initial duration of the project will be 7 months with possible continuity. ☐

Thesis 1

Simulation of oncogenic proteins by Molecular Dynamics and in silico drug design

> Zheyao Hu, a student with a scholarship from the China Scholarship Council, defended her doctoral thesis entitled "In silico design of inhibitors of RAS oncogenic proteins and strategies for blocking of tumor growth" and directed by Dr. Jordi Martí Rabassa on January 14, 2025, at the UPC North Campus. The thesis presents a detailed study of the behavior of oncogenes from the RAS family, which is related to a third of all cancers, and proposes a new methodology for the computer design of drugs capable of blocking the activation of oncogenes. As an example, two prototype drugs are proposed, one of them potentially suitable for treating patients with pancreatic cancer and another for patients with melanoma.



This Doctoral Thesis is dedicated to the study of the structural properties of RAS oncogenes, which have a fundamental influence on 30% of human tumors, mainly pancreatic, lung, colon, and skin cancers. RAS proteins are a family of important molecular regulators that play a key role in a wide variety of cellular functions such as proliferation, differentiation, adhesion or apoptosis. KRAS-G12D mutations are one of the most frequent oncogenic drivers in human cancers. However, no therapeutic agent directly targeting KRAS-G12D has yet been approved for clinical use. Authors have discovered that the cofactor Mg2+ plays a crucial role in the conformational changes of the KRAS-GDP complex. Authors have identified two novel pharmacological dynamic pockets unique to KRAS-G12D and designed in silico the inhibitor DBD15-21-22, which can target the KRAS-G12D-GDP-Mg2+ ternary complex specifically and closely, providing a suitable strategy for its inhibition. □

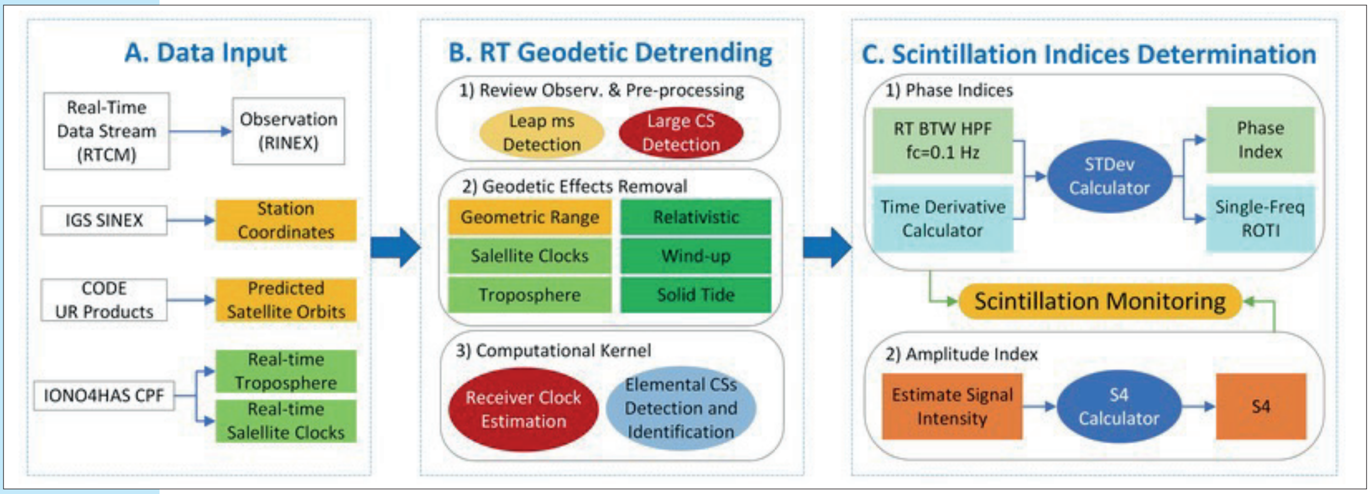
Thesis 2

Innovative Contribution to Real-Time Ionospheric Scintillation Monitoring Using GNSS Observations

> Candidate Yu Yin defended his thesis co-directed by Guillermo González and Angela Aragon-Angel on March 3 at Campus Nord. Titled "Innovative Contributions to Ionospheric Scintillation Monitoring using GNSS Observations," this thesis presents solid research that significantly advances scintillation monitoring with accurate, economical, and wide-coverage solutions, improving GNSS performance in complex ionospheric conditions.

Ionospheric scintillation adversely impacts Global Navigation Satellite System (GNSS) receivers by inducing signal amplitude fading and rapid carrier phase variations, degrading positioning accuracy in regions with high ionospheric activity. Monitoring scintillation is essential for ensuring the reliability of GNSS applications, particularly in precise positioning.

This research addresses key challenges in scintillation monitoring, utilizing Geodetic Detrending (GD) as the primary methodology, and advances scintillation monitoring by offering a solution that is accurate, cost-effective, and capable of providing extensive coverage. □



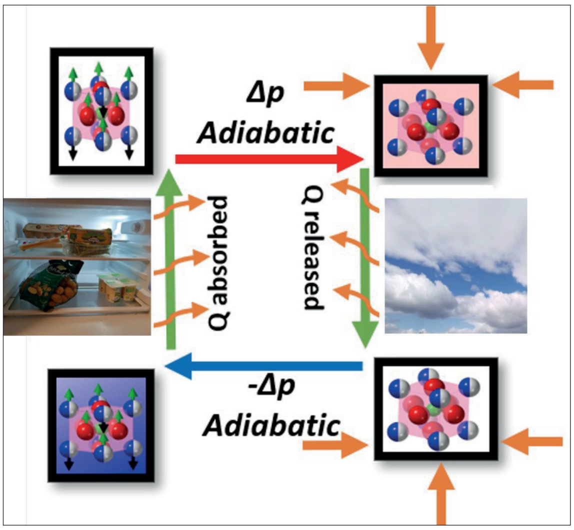
Thesis 3

Study of barocaloric and multicaloric effects under hydrostatic pressure and electric field in disordered materials and ferroelectric compounds

> Ming Zeng defended his thesis, co-directed by Pol Lloveras and Josep Lluís Tamarit, on December 4, 2024, at the Besòs Campus. Entitled "Barocaloric and multicaloric effects under hydrostatic pressure and electric field", the thesis presents the caloric effects in first-order phase transitions in solids of different types. These effects are of interest for efficient and sustainable refrigeration applications.

At present, HFC refrigerants with a global warming potential of thousands of times that of CO2, are widely used in air conditioners and refrigerators. Due to a lack of maintenance, poor management, and low or moderate efficiencies, cooling devices contribute to approximately 8% of total greenhouse gas emissions. Given the increasing global warming, it is urgent to find new cooling technologies with low carbon emissions.

Cooling methods based on solid-state caloric effects (adiabatic temperature changes ΔT and isothermal entropy changes ΔS) driven by external fields have been proposed as an environmentally friendly alternative to today's gas compression equipment. This thesis focus on caloric effects



driven by hydrostatic pressure (barocaloric, BC) and/or electric field (electrocaloric, EC) near first-order phase transitions and has demonstrated the feasibility, novelty, and impact of multicaloric effects under p and E, thus opening up a new area of caloric effects that should provide new physical insights on the wide family of ferroelectrics. ❑

Thesis 4

Study on social patterns and information transmission in schools of fish

> Andreu Puy defended his thesis, supervised by Romualdo Pastor-Satorras, on January 21, 2024, at Campus Nord. Entitled "Dynamic social patterns and information transfer in schooling fish", the thesis focuses on empirically investigating and using theoretical models of the collective movement in schools of fish, analyzing social interactions, information transmission, risk perception effects, and criticality signatures

Moving animal groups, such as flocks of birds, schools of fish, insect swarms, herds of mammals,

and human crowds, exhibit intricate and highly coordinated behaviors. This thesis examines the underlying mechanisms of collective behavior by analyzing extensive, high-resolution experimental data on the trajectories of schooling fish in a controlled environment. The image of the left, taken by Marc Alonso and selected as the cover of PNAS magazine, shows a school of fish of the black neon tetra species used in the experimental analyses of the thesis.

Authors first introduce the existence of temporal leadership dynamics based on relative speeds, a hypothesis we support through both agent-based modeling and analysis of leader-follower relationships in the experimental data. Next, they examine how variations in perceived risk influence the behavior and interactions of fish within a group. They also investigate spontaneous behavioral cascades in schooling fish, focusing on turning avalanches, where large directional shifts are propagated through the group. Finally, they explore and extend the nearest-neighbor declustering technique for analyzing aftershock correlations in point processes.

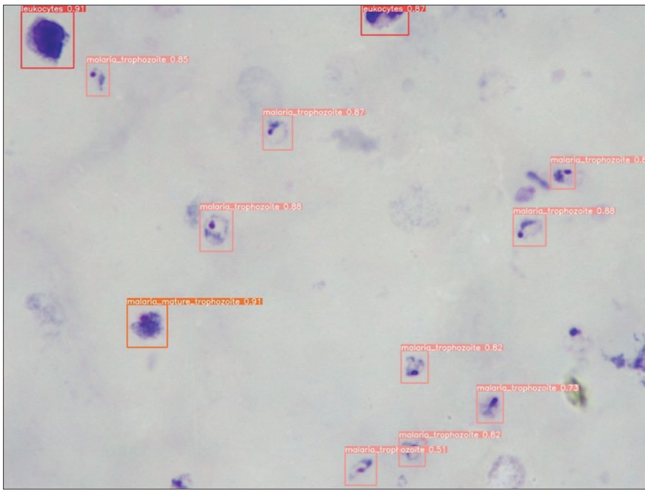
Overall, this thesis offers novel insights into the mechanisms that drive collective behavior in animal groups, highlighting the role of selective social interactions and critical dynamics. The empirical data-driven approach of the thesis highlights the complexity of animal collectives and lays a foundation for future studies on collective decision-making, leadership, and information transfer in biological systems. ❑

Thesis 5

Development of an automated diagnostic system for malaria and urogenital schistosomiasis using artificial intelligence tools and a low-cost universal robotic microscope

> Carles Rubio Maturana defended his doctoral thesis on June 3, titled “Diagnosis of Malaria and Urogenital Schistosomiasis Using Artificial Intelligence Tools and a Low-Cost Robotic Microscope,” in the Doctoral Program in Microbiology at the Autonomous University of Barcelona, under the direction of Doctors Joan Joseph Munné and Elisa Sayrol Clols. The thesis is part of a project funded by the World Health Organization and directed by professor Daniel Lopez-Codina from BIOCOM-SC research group in the Department of Physics at the UPC.

Malaria is one of the most prevalent infectious diseases in sub-Saharan Africa, with 263 million cases reported worldwide in 2023 according to the World Health Organization (WHO). Microscopy remains the gold standard technique for the diagnosis of both diseases. However, it is a professional-dependent method. As an alternative, new diagnostic techniques based on image analysis with Artificial Intelligence (AI) tools are being developed. The diagnostic algorithms were integrated into a smartphone application and laboratory software designed for use on a computer.



A proof of concept has been carried out at the Nossa Senhora da Paz Hospital (Cubal, Angola) for the diagnosis of malaria, demonstrating satisfactory results for the implementation of the system in laboratories with few resources. □

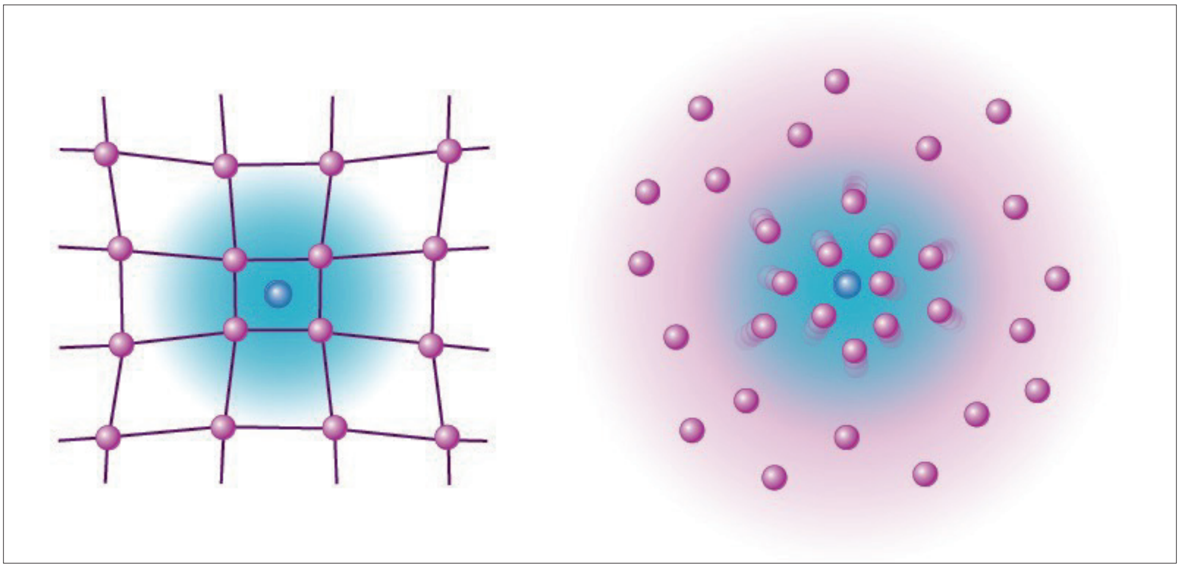
Thesis 6

Study of the behavior of impurities in Bose and Fermi systems

> Gerard Pascual López defended his thesis, supervised by Jordi Boronat Medico, on April 24, 2025, at the Campus Nord. Titled “Quantum Monte Carlo studies of impurities in Bose gases at finite temperature and in the Fermi-Hubbard model”, the thesis focuses on investigating the behavior of impurities in environments governed by many-body quantum phenomena.

An electron moving through a crystal interacts with the atoms of the lattice, creating a quasiparticle called a polaron, composed of the electron surrounded by phonons. The properties of the polaron, such as its effective mass and mobility, can differ significantly from those of the free electron, affecting the electrical and thermal properties of the material. This phenomenon, which has been known for a long time, has recently been linked to the behavior of impurities in ultracold gases.

Authors explore the behavior of impurities embedded in Bose and Fermi systems, providing insights into the interplay between impurity dynamics and many-body quantum effects and deepening our understanding of impurity physics in quantum systems, shedding light on thermal effects, miscibility, and quasiparticle properties in diverse scenarios. □



The Breeding Blanket. A key step in Fusion Nuclear Energy

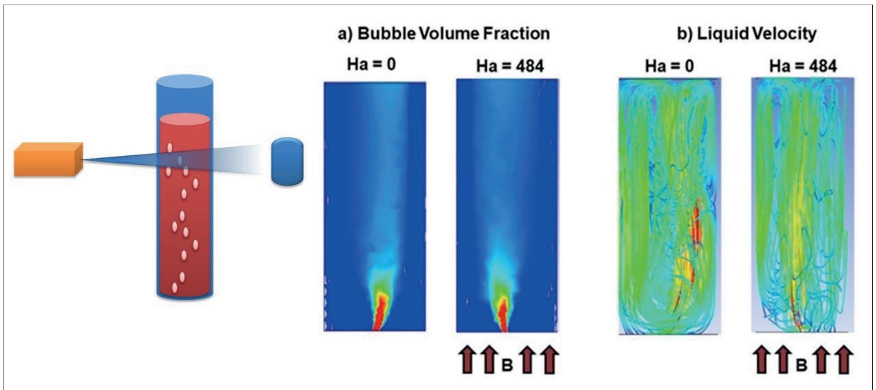
Lluís Batet Miracle is Engineer (1992) and Doctor-Engineer (2004) from the Universitat Politècnica de Catalunya (UPC). His current research is in fusion nuclear technology. He has served as Director of the Master's Degree in Nuclear Engineering since its inception. He is the rector's delegate for the KIC InnoEnergy, and a member of the Supervisory Board of InnoEnergy. He became full professor in 2024.

> In the quest for a carbon-free, sustainable source of energy, the European Union, together with other international players, is devoting significant R&D efforts to one of the critical components of a fusion nuclear reactor: the Breeding Blanket (BB). It envelops the plasma, providing three essential functions: shielding the superconducting magnets that confine the plasma, recovering heat so that the thermal power released in fusion reactions can eventually be converted into electricity, and breeding tritium.

Indeed, current fusion reactor designs rely on the deuterium (D) and tritium (T) reaction to release a large amount of energy (D + T → helium-4 + n + 17.6 MeV). Deuterium can be easily extracted from natural bodies of water, but tritium must be produced artificially. For fusion energy to be sustainable, tritium must be generated within the reactor in slightly higher quantities than the rate at which it is consumed in the plasma. Tritium breeding is achieved using the neutrons released in the DT reaction; these neutral particles escape the plasma and enter the surrounding breeding blanket. Several breeding blanket designs are under consideration worldwide, all relying on lithium to produce the desired hydrogen-3 isotope. Most designs use a lead-lithium eutectic (LLE) with approximately 17 at% lithium, which remains liquid at temperatures relevant for heat recovery and conversion. Lead also enables neutron multiplication.

This is the context in which my team's research (within the Advanced Nuclear Technologies Research Group) is situated. First, in the magnetic field required to confine the plasma, the flow of the liquid metal (LLE) is subject to Magneto-Hydrodynamic (MHD) effects; velocity profiles and pressure losses differ significantly from those in purely hydrodynamic flows. We simulate the MHD flow of liquid metals using the open-source Computational Fluid Dynamics tool OpenFOAM, with MHD models developed by our team - beginning with the PhD Thesis of Elisabet Mas de les Valls.

Second, bred tritium must be collected, processed, and reused as quickly as possible to minimize the tritium inventory within the fusion reactor systems. A high inventory would require large initial quantities of this scarce and expensive isotope and would increase the difficulty of keeping tritium leakage to the environment below regulatory limits. Our team has developed models to simulate, using OpenFOAM, the migration of tritium in the liquid metal and structural materials of the blanket. We are also developing capabilities to simulate tritium transport across other plant systems. In this regard, we are interested in predicting system performance and tritium inventories while accounting for the limited accuracy of measuring instruments and the challenge of distinguishing tritium from deuterium and protium in measurements. To this end, an industrial PhD thesis was conducted in collaboration with Inprocess Technology & Consulting Group S.L., focusing on the application of Machine Learning to predict system states.



Experiments and simulation with magneto-hydrodynamics models.

Third, helium will be produced in the breeding blanket along with tritium. Helium has extremely low solubility in liquid metals. Given the long residence times of LLE in the breeding blanket (a consequence of MHD pressure losses making low flow velocities preferable) and the relatively large amounts of helium produced (due to the need for tritium self-sufficiency), it is possible that helium nucleate in form of bubbles. This could create several design problems (from disturbing the MHD flow, to impairing heat transfer, to interfering with tritium migration). Because the scarcity of experimental data, the phenomena associated with helium nucleation are being studied by two PhD candidates (one of them in the Condensed, Complex and Quantum Matter Group) using Molecular Dynamics simulations. Their work has provided new insights into helium solubility in LLE and the supersaturation conditions under which nucleation may occur.

A final thought. Although research on fusion is key for the future, we must keep an eye on Fission Nuclear Energy. There are open questions, such as optimizing the management of spent fuel during transfer from the pool to the Individual Spent Fuel Storage Installation, or assessing the role of nuclear power plants in electricity price setting by modeling the electricity grid and market, where I hope to contribute with my research now and in the future. ☐