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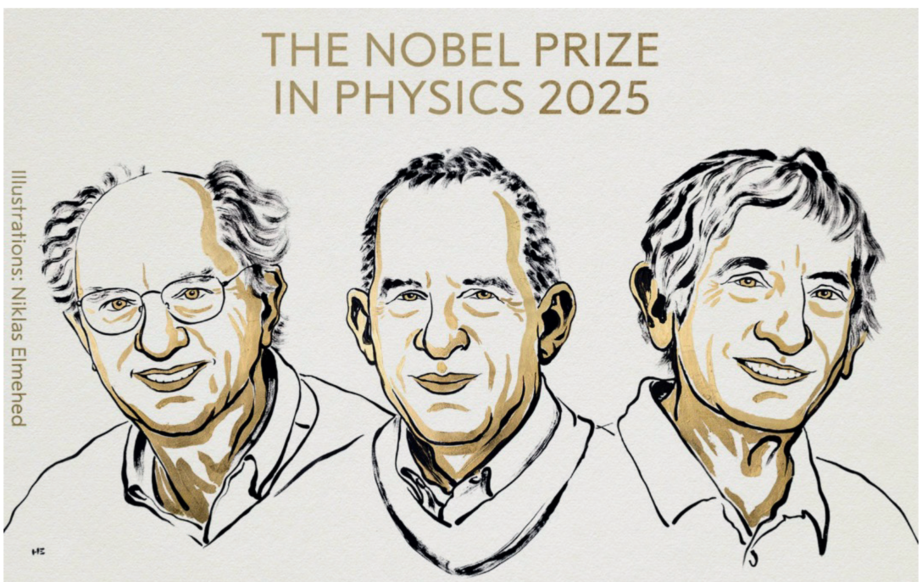
The Nobel prize of physics 2025 awarded to quantum technologies

Javier Argüello

> The Nobel prize of Physics 2025 celebrates "*the discovery of macroscopic quantum mechanical tunneling and energy quantisation in an electric circuit*". This achievement took place back in the 80s, in the experimental group of John Clarke. Based at the University of California Berkeley, he was investigating superconducting circuits together with his PhD student, John M. Martinis, and postdoc, Michel H. Devoret. Their extraordinary observation of tunneling at the macroscopic scale paved the way to the current development of quantum computation. But…, which is the macroscopic quantity measured in this exotic system, and how is quantum tunneling involved in this story?

Let us start from the beginning. In a Josephson junction, two superconducting materials are separated by an insulating barrier. The theorist Brian Josephson predicted in 1962 that a supercurrent would flow through the insulator, provided there is a macroscopic phase difference, δ, between the two superconducting leads, as it was later experimentally confirmed (and awarded with the Nobel prize of Physics, 1973).



John Clarke, Michel H. Devoret and John M. Martinis. [Nobel Foundation]

From a physical point of view, the evolution of this macroscopic phase can be described by a tilted potential of the form $\cos\delta - \delta \cdot I/I_0$. For an input current I, greater than the threshold parameter I_0, we observe in Fig. 2 (a) that no local minima are present. Consequently, the phase difference would increase over time, resulting in a voltage that can be measured in the device. In the opposite regime of small input currents ($I<I_0$), a potential barrier now emerges [Fig. 2 (b)], and no voltage would classically appear at zero temperature for the resulting stationary state. However, we should not forget that we are dealing with a quantum system! Following quantum mechanics, this confined state can still tunnel away from the trap, inducing a voltage bias that can only be explained from the quantum tunneling of the macroscopic phase δ.

In 1978, Anthony Leggett (also a Nobel laureate, 2003) suggested that these superconducting currents could be ideal to observe macroscopic tunneling. Given that resistivity is suppressed, superconducting currents are very weakly coupled to dissipative degrees of freedom that may conspire with the observation. Different groups thus focused on meas-

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uring the voltage of the circuit in the classically forbidden regime, $I<I_0$. As the temperature was reduced, the thermal escape also decreased, up to a crossover temperature where the classically forbidden escape is however present and independent of temperature [see Fig. 2(c)]. One important question still remained: was this observed escape a consequence of quantum tunneling, or just some excess noise that could not be suppressed?
This is precisely the challenge that the three laureates addressed in their seminal experiment. Using carefully crafted microwave filters and weakly coupled control lines, they could measure the escape rate in the regime of macroscopic tunneling, finding an exquisite agreement with the theoretically predicted crossover temperature.

Javier Argüello is a physicist and mathematician with a PhD in Photonics. He is currently an Assistant Professor in the Physics Department at UPC, where he works on quantum technologies at the Barcelona Quantum Monte Carlo group.

Beyond its fundamental implications, the ability to measure quantum tunneling in a macroscopic regime has had an enormous impact in current quantum technologies. For example, Josephson junctions are nowadays the key component of quantum bits used in superconducting quantum computers. Using that approach, the long-ago PhD student, John M. Martinis, recently pushed the limits of the technology, announcing in 2019 that quantum supremacy had been achieved in a 53-qubit quantum processor they had developed at Google Quantum AI Lab. The effort continues, and experiments now focus on scaling up the number of qubits while gaining quantum error correction, in parallel with other platforms, such as atomic and photonic systems.

Going beyond its role in quantum computation, superconducting circuits have also impacted the field of quantum optics, which traditionally studies how atoms interact with electromagnetic fields. Interestingly, energy states of Josephson junctions can play the role of artificial atoms, whose parameters can be highly engineered to reach regimes of strong coupling beyond what is accessible in real atomic systems.

Overall, the Nobel Prize of Physics 2025 celebrates a successful chapter of modern physics, where theoretical predictions and enormous experimental efforts have resulted into a new technology that brings the quantum world closer to our macroscopic realism, thus offering exciting opportunities for the development of quantum technologies and the advance of fundamental science. □

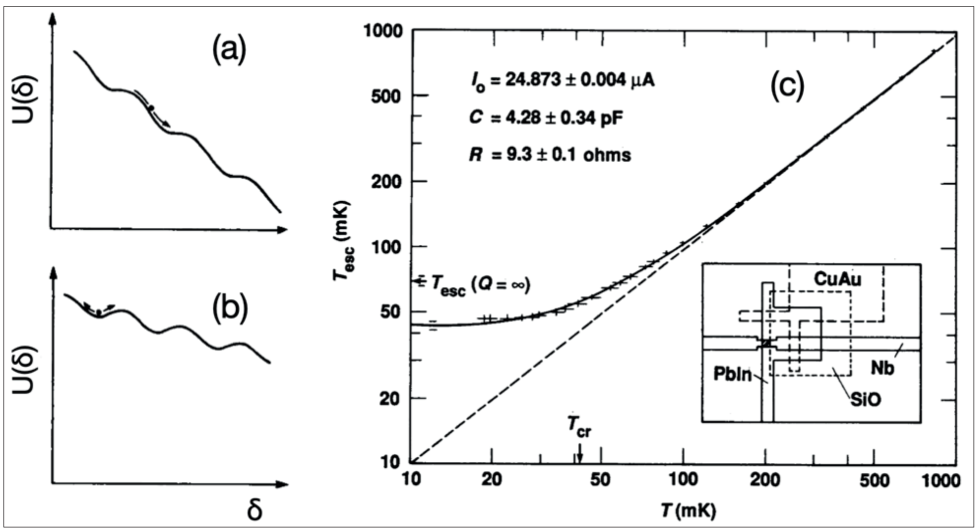
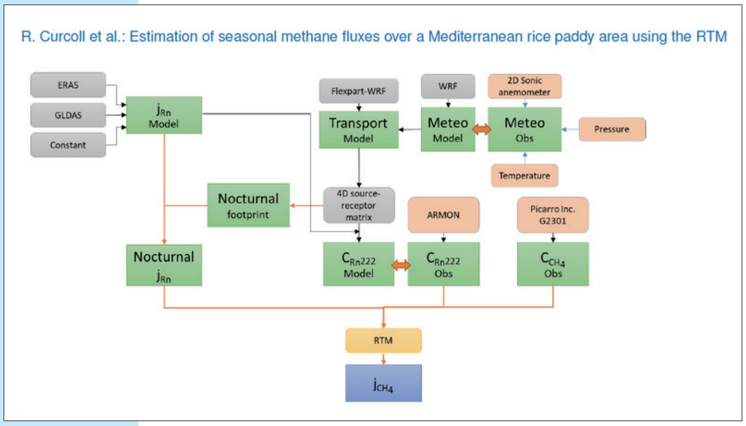


Fig. 2. (a) For $I>I_0$, a running state appears ($V\neq 0$). (b) In the opposite regime, $I<I_0$, a stationary state is classically expected at zero temperature. (c) The saturation of the escape at low temperatures indicates that transport is however present, in exquisite agreement with tunneling quantum theory (continuous line). [Science, 239(4843) (1988); PRL, 55(18) (1985)].

Estimation of seasonal methane fluxes over a Mediterranean rice paddy area

> Researchers of IONHE group have recently published results on the: 'Estimation of seasonal methane fluxes over a Mediterranean rice paddy area using the Radon Tracer Method (RTM)' within the Atmospheric Chemistry and Physics journal.

The Ebro River Delta, in the northwestern Mediterranean basin, has an extension of 320 km^2 and is mainly covered by rice fields. In the framework of the ClimaDat project, the greenhouse gases atmospheric station DEC was designed and installed in this area in 2013. The DEC station was equipped to measure both CH_4 and CO_2 and ^{222}Rn concentrations. The variability of methane fluxes over this area and during the distinct phases of the rice production cycle was evaluated in this study using the Radon Tracer Method (RTM). The RTM was carried out using nocturnal hourly atmospheric measurements of CH_4 and ^{222}Rn between 2013 and 2019 and FLEXPART-WRF back trajectories coupled with radon flux maps for Europe with a resolution of 0.05° times 0.05° available thanks to the project traceRadon. The fluxes were compared with fluxes directly measured with static accumulation chambers by other researchers in the same area. Results show strong agreement between both methodologies, having both a similar annual cycle and similar monthly mean absolute values. ☐



Reference:

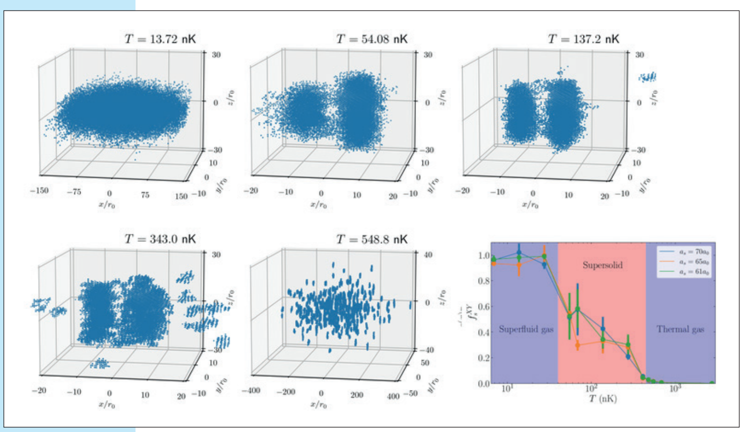
Curcoll, R., Àgueda, A., Morguí, J. A., Cañas, L., Borràs, S., Vargas, A., & Grossi, C. (2025). Estimation of seasonal methane fluxes over a Mediterranean rice paddy area using the Radon Tracer Method (RTM). *Atmospheric Chemistry and Physics*, 25(12), 6299-6323.

Creation and destruction of a quantum dipolar supersolid by heating

> A study by researchers Juan Sánchez-Baena, Ferran Mazzanti and Jordi Boronat, from the Polytechnic University of Catalonia, together with researcher Raúl Bombín, from the University of Bordeaux, shows for the first time the creation and destruction of a quantum supersolid by heating a dipolar system, initially in a superfluid phase without spatial order. The work illustrates the connection between the counterintuitive appearance of a solid by heating, exclusive to the quantum realm, and the expected phenomenology of fusion when the temperature is raised.

A superfluid is a liquid or gaseous state in which particles can flow without friction. To visualize it, we can imagine that we rotate a bucket full of helium at a temperature below 4 Kelvin. If the rotation speed is low enough, the helium will remain at rest, even though the surface of the container it is in contact with is moving. A supersolid is an exotic state of matter that goes one step further: it mixes this strange property of superfluidity with spatial periodicity, reminiscent of a classical crystalline solid. In these supersolids, the atoms accumulate mostly at certain positions in space, while a halo of remaining atoms surrounds these majority concentrations.

The study represents a further step in understanding the relatively unexplored territory of finite-temperature dipolar systems. The conclusions also leave the door open to further unknowns to be investigated, such as the characterization of the dipolar system in the thermodynamic limit, or the relationship between the emergence of the supersolid upon heating and the formation of ultra-dilute dipolar liquid droplets. ☐



Reference:

Langen, T., Boronat, J., Sánchez-Baena, J., Bombín, R., Karman, T., & Mazzanti, F. (2025). Dipolar droplets of strongly interacting molecules. *Physical Review Letters*, 134(5), 053001.

4MOST telescope begins observing 77,000 stars

> The 4MOST telescope, at the European Southern Observatory in Chile, has obtained first light. An international scientific team, led by Alberto Rebassa, a researcher at the UPC and member of the Institute of Space Studies of Catalonia (IEEC), and Odette Toloza, a researcher at the Federico Santa María Technical University (USM) in Chile, will observe and analyze the spectra of 77,000 binary stars.

The 4MOST telescope is the largest multi-object spectroscopic study facility in the southern hemisphere, unique for its combination of large field of view, number of simultaneously observed objects and number of simultaneously recorded spectral colors. 4MOST can disentangle the light from 2,400 celestial objects simultaneously into 18,000 color components. In its first five years of operation, 4MOST will carry out 25 international scientific programs, among which the project led by Alberto Rebassa on binary stars was selected.

Currently, only a few thousand spectra of binary stars are available. The study of these systems allows us to decipher scientific unknowns such as the relationship between the age and metallicity of our galaxy, the evolution of compact binary stars or the physical and magnetic properties of stars of the same type as the Sun. □

Publication of the popular science book: Quantum Simulators: Building Models of the Microscopic World

> Professor Javier Argüello Luengo of the UPC Physics Department, along with Professor Alejandro González Tudela, a researcher at the CSIC's Institute of Fundamental Physics, are publishing this book, which is the result of the RSEF-BBVA Foundation award for the best popular science article on the same topic.

The quantum revolution is one of the most radical technological transformations of the century. It is a field that explores fascinating problems with very real consequences, such as protecting our communications, improving the precision of physical measurements, or understanding why some materials conduct electricity without offering any resistance.

We will discover messages encrypted thanks to quantum physics, models that solve space accidents, and laboratories where work is done at the lowest temperatures in the universe, in a fascinating story that delves into one of the least-known branches of quantum physics. □

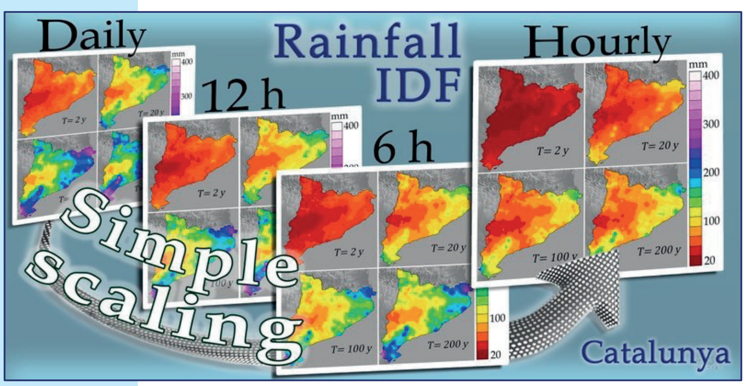
For more information:
https://www.catarata.org/libro/simuladores-cuanticos_165608

Characterization of the rainfall intensity, duration and frequency for Catalonia

> A study led by researchers from the Fluid Dynamics and Geophysical and Technological Applications group (DF-GeoTech) at UPC presents a new methodology to calculate rainfall values of hydrological interest across Catalonia.

Researchers María del Carmen Casas Castillo and Raül Rodríguez Solà, from the DF-GeoTech research group at UPC, have published an article in the journal Climate, titled: "Scaling Properties of Rainfall as a Basis for Intensity–Duration–Frequency Relationships and Their Spatial Distribution in Catalunya, NE Spain". The study details the methodology developed by the group to obtain IDF (Intensity–Duration–Frequency) rainfall values, which are essential for hydrological applications and local-scale territorial planning.

The results of this research were used by the Meteorological Service of Catalonia (SMC), which published the corresponding raster data layers on its website (IDF Maps). These data have also been included in the Hypermap of the Generalitat de Catalunya, as part of the publicly accessible climate information. □



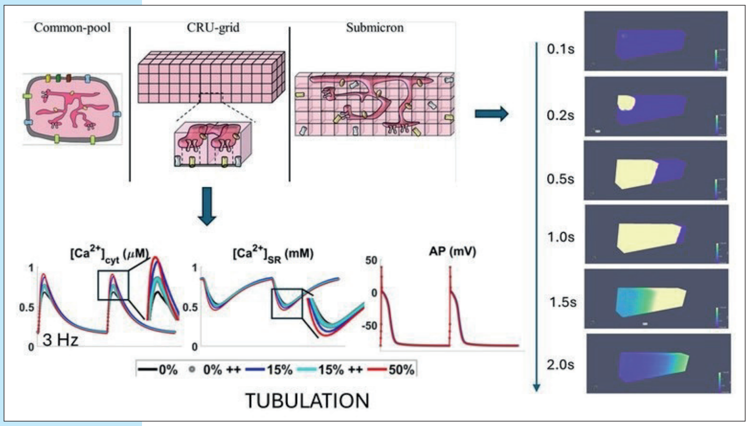
Reference:
Casas-Castillo, M. D. C., Llabrés-Brustenga, A., Rodríguez-Solà, R., Rius, A., & Redaño, À. (2025). Scaling properties of rainfall as a basis for intensity–duration–frequency relationships and their spatial distribution in Catalunya, NE Spain. *Climate*, 13(2), 37.

Thesis 1

Development of a new modelling platform to study Calcium subcellular behavior in cardiomyocytes

> David Conesa defended his thesis "Empirical and Structural Mathematical Models for Biological Systems: Case Studies in COVID-19 and Cardiac Dynamics" in the EPSEB in Campus Sud on the 18th of December. Under the supervision of Dr. Enric Alvarez Lacalle, the thesis develops different mathematical models to study two branches of biology: epidemiology, and cardiac dynamics.

Error minimization fit of Gompertz-like models were used to forecast, 2 weeks in advance, increases in COVID-19 incidence using country-level reported data from the WHO during the epidemics.



The thesis also presents a study of the correlation between COVID-19 incidence in Spain, province by province, and mobility data from two sources: the Spanish Ministry of Transport and Mobility and Facebook Data for Good. The thesis shows that mobility is either directly causal or highly directly correlated with other measures that affected COVID-19 propagation.

Turning to cardiac dynamics, this thesis has focused on the development of computational models to study calcium dynamics in cardiomyocytes, as a basis for a future platform to link subcellular behavior to whole-organ cardiac diseases. During the process, the thesis develops a novel methodology to build a population-of-models approach. Last but not least, we develop another model at the submicron scale to analyze how subcellular calcium waves originate, propagate, die out, and reappear. ❑

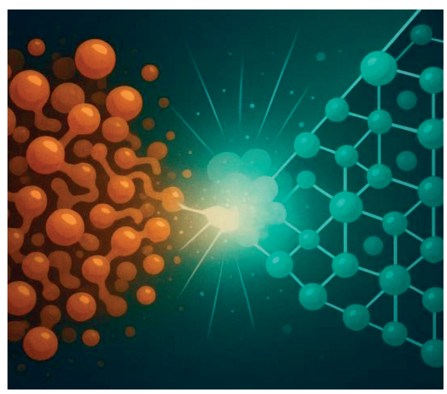
Thesis 2

New catalysts based on non-crystalline metals

> In a joint project between the research groups GCM (Department of Physics) and NEMEN (Department of Chemical Engineering), PhD student Maahin Mirzay Shahim, from South Azerbaijan, Iran, has developed new catalytic materials by combining glassy alloys and cerium oxide in her PhD defended on December 16 and directed by Eloi Pineda and Lluis Soler.

This thesis explores the catalytic potential of metallic glasses (MGs) and their combination with cerium oxide (CeO_2) for low-temperature carbon monoxide (CO) oxidation and CO preferential oxidation ($COPrO_x$) reactions. Metallic glasses, due to their non-crystalline structure and tunable composition, offer a promising platform for catalytic applications when appropriately engineered.

These findings of this thesis offer new strategies for creating highly active materials for pollution control and hydrogen purification technologies, opening the path to use amorphous metals for heterogeneous catalysis. ❑

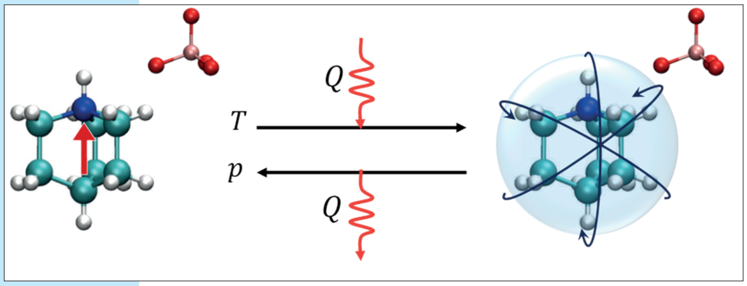


Thesis 3

Barocal effects in organic and ferroelectric plastic crystals

> Alejandro Salvatori defended his thesis co-directed by Michela Romanini and Pol Lloveras, on July 1, 2025 at the Besòs Campus. Entitled "Barocal effects in organic and ferroelectric plastic crystals", the thesis investigates the caloric effects induced by hydrostatic pressure through first-order phase transitions in molecular crystals that present orientational disordered phases, called plastic crystals. These effects promise more efficient and sustainable refrigeration technologies than current gas compressors, and also thermal batteries. The materials studied are of two types: organic plastic crystals, which present giant latent heats, and ferroelectric plastic crystals, novel compounds that present multiaxial ferroelectricity, orientable with an electric field.

The characterization of their thermodynamic properties and barocaloric response allowed to assess their suitability for applications in both industrial and domestic cooling and heating. This work is the first report of barocaloric effects in this material family. Despite the effects are smaller than



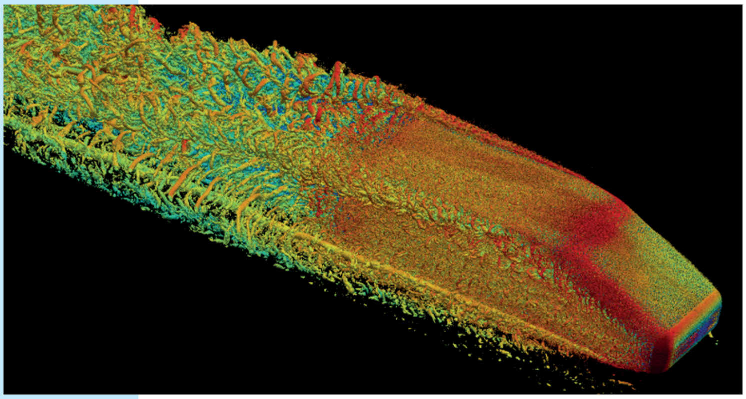
those by organic plastic crystals, This study opens the door to possible multicaloric effects under pressure and electric field. For these two particular materials, however, large electric fields appear to be necessary to achieve significant electrocaloric effects. ☐

Thesis 4

Artificial intelligence and supercomputing at the service of aerodynamics: from vehicle optimization to urban hazard mitigation

> Benet Eiximeno Franch defended his thesis co-directed by Oriol Lehmkuhl Barba and Ivette Maria Rodríguez Pérez on October 31, 2025 at Campus Nord. The thesis is titled "High performance computing and artificial intelligence for dimensionality reduction of turbulent flows" and investigates how large-scale artificial intelligence can help compress aerodynamic simulation data to better understand chaotic turbulence phenomena.

This thesis presents a set of methodologies for dimensionality reduction of turbulent flow data, with a focus on high-fidelity simulations of external aerodynamics in industrial contexts, such as the flow around simplified automobiles. These simulations, typically performed on unstructured meshes with hundreds of millions of degrees of freedom, require scalable tools for analysis and modeling. All developments have been implemented in pyLOM, an open source Python library designed to reduce dimensionality of data on the order of magnitude of terabytes.

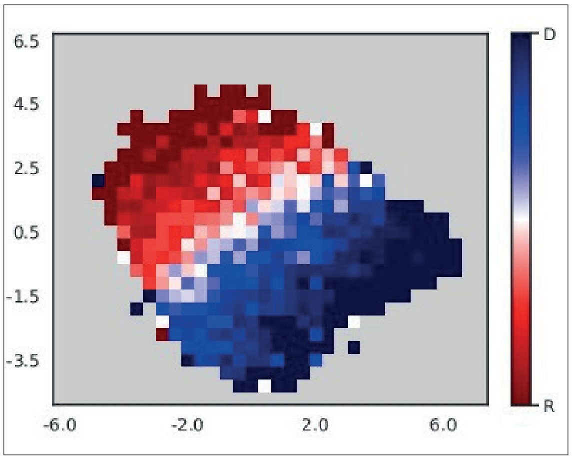


The work progressed in four main stages. First, classical reduction techniques, based on singular value decomposition (SVD), have been adapted to high-performance computing by taking advantage of parallel QR factorization. This allowed these algorithms to be applied to multi-terabyte datasets, such as the direct numerical simulation of flow in the Stanford diffuser. Secondly, a variational autoencoder (VAE) based on convolutional neural networks (CNN) was developed for nonlinear dimensionality reduction. This strategy is able to successfully capture the temporal dynamics of the Windsor car rear pressure with only two latent variables. Both methodologies were combined to create a new method called Geometry-Agnostic Variational-autoencoder Integration (GAVI). GAVI provides compact latent spaces without the need for structured meshes, achieving high energy recovery in several test cases. Finally, a transformer-based strategy is proposed to compensate for the energy loss in the reduced models. ☐

Thesis 5

The Effect of Social Interactions on Collective Behavior: Flocking and Opinion Polarization

> Jaume Ojer Ferrer defended his thesis co-supervised by Romualdo Pastor Satorras and Michele Starnini on July 30 at Campus Nord. Entitled "The Effect of Social Interactions on Collective Behavior: From Flocking to Opinion Polarization", the thesis explores how social interactions between individuals give rise to different types of collective behavior that are observed in nature and society, in particular the dynamics of flocking in animals and the polarization of opinions in humans.

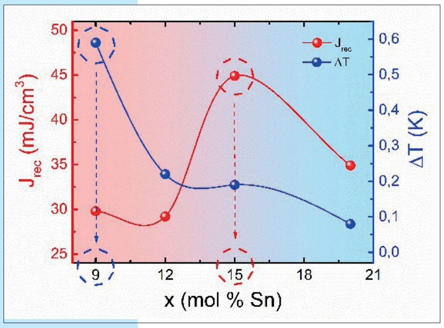


In the context of animal behavior, we use social networks to represent the interactions within the flock. We extend the definition of Vicsek-like models to explore the effects that structural properties of social networks have on flocking stability. Next, in the context of human behavior, we address the dynamics of opinion formation and polarization using a multidimensional perspective. To this aim, we use empirical opinions with respect to many different topics collected by the American National Election Studies. By mapping the opinions within a twodimensional ideological space, we provide a nuanced analysis of how ideological polarization evolves over time in the United States. The findings contradict the partisan sorting hypothesis, which suggests that parties have become more consistent and ideologically more homogeneous in last decades. ☐

Thesis 6

Eco-friendly ferroelectric oxides for energy applications

> Ramon G. F. Dornelas defended his thesis, co-advised by Jose Eduardo García and José de los Santos Guerra, on July 18th on the Campus Nord. Entitled "Lead-free $BaTiO_3$-based ferroelectric ceramics for energy storage and related applications", the thesis focuses on the structural, dielectric, and ferroelectric study of tin-modified $BaTiO_3$ ceramics, aimed at their application in energy storage and solid-state cooling.

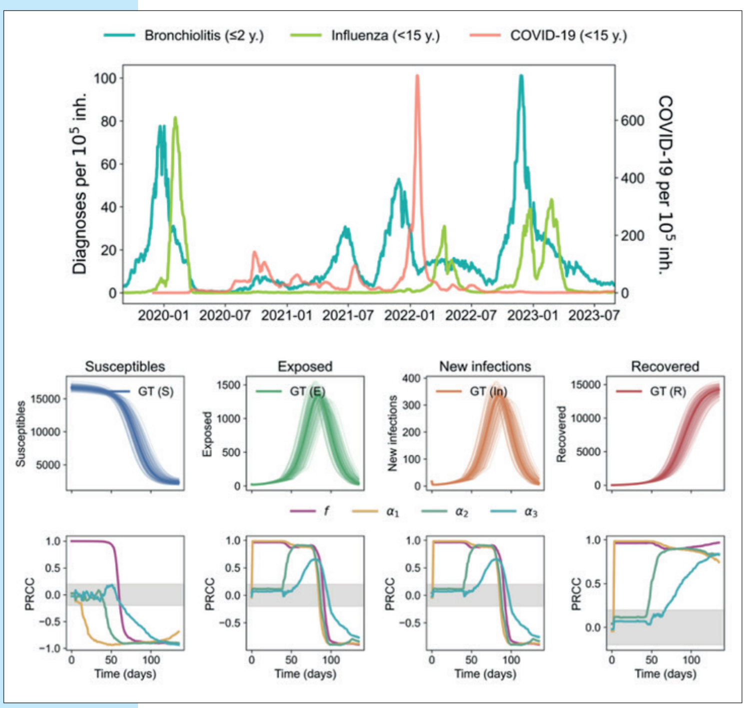


The growing global demand for sustainable technologies has driven the development of new functional materials capable of addressing current energy and environmental challenges. This thesis presents a detailed experimental study of the $BaTi_{1-x}Sn_xO_3$ system for compositions with different values of x, synthesized using the conventional solid-state reaction method. The structural, dielectric, and ferroelectric properties of the materials were investigated with the aim of evaluating their potential for applications in energy storage and solid-state cooling. The phase transitions, electrocaloric response, and energy storage performance were analyzed, identifying the optimal compositions with high recoverable energy density and remarkable electrocaloric strength. ☐

Thesis 7

Respiratory viruses in Catalan childhood: lessons, status and predictions after the pandemic

> Aida Perramon Malavez defended her thesis co-directed by Clara Prats Soler and Antoni Soriano Arandes on July 16, 2025 at the Baix Llobregat Campus. Titled "Respiratory viruses in childhood: surveillance, analysis, and modelling of their epidemiological dynamics. The case of Catalonia", the thesis presents the history and evolution of the main respiratory infections in Catalan childhood, from a perspective of dynamic analysis of complex systems and providing tools for monitoring, understanding and predicting these epidemics in Catalonia.



This doctoral thesis has focused on the characterization and study of the dynamics of SARS-CoV-2, the influenza virus (flu) and the respiratory syncytial virus (RSV) in children in Catalonia during the last decade. Through a combination of empirical epidemiological analyses and dynamic modeling, we have explored how the COVID-19 pandemic has altered the seasonality and interaction patterns of respiratory viruses, modifying their epidemiological behavior and impact on public health. We have described the epidemiological changes before, during and after the pandemic.

The models have been used to predict their pre- and post-pandemic epidemic peaks (when possible) almost a month in advance, with a maximum margin of error of one week and a magnitude that falls within the 95% confidence interval of the models, although human supervision and intervention improve their performance. To better understand the factors that modulate influenza transmission, we have developed a compartmental SEIR model, using a two-step transmissibility function that has been related to meteorological factors. This model has revealed a significant association between temperature and influenza transmissibility, with a lag of two weeks.

The practical effectiveness of preventive strategies against RSV has also been evaluated, particularly the monoclonal antibody nirsevimab, which has demonstrated high effectiveness in reducing hospitalizations and admissions to the pediatric intensive care unit (PICU), by more than 80%. ☐

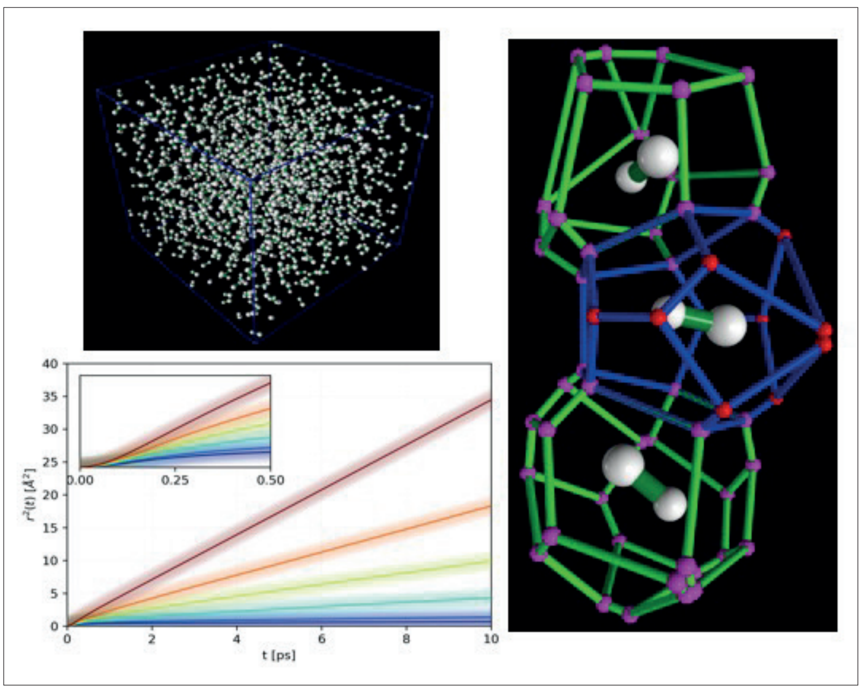
Learning how liquids become glasses

Gemma Sesé obtained her PhD in Physics from the UB in 1990. She completed a one-year postdoctoral appointment at The Royal Institution in London. In 1991, she secured a permanent academic position at UPC. She was promoted to full professor in 2023 and currently serves as Vice Dean at FIB.

> When a liquid is cooled below its freezing point, it may form a disordered, structurally arrested phase, a glass, provided crystallization is avoided –for example, by rapidly cooling the system. The glass transition is not a standard phase transition because it does not involve discontinuities in properties such as specific heat or volume. In addition, the glass transition temperature depends, within limits, on the cooling rate. At temperatures just above this transition, the system is referred to as a supercooled liquid. Characterizing the properties of supercooled liquids is essential for understanding how the glassy state forms. The general purpose of our work is to elucidate the microscopic mechanisms that operate in supercooled molecular liquids, such as low-weight alcohols and water, as they approach the glass transition. Insights into their behavior are not only of fundamental interest but they also are expected to provide guidance for the design and analysis of molecules that exhibit complex hydrogen-bond aggregations.

Within the existing theoretical framework, the glass transition can be interpreted either as a configurational singularity –associated with a reduction in the number of accessible states– or as a purely kinetically driven phenomenon. Consequently, our study addresses supercooled liquids from both thermodynamic and dynamic perspectives. Thus, we developed a model to evaluate thermodynamic properties, including absolute entropy, free energy and heat capacity, using data generated from computer simulations, which are the primary tool in our investigation.

A notable feature of supercooled liquids is that the dramatic slowing of their dynamics occurs in the absence of an obvious structural cause. Bulk structural pair-correlation functions show little changes as the system approaches the glass transition temperature. In contrast, long time relaxation evolves from exponential to stretched exponential behavior, and the corresponding relaxation times increase by several orders of magnitude. Although these changes occur apparently without pronounced structural signatures, our results demonstrate that the dynamics of a supercooled diatomic molecular liquid is spatially heterogeneous. Clusters of molecules with different mobilities emerge, and each dynamic subset is characterized by its own distinct geometry. Still, many questions concerning dynamic heterogeneities remain to be answered.



We recently analyzed the local structure of a diatomic molecular model using Voronoi tessellation in order to determine whether local structural ordering contributes to the dynamical slowdown as the glass transition is approached. The technique partitions the total volume into non-overlapping regions, or polyhedra, with well-defined boundaries, enabling a detailed geometric characterization of local environments. Our results show that the diversity of polyhedra decreases markedly in the supercooled state, and that icosahedral ordering becomes significant. However, the long-time translational dynamics exhibit no strong correlation with either the volume or the shape of the corresponding Voronoi regions.

Simulation provides a powerful means to address fundamental questions concerning the role of molecular interactions, such as hydrogen bonding. It enables not only realistic representations of material behavior but also controlled theoretical studies. It will undoubtedly aid in understanding the complex phenomena observed in the supercooled state, notably the decoupling between translational and rotational dynamics, or the molecular mechanisms governing the interplay between mobile and immobile regions. □