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Quantum Simulators: the Models of the Microscopic World

What do Antoni Gaudi and quantum physicists like Daniel Barredo, Ignacio Cirac, or Leticia Tarruell have in common? Javier Argüell Luengo, co-author together with Alejandro Gonzalez Tudela of *Quantum Simulators: Building Models of the Microscopic World*, draws a surprising parallel between the Catalan architect and researchers working on quantum simulation.

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Anyone who has visited the Sagrada Familia will remember the intricate models Gaudi used to design his masterpiece. With strings and small weights, he let gravity sketch inverted shapes that mirrored the stunning structures he envisioned.

When Javier visited Gaudi's unfinished basilica, he was still working on his PhD in quantum simulation (supervised by Professor Darrick Chang at ICFO and Alejandro Gonzalez Tudela at CSIC). Standing among the vast columns glowing with the evening light filtered through stained glass, he had a revelation that stayed with him from then on: he and Gaudi weren't so different. It struck me that Gaudi used a mechanical system (strings and weights) to simulate a much more complex problem that couldn't be solved directly at the time, Javier recalls. In quantum simulation, we actually do something very similar. Indeed, quantum simulation involves using a well-understood quantum system (the equivalent of strings and weights) to better grasp other, more complex quantum systems, which are typically more difficult to access, such as the behavior of electrons in certain materials or in condensed matter (the quantum counterpart of the Sagrada F

Outreach as Reward and Responsibility

Back then, I didn't know how to explain my PhD research in a way that non-specialists could follow, Javier shares. Quantum simulation was, and still is, a highly specialized niche within the already stigmatized field of quantum physics -a discipline that, over the years, has accumulated an aura of mystery and complexity, often distancing it from everyday citizens. Gaudi's models gave him a way in, becoming a bridge between his work and a general audience. Soon, he was participating in ICFO's outreach programs, giving talks and workshops for school groups, always with Gaudi's models as props. It was a resource that never failed, he notes. Watching students engage and become motivated

With his explanations was immensely rewarding in the short term, something you don't always get in basic science research. Still, Javier believes outreach shouldn't just be a side hobby for scientists, but should rather be a responsibility. Most of us work with public funding, taxes that citizens pay out of their own pockets, he stresses. People have the right to know where their money is going. For him, trust in science -and the institutional support it requires to weather political shifts- can only come from a deep understanding of science. You can't make what you don't comprehend, he emphasizes.

From Gaudi's Analogy to a Popular Science Book

Balancing outreach with his own research, Javier gradually built experience in both. Then came an opportunity: he and Alejandro were invited to write an article on quantum simulation for the Spanish Journal of Physics. Naturally, Gaudi's models made their way into the text. The article was very well received, Javier recalls. In fact, people liked it so much that the editors suggested they expand it into a full book about quantum simulation for general readers.

Translating the frontiers of quantum science into plain language is no easy feat, especially when equations, the native tongue of physics, are left out. That choice, however, was deliberate. For many people, math is more intimidating than helpful, Javier explains. But this, in turn, posed a significant challenge. Abandoning mathematics forced us to heavily lean on metaphors and imagery that, while useful for building intuition, are never going to be completely accurate. In this way, the authors managed to make a concept as seemingly distant as quantum physics far more accessible. The book begins with familiar examples from classical physics. Alongside Gaudi's hanging models, the authors also discuss wind tunnels used to test airplanes and Formula 1 cars in a controlled environment before they are deployed in the real world. Step by step, they then introduce elements of quantum physics, guiding readers and equipping them at each stage with the tools needed to understand the key concepts of quantum simulation. By the end of the book, readers have learned, among other things, what optical tweezers and optical lattices are, how these tools are used to trap atoms moving at incredibly high speeds, and how this process can be harnessed for quantum simulation. But Javier and Alejandro go beyond explaining concepts: they also highlight the people behind science. We wanted to take the opportunity to show what the day-to-day life of scientists is really like, he authors say. To do so, each chapter features a short narrative sketch of a real researcher, reminding readers that science is done by people with everyday worries, concerns, and joys, not abstract and distant figures. We must not forget that all these world-class scientists were once PhD students with their entire future ahead of them, he says.

Leticia Tarruell, Pioneer in Quantum Simulation

One of the figures that appear in the book is Professor at ICFO Leticia Tarruell, head of the [Ultracold Quantum Gases](#) group since 2013. **Leticia has been a pioneer in atomic control**

for quantum simulation, says Javier. Mentioning her was the most natural thing to do. She was, in fact, the first to set up a cold-atom laboratory in Spain. This milestone was then followed by groundbreaking studies on exotic states of matter such as quantum droplets and supersolids.

More recently, she created the world's first strontium quantum gas microscope, capable of photographing individual atoms of this gas. Javier is particularly excited about such an achievement: For a theorist like me, it's thrilling to imagine what kind of experiments could be carried out with this new technology, which opens the door to radically new types of simulations.

Javier and Alejandro also felt it was important to emphasize that cutting-edge research is being carried out in their own country. In physics (and especially in quantum physics) we tend to see the same role models from 50 years ago, all belonging to a very specific demographic, they remark. **We wanted to show that Spanish scientists, too, are conducting frontier research.**

Thus, alongside Tarruell, the book also features Daniel Barredo (now at Spain's Center for Research in Nanomaterials and Nanotechnology) and Ignacio Cirac (director of the Theory Division at the Max Planck Institute of Quantum Optics in Germany). Cirac, for instance, trained at Spanish universities before laying the groundwork for quantum computation and simulation, Alejandro notes, assuring that he has since become a global leader in the field.

The Future of Quantum Simulation: A Blank Page

With more than eight years of experience in the field, Javier describes quantum simulation as a young discipline, but full of promise. The first experiments took place in 2002, and in just two decades we've witnessed astonishing progress, he says. Quantum gas microscopes, for instance, were unthinkable twenty years ago.

According to Javier, the field holds vast potential, with many avenues still to explore. Several laboratories have already simulated exotic materials such as graphene. Other problems, like simulating real molecules or the laws governing the most fundamental particles in the universe (such as protons and neutrons), remain theoretical proposals under development. The advances, however, have been so remarkable that, as the book notes: In the near future, quantum simulators may not only help us discover new superconductors and materials, but also help us unveil the true workings of the universe's most intimate fabric. On this path, Javier points out, ICFO is exceptionally well positioned, both at the national and international levels. He stresses that its strength lies in having world-class groups in both theory and

xperiment. As we've seen, Tarruell's team leads the experimental front. On the theoretical side, the [Quantum Optics Theory](#) group led by Prof. Maciej Lewenstein focuses on developing theories that can, on the one hand, guide experimental design, and on the other, interpret the results obtained. Reflecting on the institution's future, Javier concludes: Having both approaches working together is truly beautiful. In my opinion, the quality of ICFO's research places the institution on par with the world's leading centers.

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Illustration of Leticia Tarruell at her laboratory. Credit: Javier Argüello Luengo.