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 o i¿½Quantum Simulators: Building Models of the Microsco ic Worldi¿½, draws a surprising parallel between the Ca alan 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. i¿½It struck me that Gaudi used a mechanical system (strings and weights)

o simulate a much more complex problem that couldn't be solved directly at the time,i¿½ Ja
ier recalls. i¿½In quantum simulation, we actually do something very simil
r.i¿½ Indeed, quantum simulation involves using a well-understood quantum sys
em (the equivalent of strings and weights) to better grasp other, more complex quantum
ystems, 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

i¿½Back then, I didn't know how to explain my PhD research in a way that non-specialis
s could follow,i¿½ Javier shares. Quantum simulation was, and still is, a highly specialized n
che 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 citiz
ns. Gaudi's models gave him a way in, becoming a bridge between his work and a gen
ral audience. Soon, he was participating in ICFO's outreach programs, giving talks
and workshops for school groups, always with Gaudi's models as props. i¿½It was a resourc
that never failed,i¿½ he notes. Watching students engage and become motivated
ith his explanations was i¿½immensely rewarding in the short term, something you don't
lways get in basic science re
earch.i¿½ Still, Javier believes outreach shouldn't just be a side hobby for scientists, but s
ould rather be a responsibility. i¿½Most of us work with public funding, taxes that citizens pa
out of their own pockets,i¿½ he stresses. i¿½People have the right to know where their
oney is going.i¿½ For him, trust in science -and the institutional support it requires to weath
r political shifts- can only come from a deep understanding of science. As he puts it, i¿½**You can't value what you don't comprehend,**i¿½ he emphasize

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.
i¿½The article was very well received,i¿½ Javier recalls. In fact, people liked it so much
hat the editors suggested they expand it into a full book about quantum simulation for gen
ral read
rs. Translating the frontiers of quantum science into plain language is no easy feat, especi
lly when equations, the native tongue of physics, are left out. That choice, however,
was deliberate. i¿½For many people, math is more intimidating than helpful,i¿½ Javier e
plains. But this, in turn, posed a significant challenge. i¿½Abandoning mathematics fo
ced us to heavily lean on metaphors and imagery that, while useful for building intuition,
are never going to be completely accurate.i¿½ In this way, the authors managed to make
concept as seemingly distant as quantum physics far more

accessible. The book begins with familiar examples from classical physics. Alongside Gau
i'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 ste
, they then introduce elements of quantum physics, guiding readers and equipping them a
each stage with the tools needed to understand the key concepts of quantum simulation. B
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 highligh
the people behind science. i¿½We wanted to take the opportunity to show what the day-
o-day life of scientists is really like,i¿½
he authors say. To do so, each chapter features a short narrative sketch of a real resea
cher, reminding readers that science is done by people with everyday worries, concern
, and joys, not abstract and distant figures. i¿½We must not forget that all these world-cla
s scientists were once PhD students with their entire future ahead of them,i¿?

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. i¿½**Leticia has been a pioneer in atomic control for quantum simulation,**i¿½ says Javier. i¿½Mentioning her was the most natural thin
to do.i¿½ She was, in fact, the first to set up a cold-atom laboratory in Spain. This milesto
e was then followed by groundbreaking studies on exotic states of matter such as q
antum droplets and supers
lids. More recently, she created the world's first strontium quantum gas microscope, capa
le of photographing individual atoms of this gas. Javier is particularly excited about s
ch an achievement: i¿½For a theorist like me, it's thrilling to imagine what kind of exp
riments could be carried out with this new technology, which opens the door to radically n
w types of simula
ors.i¿½ Javier and Alejandro also felt it was important to emphasize that cutting-edge r
search is being carried out in their own country. i¿½In physics (and especially in quantum
physics) we tend to see the same role models from 50 years ago, all belonging to a v
ry specific demographic,i¿½ they remark. i¿½We wanted to show that **Spanish scientists, too, are conducting frontier research**.i¿
? Thus, alongside Tarruell, the book also features Daniel Barredo (now at Spain's Center f
r Research in Nanomaterials and Nanotechnology) and Ignacio Cirac (director of the Theo
y Division at the Max Planck Institute of Quantum Optics in Germany). i¿½Cirac, for insta
ce, trained at Spanish universities before laying the groundwork for quantum computation
and simulation,i¿½ Alejandro notes, assuring that i¿½he has since become a global leade
in the f

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. i¿½The first experiments took place in 2002, and n just two decades we've witnessed astonishing progress,i¿½ he says. i¿½Quant m gas microscopes, for instance, were unthinkable twenty years a o.i¿½ 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 proble s, like simulating real molecules or the laws governing the most fundamental particle in the universe (such as protons and neutrons), remain theoretical proposals under deve opment. The advances, however, have been so remarkable that, as the book notes: i¿½I the near future, quantum simulators may not only help us discover new supercond ctors and materials, but also help us unveil the true workings of the universe's most intimate abric.i¿½ On this path, Javier points out, ICFO is exceptionally well positioned, both at the ational and international levels. He stresses that i¿½its strength lies in having world-class roups in both theory and xperiment.i¿½ 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: i¿½Having both approach s working together is truly beautiful. In my opinion, the quality of ICFO's research places t e institution on par with the world's leading centers.i¿½

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