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Carmen Rubio-Verdu: "In fundamental physics, we remove any perturbation to reveal what lies underneath, to access the unknown"

Carmen Rubio-Verdu, Group Leader at ICFO since 2023, has now received an ERC Starting Grant, one of the most prestigious European grants for early-career researchers. Over the next five years, this funding will allow her and her team to explore fundamental questions at the frontier of quantum materials science, such as: Why do two-dimensional materials exhibit such unusual behaviors?

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Carmen Rubio-Verdu discovered her passion for two-dimensional (2D) materials during her PhD at nanoGUNE (San Sebastian, Spain); a passion that continued to grow alongside her expertise through her postdoctoral fellowships at Columbia University (USA) and Freie Universitat Berlin (Germany). There, she explored the correlated electronic phases that emerge in twisted 2D materials, a cutting-edge area of condensed matter physics.
In 2023, Carmen launched her own research group at ICFO and, since then, the whole team has been delving even more into Carmen's longstanding interests in fundamental science.
Now, just over two years after becoming a Principal Investigator, she has been awarded a European Research Council (ERC) Starting Grant -one of Europe's most competitive and respected funding opportunities for exceptional early-career researchers. The grant supports a five-year project in fundamental science, giving awardees the freedom to pursue high-risk, high-reward research of their choice.
Carmen is seizing this opportunity to investigate one of today's hottest topics in frontier science. A topic that involves atomically thin materials, exotic quantum phases such as unconventional superconductivity, and state-of-the-art equipment to probe the fundamental properties of matter.
In this interview, Carmen walks us through the path she took in fundamental condensed matter physics and how she ultimately achieved this grant.

Can you summarize the idea of the project that the ERC Starting Grant will support?

The idea is to understand why this new family of materials called moire materials behave the way they do. Moire materials are atomically thin crystals (that is, 2D materials) stacked on top of each other with a slight rotation between them. The atoms of these layers then create a so-called moire pattern, which deeply modifies the properties of the electrons moving through the material, giving rise to exotic phases of matter like unconventional superconductivity.

The most prominent example is magic-angle twisted bilayer graphene. When you take two layers of graphene, which are each just one atom thick, and place them on top of each other with a twist angle of 1.1 degrees, the whole system becomes superconducting. However, the two individual layers are not superconducting on their own. Similarly, if you choose a different twist angle, even if it is just slightly different, the resulting system is not superconducting either. With this project, we want to understand why this happens, what is the physical mechanism behind.

Why are you interested in 2D materials and why did you choose this specific topic?

I'm interested in 2D materials because, for starters, these correlated phases that emerge, such as superconductivity and magnetism, were not even supposed to exist in two dimensions. But now we know they do, even if they often take forms that are not present in other three-dimensional materials. For me, this means that the field is full of interesting possibilities.

In fact, the field of twisted 2D materials is fairly new. The first experiments took place in 2018, so there are still many open questions, a lot of room for cutting-edge research. In just a few years, however, we have already seen that the physics in these materials is remarkably rich. It all revolves around the idea of collective behavior: you cannot understand what occurs in these materials by focusing only on the individual particles, but instead you must consider the whole ensemble of electrons. As a consequence, many interesting exotic phases emerge.

Regarding this specific project, I chose it precisely because many unknowns remain. To finally address them, I strongly believe we need to approach the problem from different perspectives. In my group, we will tackle these questions through independent yet complementary experiments, so that we can build a deep understanding of the quantum phases that emerge. **A major breakthrough would be to discover a new form of superconductivity that has never been seen before. That's what we aim for.**

How are you and your group planning to achieve so? What are the main steps you will follow?

First, we need to fabricate these twisted 2D materials and get them very clean and uniform. Then, we will use state-of-the-art equipment, in particular, a special microscope called a Scanning Tunneling Microscope. With this microscope, you can image the atoms and investigate the electronic properties at the local level at temperatures below 100 millikelvin. This capability is essential to investigate quantum phases, as they only arise under ultralow temperatures.

I assume it takes time to plan a large-scale project like this one. How and when did this scientific idea and methodology come to your mind?

It's been a long process. During my PhD, I already started working in two-dimensional materials, and when I was about to go for a postdoc, this whole field of twisted 2D materials exploded. So, I became very curious about it, and during my postdoc I investigated twisted graphene.

When I decided that I wanted to establish my own research group, I just went towards the open questions in the field. I asked myself: what are the biggest unknowns today? Throughout the last couple of years, I kind of built this project in my head. I am very excited that the ERC decided to fund it, so I can dive into it.

What does this ERC grant mean to you and to your group in terms of the research that you will be able to pursue?

The ERC is of great importance to both my group and myself. I don't think I would be able to undertake this project without such a prestigious grant. This is not only because of the substantial resources required, particularly the high cost of the instrument, but also because the ERC Starting Grant provides five years of sustained support. In five years, you do have the opportunity to carry out difficult experiments and to analyse the data in depth, so that you can build deep and robust conclusions about the underlying physics.

In a broader sense, the ERC is a great opportunity for my group to grow and to carry out cutting-edge research. This project really aligns with the research topics of my group, since we focus on the new phases that emerge in 2D materials, either in individual layers or twisted layers, or even more complex structures. In that sense, it is a perfect fit.

I'd like to end with a more personal question: when did you know that you wanted to study science, and why did you choose this specific field?

I've always been a very curious person, ever since I was a kid. Now, looking back, I think it all makes sense. When I went through high school, I realized that I liked science -I just found it interesting. But even today, I'm still wondering why nature behaves the way it does. My heart is now in physics, but ultimately it is about curiosity and trying to understand how the world works. Very often I think that, maybe, in another life, I will be an anthropologist.

In the end, though, I chose physics. After completing my degree, I delved into 2D materials because in fundamental physics you get to spend your time asking yourself why something behaves in a certain way. More specifically, **in my field**, we isolate the system as much as we can by placing the materials under ultra-high vacuum conditions and at very low temperatures. This way, **we remove any perturbation to reveal what lies underneath, to access the unknown**.

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Portrait of Carmen Rubio-Verdu. Credit: ICFO.