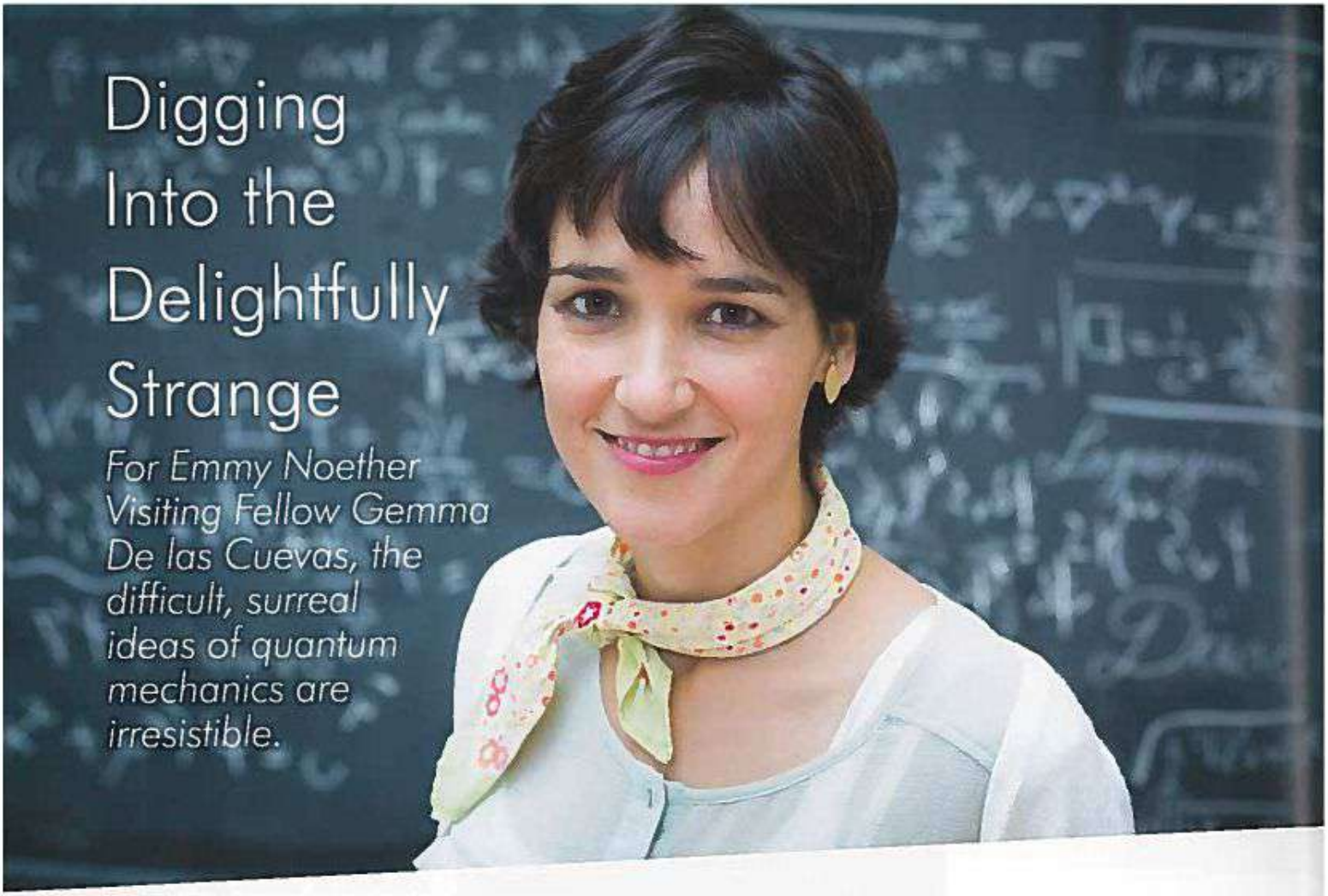
Digging Into the Delightfully Strange

For Emmy Noether Visiting Fellow Gemma De las Cuevas, the difficult, surreal ideas of quantum mechanics are irresistible.



Of all the subjects she could have studied, Gemma De las Cuevas was drawn to quantum physics because of its strange, surreal qualities.

"Everything that has to do with quantum physics is surprising and exciting because it is so different to anything we are used to," she says. "Never mind science fiction, it is quite enough to understand quantum mechanics."

De las Cuevas is an Elise Richter fellow, a senior postdoctoral researcher in quantum information at the Institute of Theoretical Physics at the University of Innsbruck, Austria. She is also one of seven Emmy Noether Visiting Fellows who are spending time at Perimeter in the 2016/17 academic year.

Noether was an influential 20th century German mathematician whose theorems underpin much of modern physics. Through a series of Emmy Noether Initiatives, including the visiting fellowships, Perimeter is seeking to help redress the long-standing imbalance of women in physics while encouraging breakthrough discoveries.

While more women are going into physics, De las Cuevas acknowledges that there are still challenges, including the lack of role models for young women. "It is not fun, for women or for men, to have such an unbalanced situation. So I think programs such as this are a good idea."

De las Cuevas has an eclectic and curious mind, and is prone to picking up books that range from *The History of Western Philosophy* by Bertrand Russell to *The Beginning of Infinity* by David Deutsch. She loved many subjects in school, but chose physics because it offered the greatest challenges.

With its blend of difficult and surreal ideas, quantum physics proved irresistible. "It has a mixture of both understanding the world physically, and also abstract thought," she says. "[It is] a starting point for understanding the world."

Her research focuses on tensor networks, which try to describe quantum many-body systems that involve a large number of interacting particles. Understanding these systems is important to many areas of physics, such as condensed matter and quantum information.

Tensor network theory can take the many-body wave functions of a strongly correlated system, like the electrons that move tightly together in a superconductor, encode them and break them down to a series of tensor operations. This can simplify our understanding of how quantum particles behave en masse, exhibiting new emergent properties that the individual particles don't have. (Buoyancy, for example, is an emergent property of water – single water molecules don't exhibit buoyancy, but many of them together do.)

"We may understand how a few quantum objects behave and how to describe them, but the description does not work well when you scale up and try to put together many quantum objects. So we need new ideas and we need to find an emergent description," De las Cuevas explains. Just as a brain can be described at the

level of neurons or in terms of psychology, so it is that in physics, "when we look at different scales, we require completely new descriptions," she adds.

Her research involves using tensor network theory to improve the understanding of mixed quantum states and continuum limits within certain classes of tensor networks. But recently, she has also been working on developments at the intersection between theoretical computer science and physics.

"I was attracted to the fact that it is a young field with close connections to experiments on the one hand, and to abstract concepts in mathematics and theoretical computer science on the other hand," De las Cuevas says.

In theoretical computer science there are "universal Turing machines," which are abstract models of computation that help investigate the limits of computation. These computational models are "universal," because with appropriate input, they can simulate the steps to compute anything that can be computed.

Earlier this year, De las Cuevas showed that something similar happens in physics. In a paper published in *Science*, "Simple Universal Models Capture all Classical Spin Physics," she and co-author Toby Cubitt showed that the physics of "classical spin models," which are simplified models of interactions between particles, is reproduced in the low-energy sector of certain universal models in physics.

Now, she is continuing to look at the similarities between these universal models for simulation in physics and universal Turing machines for computation. In theoretical computer science, there is the concept of an undecidable problem, a decision problem for which it is known to be impossible to construct a single algorithm that always leads to a correct yes-or-no answer. De las Cuevas is investigating the role of undecidability in physics.

Perimeter's Tensor Network Initiative and the diversity of its research areas were prime attractions for De las Cuevas. She recently completed a month-long visit in the fall, and plans to make several more research visits to the Institute during her year-long fellowship.

"I was really excited to be able to come here and to be able to talk to people in different fields and learn from them," she says. "I really am just working on a tiny corner of a very big theory, but I feel that I am part of a large community and team."

She says Perimeter is a "unique and special place" where she gets to meet interesting people who are thinking deeply about many questions. "For me, it is a like a place I had dreamt of, but didn't know it could exist."

– *Rose Simone*

Perimeter is challenging the under-representation of women in physics through its Emmy Noether Initiatives, backed by the Emmy Noether Circle of donors who champion women in science. To become a supporter, email jwatty@perimeterinstitute.ca

EMMY NOETHER FELLOWSHIP

Emmy Noether Visiting Fellows are invited to work at Perimeter for periods of three months to one year. They pursue research and collaborate within the Institute's scientific community while on leave from their home institutions.

Applications for the 2017/18 Fellowships close on **January 10, 2017**.

For more information, please visit **perimeterinstitute.ca/emmy-noether-visiting-fellowships**.

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