Rice physicist emerges as leader in quantum materials research

August 21 2014

Andriy Nevidomskyy CREDIT: Jeff Fitlow/Rice University

"Emergent" is a key concept in the work of Rice University theoretical physicist Andriy Nevidomskyy, and thanks to two prestigious new awards, it is also an apt description of his work.

Nevidomskyy, assistant professor of physics and astronomy, has won both a CAREER Award from the National Science Foundation (NSF) and a Cottrell Scholar Award from the Research Corporation for Science Advancement (RCSA).

Nevidomskyy will use the research funding from each award to apply state-of-the-art analytical and computational techniques to investigate the emergence of superconductivity in compounds known as "strange metals." Each grant also includes an educational component, and he will use those funds to help transform his quantum mechanics course for upper-level undergraduates and to help develop a planetarium show to teach school children and their parents about the interactions that form a fabric of the universe.

CAREER Awards support the research and educational development of young faculty whom the NSF expects to become leaders in their field. The five-year grants are worth about $450,000 and are among the NSF's most competitive. The agency grants only about 400 each year across all disciplines.

Cottrell Scholar Awards fund early career faculty in physical sciences and related fields who are committed to excellence in both research and undergraduate teaching at U.S. research universities. RCSA selects only about a dozen recipients each year who it believes "have the potential to change the way science is taught in the U.S." Researchers may only apply once for a Cottrell Scholar Award at the midpoint of their first tenure-track appointment.

"Each of these awards is highly competitive, and I am honored to have been selected," Nevidomskyy said.

He said the common goal of the research component of each award is to study emergent electronic properties in strange metals. "Emergence," in this context, refers to the way nontrivial complex systems and patterns arise out of many relatively simple constituents.

"An everyday example is the complex pattern of a flying flock of birds, seemingly behaving as one 'unit' despite comprising thousands of individual birds," he explained. "While this is a classical example, quantum physics adds an extra dimension, making quantum emergence even richer. For instance, understanding the electronic and vibrational properties of a single water molecule does not trivially imply the properties of liquid water or the emergent sixfold symmetry of snowflakes."

Physicists have studied the "strange" metallic state in a variety of materials for several decades. Because of strong interactions among electrons in these materials, electric current travels through them differently than it travels through regular metals like aluminum or copper. Solving the mystery of why the phenomenon arises is one of the foremost challenges in condensed matter physics, due in part to the fact that high-temperature superconductivity can also emerge out of the strange metallic state.

"One way of thinking about this is to envision a crowded stadium of soccer fans standing up in unison to create a traveling 'wave,'" he said. "If you were to observe any single person in the stadium, you would just see an individual standing and sitting back down. You would not see the wave, because it is an example of a collective behavior; you can only observe it by looking at the entire system."

When an electric current or thermal heat moves through an ordinary metal, the flowing electrons inside the metal can be modeled as moving independently and interacting only very weakly with one another. This is not the case with strange metals. When a current travels through a strange metal, the electrons lose their individuality and behave as a collective entity.

For the CAREER Award research, Nevidomskyy will focus on a fascinating class of strange metals called "heavy fermion" materials, in which the interactions between the constituent particles are so strong that they acquire a very heavy mass, sometimes several hundred times greater than that of a bare electron. As a result of this "heaviness," many properties of the material, including the electrical and thermal conductivity, are profoundly affected.

"Unfortunately, the very feature that makes these materials so interesting—the strong interactions between electrons—also makes them challenging to study," he said.

Nevidomskyy hopes to build a new theory to explain the electronic properties of the heavy fermions by combining existing methods of quantum chemistry with the state-of-the-art computational techniques. In particular, he aims to capture the interplay between magnetism and various interesting quantum mechanical properties, including superconductivity.

"People have tried to do this before, but a complete theory is very difficult to attain," Nevidomskyy said. "Experimentalists have compiled a great deal of empirical evidence about how heavy fermions work. We have an understanding of some of the specific phenomena associated with these materials, but we still lack a coherent theoretical understanding of why the phenomena come about and how they relate to the 'heaviness' that emerges in these materials."

For the educational component of the Cottrell grant, Nevidomskyy plans to incorporate active learning techniques in his upper-level quantum mechanics course, such as "flipped" classroom, cooperative learning and "just-in-time teaching." He said the idea is to help students better assimilate and retain information by posing thought-provoking questions that actively involve students in the learning process.

"A lot of research has been done for the lower-level undergraduate courses, the huge introductory courses like physics 101, where educators have thought at length about pedagogical techniques and how you administer quizzes," Nevidomskyy said. "But what about the third and fourth years? Courses for juniors and seniors are often much more technical, and less has been done to incorporate active learning in this context."

For the NSF CAREER award, he said he is planning to work with Rice physicist Pat Reiff and partners at the Houston Museum of Natural Sciences to develop a planetarium show tentatively titled "The Invisible Forces of Nature."

"The idea is to cover gravitational forces as well as electromagnetism, radio waves and nuclear forces—things that we can't see but that make the universe exist and be what it is," Nevidomskyy said. "It's a huge undertaking. I am not the one leading it, but I would be assisting with the content development, specifically in my area of expertise, which is electromagnetism."

Provided by Rice University

Citation: Rice physicist emerges as leader in quantum materials research (2014, August 21) retrieved 25 April 2024 from
https://phys.org/news/2014-08-rice-physicist-emerges-leader-quantum.html