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Quantum vortices confirm superfluidity in supersolid

Supersolids are a new form of quantum matter that has only recently been demonstrated. The state of matter can be produced artificially in ultracold, dipolar quantum gases. A team led by Innsbruck physicist Francesca Ferlaino has now demonstrated a missing hallmark of superfluidity, namely the existence of quantized vortices as system's response to rotation. They have observed tiny quantum vortices in the supersolid, which also behave differently than previously assumed.

Matter that behaves like both a solid and a superfluid at the same time seems impossible. Yet, more than 50 years ago, physicists predicted that quantum mechanics allows such a state, where a collection of indistinguishable particles can simultaneously exhibit seemingly contradictory properties. "It is a bit like Schrödinger's cat, which is both alive and dead, a supersolid is both rigid and liquid," explains Francesca Ferlaino from the Department of Experimental Physics at the University of Innsbruck and the Institute of Quantum Optics and Quantum Information (IQOQI) of the Austrian Academy of Sciences (ÖAW). While the crystalline arrangement giving rise to the „solid" nature of supersolids has been directly imaged, the superfluid properties are much more elusive. While researchers have probed various aspects of superfluid behavior, such as phase coherence and gapless Goldstone modes, direct evidence of one of superfluidity's defining features—quantized vortices—has remained elusive.
Now, in a major breakthrough, quantized vortices have finally been observed in a rotating two-dimensional supersolid, providing the long-awaited confirmation of irrotational superfluid flow into a supersolid and marking a critical step forward in the study of modulated quantum matter.

Challenging experiment

In this new study, scientists combined theoretical models with cutting-edge experiments to create and observe vortices in dipolar supersolids—a feat that proved extraordinarily challenging. The Innsbruck team had previously achieved a breakthrough in 2021 by creating the first long-lived two-dimensional supersolid in an ultracold gas of erbium atoms, which was a difficult task in itself. "The next step—developing a way to stir the supersolid without destroying its fragile state—required even greater precision" explains lead author Eva Casotti. Using high-precision techniques guided by theory, the researchers employed magnetic fields to carefully rotate the supersolid. Because liquids do not rotate rigidly, this stirring caused the formation of quantized vortices, which are the hydrodynamic fingerprint of superfluidity. "This work is a significant step forward in understanding the unique behavior of supersolids and their potential applications in the field of quantum matter," remarks Francesca Ferlaino.
Moreover, the experiment took nearly a year, revealing significant differences between the dynamics of vortices in supersolids and unmodulated quantum fluids, and offering fresh insight into how the superfluid and solid characteristics coexist and interact in these exotic quantum states.

Exploring new physics

The implications of this discovery reach far beyond the laboratory, potentially impacting fields ranging from condensed matter physics to astrophysics, where similar quantum phases may exist under extreme conditions. "Our findings open the door to studying the hydrodynamic properties of exotic quantum systems with multiple broken symmetries, such as quantum crystals and even neutron stars," said Thomas Bland, who guided the theoretical development of the project. "For instance, it is assumed that the change in rotational speed observed in neutron stars—so-called glitches—are caused by superfluid vortices trapped inside neutron stars. Our platform offers the opportunity to simulate such phenomena right here on Earth." Superfluid vortices are also believed to exist in superconductors, which can conduct electricity without loss. "

Our work is an important milestone on the way to investigating new physics," says Francesca Ferlaino. "We can observe physical phenomena here in the lab that occur in nature only under very extreme conditions, such as in neutron stars." The work was published in Nature and funded by the Austrian Science Fund FWF, the Austrian Research Promotion Agency FFG and the European Union.

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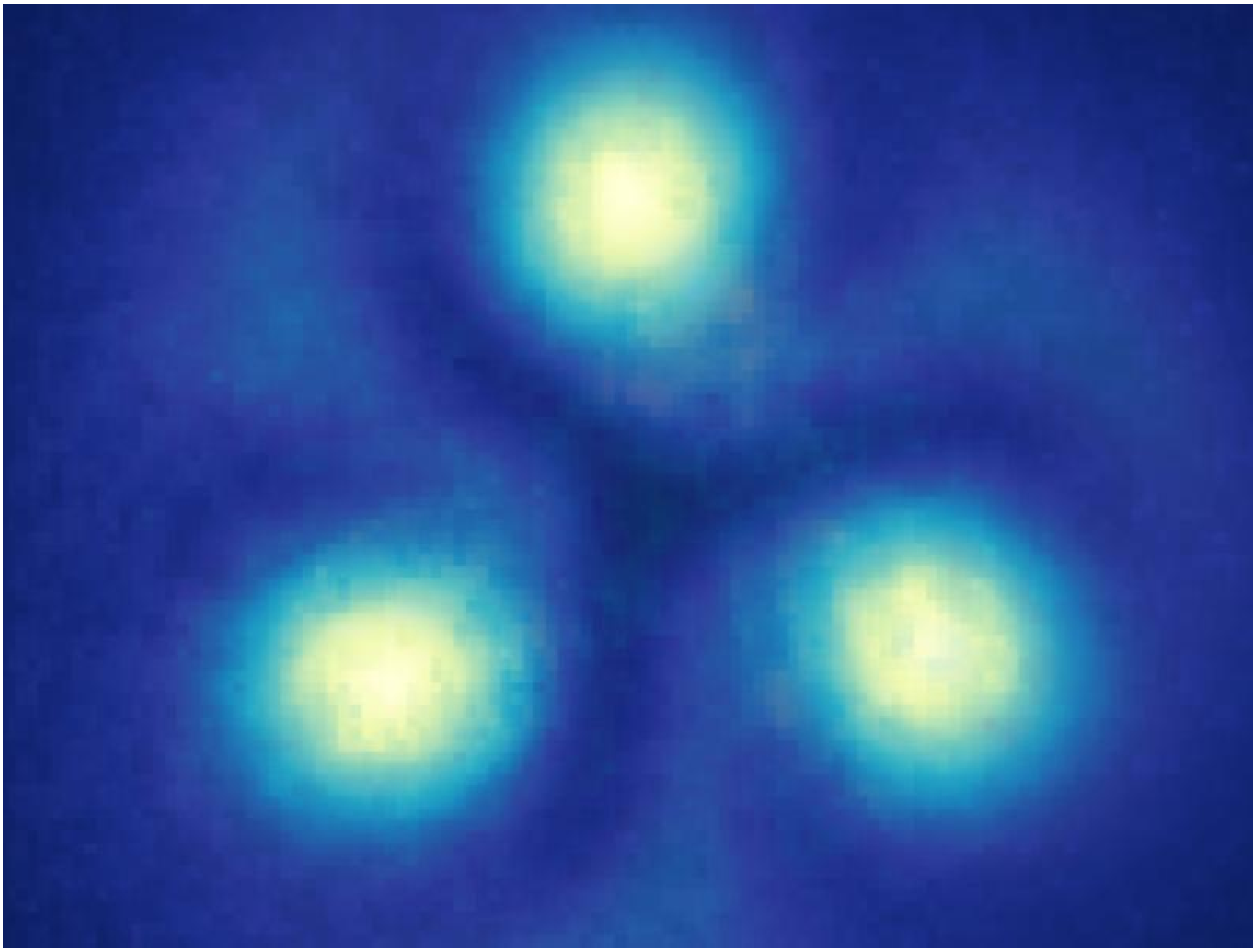

Simulation of quantum vortices superimposed with experimental data.
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