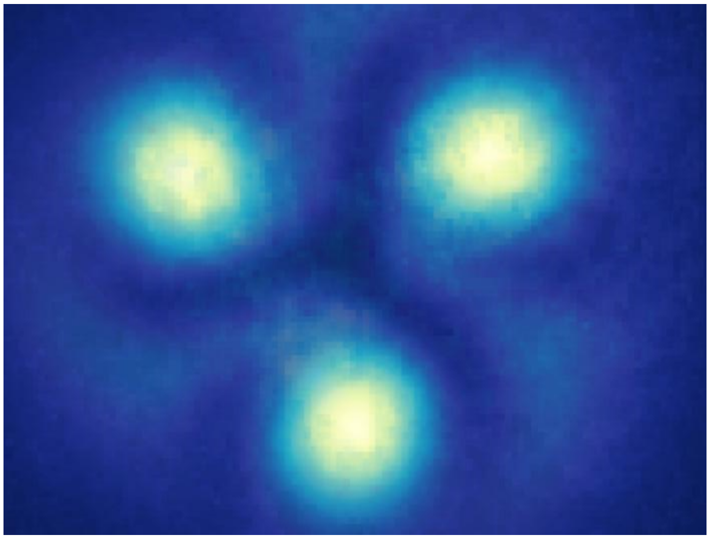
Supersolids Shown to Host Vortices

The experimental confirmation of supersolid vortices opens the prospect of making and studying laboratory analogues of rotating neutron stars.

By **Michael Schirber**

A supersolid is a walking contradiction, or, more precisely, a “flowing” contradiction. This phase of matter behaves as a zero-viscosity fluid, while at the same time exhibiting a solid’s crystalline structure. The first firm evidence of supersolids appeared in 2019 in experiments with ultracold atoms trapped in optical lattices, but one of the main predicted features—the formation of vortices—has gone unobserved, until now. Researchers from the University of Innsbruck in Austria report measuring density holes in a cloud of ultracold atoms, which confirms that vortices do indeed form in supersolids [**1**]. The team plans to use their setup to explore a possible connection between supersolids and neutron stars.

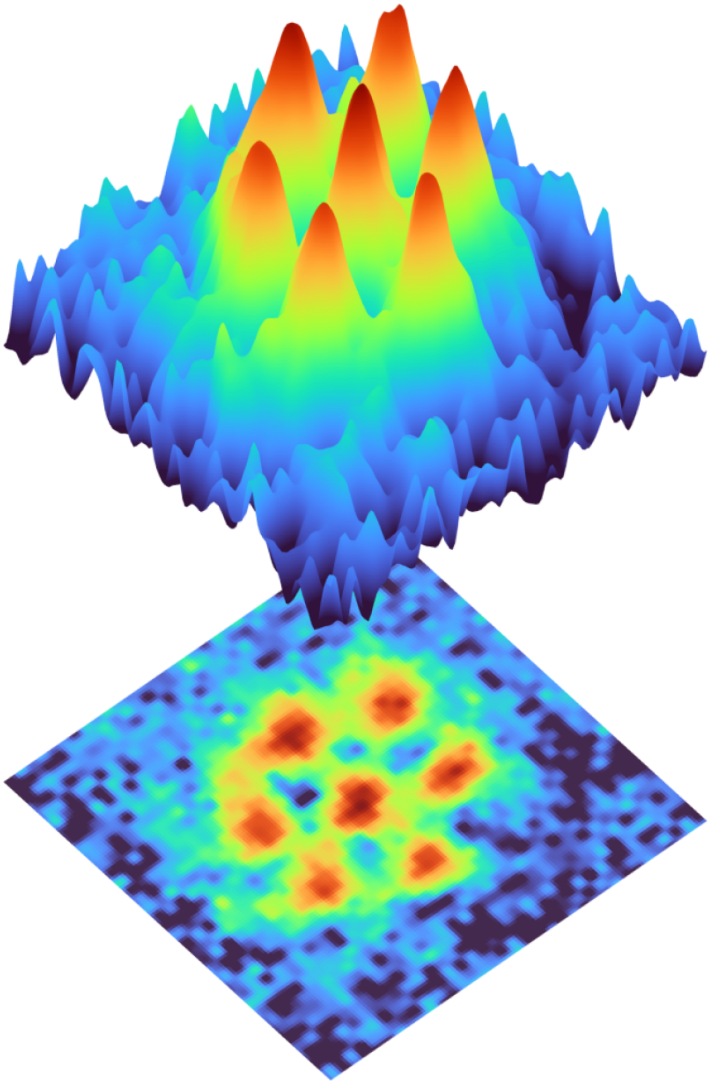


A simulation of a supersolid, showing the interference pattern produced by atoms escaping the optical trap where the supersolid forms. The presence of a vortex in the supersolid causes a dark shape with spiral arms to appear in the center of the pattern. Researchers detected this spiral shape to provide experimental evidence of vortex formation in a supersolid.
Credit: University of Innsbruck

Theoretical hints of supersolids appeared over 60 years ago as part of investigations into superfluid behavior. Superfluidity—first observed in liquid helium—is a quantum phenomenon in which the fluid atoms flow coherently, as if all locked together. Supersolids are a form of superfluid in which the density takes on a periodic pattern of high and low regions. “There is a tendency for the atoms to spontaneously organize into little ‘mountains’ and ‘valleys,”’ explains the University of Innsbruck’s Francesca Ferlaino. If the fluid were peanut butter, it would alternate between creamy and chunky.

Five years ago, Ferlaino’s group and two other teams detected the signs of this chunkiness in gases of magnetically interacting atoms cooled to near absolute zero in cigar-shaped optical traps (see **Viewpoint: Dipolar Quantum Gases Go Supersolid**). The researchers saw mountain–valley-like variations in the gas density along the long axis of their respective traps.

Subsequent experiments recorded other supersolid signatures, but the formation of vortices has proven harder to observe. Superfluids develop vortices when the system is rotated above a certain speed. Each of these vortices is like a tiny whirlpool, but the amount of flow around the center is quantized, meaning it only takes discrete values. “Vortices are a smoking gun for superfluidity,” says experimentalist Giovanni Modugno, who studies supersolids at the University of Florence in Italy. He says detecting vortices in supersolids has been very difficult because



A projected density profile of a supersolid (bottom). The data are mapped into a landscape (top) of “mountains” and “valleys.” In new experiments, researchers have rotated a supersolid like this and observed vortices in the low-density valley regions.
Credit: F. Ferlaino/University of Innsbruck

they live in the low-density regions of the system.

Ferlaino and her colleagues worked for almost two years designing an experiment that could reveal vortex behavior in a supersolid. The main challenge was devising a method for rotating the supersolid that preserves its fragile coherence. Building on earlier theoretical work [**2**], the team developed a “magnetostirring” method that consisted of a magnetic field rotating around an optical trap. Inside the trap, they placed a gas of dysprosium atoms, each of which has a magnetic dipole moment. The gas responds to the magnetic field by forming an elongated shape that rotates in step with the field. By tuning the magnetic-field strength, the researchers could control the interactions between the atoms, causing them to condense into either a supersolid or a smooth superfluid.

The researchers varied the rotation rate in their experiment and observed whether vortices formed in the gas before its coherence disappeared (after about 1 second). To detect vortices, the researchers took an image of the gas and looked for zero-density “holes” in the low-density valleys where the vortices are expected to lie. To make these holes more visible, the researchers developed a protocol that effectively “melted” the supersolid, sending atoms from the mountains into the valleys and increasing the density contrast around the vortices. The team also performed separate experiments where they looked at interference between atoms, finding a particular pattern (a dark spiral shape) that signaled the presence of vortices in the supersolid.

Ferlaino’s team found that a handful of vortices appeared in the gas when the rotation rate was above a critical value. For the supersolid, that critical rotation rate was around 10 revolutions per second. By comparison, vortices appeared in the smooth-density superfluid only for rotations above 30 revolutions per second. The relative ease of forming vortices in a supersolid has to do with the supersolid’s low-density valleys, where there’s less material to “drill” through to create a vortex.

Confirming the existence of swirling vortices in a supersolid still leaves open the question of how they can be compatible with a crystal lattice. Ferlaino admits that the results seem counterintuitive, but she explains that the atoms are not fixed to lattice sites. “There is a crystalline structure in the supersolid, but it’s not totally rigid,” she says.

“I’m very excited about these developments, as they are opening up the recently discovered supersolids to a wide range of studies,” says Blair Blakie, a theorist studying ultracold gases at the University of Otago in New Zealand. He says the experimentalists overcame many challenges to generate and observe the vortices. “Dipolar supersolids have relatively limited lifetimes, and the process for exciting the vortices takes time," he says. "The team found a window where they could get results."

Modugno is also impressed with the Innsbruck experiment, as it adds another piece of evidence for the existence of supersolids. Going forward, he would like to see measurements of the angular momentum around a supersolid vortex, as that could be compared to recent measurements that his group made of another quantity, the superfluid fraction, which characterizes the stiffness of a supersolid [**3**]. Both Modugno and Blakie are also interested in the potential of using supersolids to study the interior of a neutron star (see **Synopsis: Hot "Pasta" Beneath a Star's Crust**). Some theories predict that neutron stars have a supersolid layer and that vortices within this layer are what drive observed speedups, called glitches, in the rotation rate of neutron stars. Ferlaino hopes to build in her lab a neutron-star analogue that could test this vortex–glitch connection.

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