'Vortex lattices' may help explain material defects

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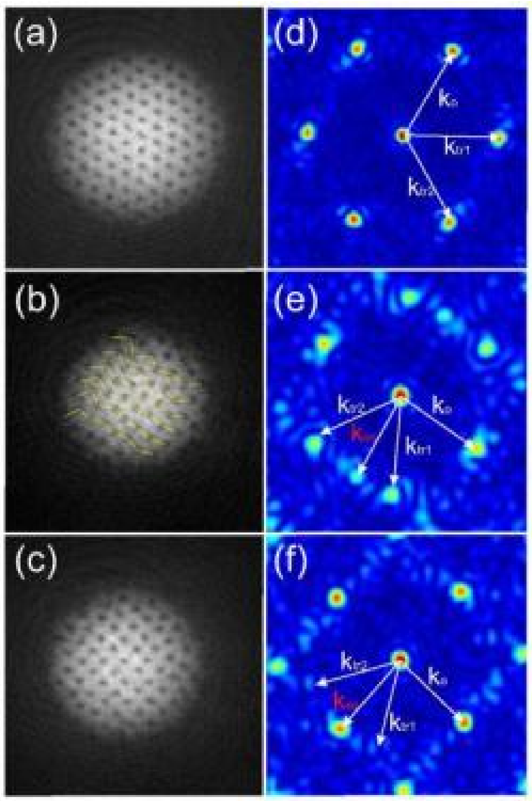

This set of JILA images shows a rotating Bose-Einstein condensate (BEC) "pinned" to a rotating lattice created with lasers as the shape of the combined "vortex lattice" evolves from triangular (top) to square (bottom). The images on the left show the BEC vortex lattice at low, medium and high pinning strengths, or optical intensity levels (top to bottom). The corresponding images on the right are computer processed to reveal the structural relationship between the BEC vortex and optical lattice, with red indicating the symmetry of the physical structures (hexagonal/triangular or square). Credit: Cornell group/JILA

What do you get when you superimpose a rotating pattern of intersecting laser beams on a spinning cloud of ultracold atoms in a thin gas? Pretty pictures, for one thing--but also a new method that could be used to simulate why and how defects arise in superconductors, important materials that are difficult to study directly.

By combining two cutting-edge laboratory creations--optical lattices and atoms in a Bose-Einstein condensate (BEC) spinning in a trap like planets orbiting the sun--physicists at JILA have developed a method of visualizing defects, or disruptions, in rotating patterns.

The experiments, reported in a paper published online Dec. 12 by *Physical Review Letters*, create the equivalent of "tornadoes in valleys," says group leader Eric Cornell, a Fellow at the National Institute of Standards and Technology (NIST). JILA is a joint institute of NIST and the University of Colorado at Boulder.

A BEC is a unique form of matter, first created by Cornell and colleague Carl Wieman at JILA, in which atoms are chilled to near absolute zero, and a point at which, by the rules of quantum physics, they condense into an amorphous "super atom" in which the individual atoms are indistinguishable. Part of the scientific fascination with BECs is that they share important physical characteristics with seemingly quite different phenomena, such as low-energy paired electrons in superconductors or the "superfluid" helium-4 that flows uphill with zero viscosity. For instance, helium-4, when stirred, doesn't circulate around the container like water in a glass, but rather breaks into an orderly array of quantized vortices, or little tornadoes. BECs behave the same way.

The JILA experiments were performed with 3 million rubidium atoms held in a magnetic trap. A superfluid of vortices was created by spinning the trap. The reddish BEC cloud, about 100 micrometers in diameter, contained about 100 hollow vortices, like a spinning bundle of fibers.

Lasers were used to set up optical lattices--grids of light in an arrangement of energy peaks and troughs--in triangular and square patterns and focus them onto the BEC.

The overlapping lattice and vortices, under certain conditions such as when spinning at about the same rates, tend to lock together. The energy peaks of the lattice "pin" the BEC at those spots by reducing the density of the superfluid flowing around the local vortex. The JILA group visualized the structure or repeating patterns of the pinned vortex lattice by taking pictures over time, and then using an image processing technique to show how the vortex lattice structure and orientation were related to the optical lattice structure and orientation. The vortex lattice and peak optical signals evolve into different shapes at various laser intensities and spinning rates. Because BECs and optical lattices can be precisely controlled, the technique may be useful in studying more mysterious patterned superfluids, such as superconductors.

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