cost projections" and urged DOE to recruit "significant international participation during the planning process."

The cuts to the basic science budget—which put it more than $100 million below the Administration's request—"are going to smart," says one DOE official. Materials science and chemistry projects could be among those hardest hit, although details won't be known for months. And a cut of nearly 50%, to $100 million, in the amount requested to start building the SNS, a neutron facility at Oak Ridge National Laboratory in Tennessee, will "most certainly" delay the project and increase its cost, Richardson said. He also blasted Congress for an 8% cut in DOE's $143 million computer research budget, saying it will slow progress in fields from genetics to climate change.

Richardson did win other battles. A $352 million nuclear physics budget—5% more than last year—includes $14 million to save the Bates Linear Accelerator Center, a nuclear physics facility at the Massachusetts Institute of Technology in Cambridge. In February, DOE officials released a budget that called for closing the facility. But within a day Richardson had reversed direction (*Science*, 12 February, p. 917), and Senate negotiators dropped their colleagues' earlier opposition.

–DAVID MALAKOFF

SUPERFLUIDS

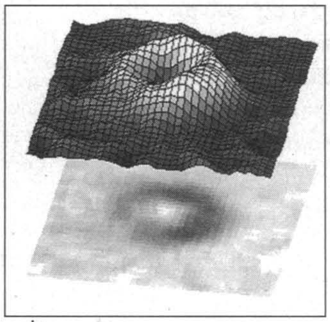
Tweaking Twisters in a Quantum World

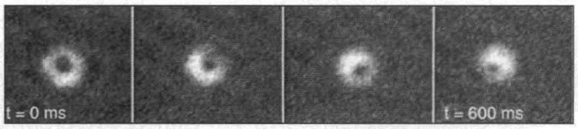
A hurricane is perhaps Earth's most devastating vortex. But even the deadliest hurricanes die out as they move away from warm waters that power them. Not so in the frictionless world of superfluids. When liquid helium is chilled to near absolute zero and agitated, it spawns tiny twisters that spin forever.

Now a team of physicists has stirred up and clocked such a vortex, a long-awaited step toward hands-on probing of this key feature of superfluidity. The action took place not in liquid helium, but in a dilute vapor of rubidium atoms, all in the same quantum state, called a Bose-Einstein condensate (BEC).

The BEC vortex, reported in the 27 September *Physical Review Letters*, adds weight to the idea that a BEC, created for the first time just 4 years ago (*Science*, 14 July 1995, pp. 152 and 198), is a kind of superfluid. And because liquid helium has proven to be an awkward medium for studying single vortices, the BEC vortex has experimentalists rubbing their hands in anticipation. By sleight of microwaves and lasers, the team was able to tease out the quantum properties of the atoms to map the swirling flow—a feat akin to tracking a hurricane by clocking its raindrops. "What we're hoping is that it will help us understand the microscopic nature of superfluidity, how it forms and how it breaks down," says Keith Burnett of Oxford University, United Kingdom.

Vortices are at the heart of superfluidity, a property seen in exotic fluids where all the atoms exist in the same quantum mechanical state. The shared quantum identity means that the atoms all have exactly the same energy and momentum; as a result they travel with the precision of a marching band. This quantum lockstep rules out wholesale turbulence, but when the fluid is spun, the atoms can parade in circles eternally. "Anytime you think about superfluidity you have to think about vortices," says physicist Eric Cornell of the National Institute of Standards and Technology in Boulder, Colorado.





Quantum whirlpool. The motion of a rotating ring of rubidium atoms (*top*) is revealed by quantum interference, shown here as a shadow. The vortex deforms (*bottom*) during its second-long lifetime.

Liquid helium's density makes it difficult to create lone vortices and understand their microscopic structure. So Cornell, Carl Wieman of the University of Colorado, Boulder, and their colleagues set out to make one in a BEC, where the atoms are further apart. They followed a plan proposed by their colleagues Murray Holland and James Williams and described in this week's *Nature*.

The first step was to create a cloud of BEC by cooling rubidium-87 atoms with magnets and lasers. Although it's no problem getting a BEC to spin—prodding from a laser works well—it's much more difficult to tell how the atoms are moving. "The ingenious idea of the Boulder group," says Wolfgang Ketterle of the Massachusetts Institute of Technology, was to set an outer ring of atoms revolving around a core of stationary atoms. They then looked for signs of interference between the atoms to map the ring's size and velocity.

Cornell and Wieman focused microwaves on the condensate and swirled laser beams around its perimeter. This bumped an outer ring of atoms into a slightly higher energy level (a different "hyperfine" state, distinguished by the magnetic moment of the nucleus) than that of atoms inside the ring. The kick of energy also forced the ring of atoms into motion, creating a vortex about 50 micrometers wide. Meanwhile, the stationary atoms of the core diffused slightly outward and overlapped just a bit with the rotating ring.

Stationary atoms have a constant phase—a quantum property of the wave function that can't be directly detected—while those with velocity have a phase that varies like a sine wave. Where the core atoms overlapped with those in the ring, the phases interfered with each other: Constructive interference made it easier for atoms to flip between hyperfine states, while destructive interference made it more difficult. So the researchers exposed the vortex to a second microwave field to provoke this flipping, and used a laser to count how many atoms had changed their identity. Because phase is a function of velocity, the measurement allowed the researchers to clock and map the vortex. "It's a very thorough microscopic picture you can take of this vortex," says Cornell. "You can tell where the fluid is, where it isn't, and where it's going."

Now the Boulder researchers are studying how the vortex itself moves through a larger sample. They hope ultimately to learn how a superfluid storm brews, tracking the birth and death of vortices as the entire sample is put into rotation.

And that may be just the beginning. "There's a whole rich array of other things people could do," says Burnett. Besides studying superfluidity, researchers might make condensates with several components, consisting of different hyperfine states or kinds of atoms. The right mixture could reproduce cosmic "textures"—hypothetical flaws in the fabric of space-time that might have formed in the early universe—with vortices corresponding to concentrations of energy called cosmic strings. Such states are present in superfluid helium-3, but a BEC, because it is easier to probe with lasers, might make a better microcosm for studying their behavior. Whatever researchers end up learning from Bose-Einstein condensates, one thing is certain: There will be far fewer tranquil days in the quantum world.

–ERIK STOKSTAD

CREDITS: ERIC CORNELL/NIST; FROM *PHYSICAL REVIEW LETTERS* **83**, 2498 (1999)