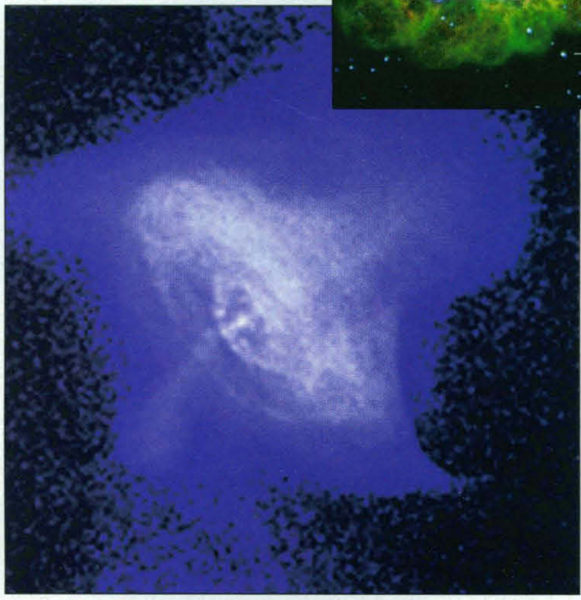
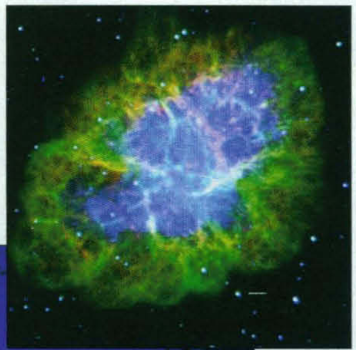
ASTRONOMY

Peering at the Crab's Power Supply

The orbiting Chandra X-ray Observatory has opened a new and detailed look at the blazing heart of the Crab Nebula, the remnants of a star that exploded into view nearly 1000 years ago. The images reveal swirls of energetic material around the spinning stellar corpse in the nebula's center. The swirls, especially a bright inner ring, may trace the long-sought "power conduits" that pump energy from a pulsar at the center to the glowing nebula, according to researchers who spoke last week at NASA Headquarters in Washington, D.C.





X-ray vision. A ring, sharp jets, and other bright x-ray features surround the central neutron star in the Crab Nebula in this new image from the Chandra X-ray Observatory. The inner ring is about two-thirds of a light-year across. The entire Crab Nebula *(inset)*, seen in a ground-based photograph, measures about 6 light-years across.

CREDITS: (TOP LEFT TO RIGHT) NASA/CXC/SAO; PALOMAR OBSERVATORY

Chinese astronomers and Native Americans recorded the Crab as a new "star" in the year 1054. The celestial beacon was a supernova, the death blast of a giant star that had consumed all its fuel and collapsed. Astronomers have known since 1968 that an ultradense neutron star spins 30 times per second within the Crab's expanding cloud of debris, emitting a lighthouse beam of radio waves. But the chaos at the center of the nebula has shrouded the mechanisms by which this pulsar lights up the glowing cloud.

The new x-ray observations lift that shroud, says Chandra project scientist Martin Weisskopf of NASA's Marshall Space Flight Center in Huntsville, Alabama. Chandra, launched 2 months ago, peered at the inner 40% of the Crab Nebula and discerned a sharp ring of x-ray light encircling the pulsar at a distance of about one-third of a light-year, along with two jets shooting into space. Astrophysicists believe these structures are the x-ray signatures of electrons and positrons accelerated by the pulsar's intense magnetic fields to nearly the speed of light. The magnetic fields whip the charged particles in tight spirals, forcing them to emit synchrotron radiation in the form of x-rays.

The high-energy waves and jets also power the Crab's bright filaments of light. Chandra's images provide a roadmap that theorists will read to determine how that occurs, Weisskopf says. "These remarkable pictures may give us definitive clues about how the neutron star loses power and deposits it in the surrounding environment."

Astronomer Jeff Hester of Arizona State University in Tempe agrees, noting that the brightest x-rays in Chandra's images coincide with the most dynamic parts of the nebula as seen in 1996 by the Hubble Space Telescope. Hubble saw wisps, jets, and sprites that changed shape within days. "The ring is in exactly the right place to tie the pulsar with the larger nebula," Hester says.

–ROBERT IRION

DOE BUDGET

Fusion Gains, Basic Science Takes a Hit

Battered by allegations of security breaches and lax worker safety controls, the Department of Energy (DOE) has been a popular target in Congress this year. But DOE's science budget has emerged from the rhetorical fire with only a few bullet holes. Last week, lawmakers approved a 4.3% increase for the agency's Office of Science, a move that is drawing generally good reviews from researchers.

It was not all that DOE was hoping for. The final figure of $2.8 billion for the office, part of a $21 billion bill that President Clinton signed on 29 September (P.L. 106-60), is $35 million less than the Administration requested. It will mean delays for several projects, including the $1.2 billion Spallation Neutron Source (SNS), and cuts in others, such as materials science. But given the battles still raging over other science budgets and the difficult year that DOE has had, lobbyists feel that the agency has held its own. "A lot of people associate DOE with dysfunctionality, but this is a big vote of confidence for [the agency's] science program," says physicist Michael Lubbell of the American Physical Society in Washington, D.C.

Fusion energy was the biggest winner: Congress approved $250 million—$27 million more than DOE requested and $20 million more than it spent in 1999. The hefty increase was due in part to the work of several DOE advisory panels, which labored to produce a plan for reinvigorating a field plagued by technical and political setbacks. Last year, for instance, Congress barred U.S. participation in the International Thermonuclear Experimental Reactor, a $10 billion prototype for producing energy from hydrogen and deuterium (*Science*, 8 May 1998, p. 818). House and Senate budget negotiators said that they were "pleased" by DOE's new fusion research roadmap, which calls for a greater emphasis on basic studies and less spending on potential commercial applications.

DOE's three largest basic research programs didn't fare as well. The $697 million high-energy physics program got a 1.6% boost, to $708 million, while the $809 million Basic Energy Sciences program—which supports materials, chemical, and other research—took a 3.2% cut, to $783 million. DOE's $444 million biology and environmental research budget, meanwhile, was trimmed by $2 million, although that's still $30 million more than the Administration asked for.

The high-energy physics number is $10 million higher than the Administration's request, but it comes with a warning about one of DOE's dream projects. Physicists hope to use a multibillion-dollar TeV linear collider, which would smash together electrons, to hunt the Higgs boson and other heavy particles also in the crosshairs of Europe's Large Hadron Collider, currently under construction in Switzerland. But while the legislators approved planning funds, they expressed "concerns about the early 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

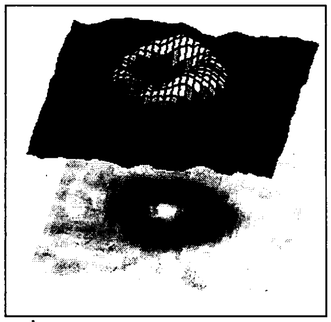
A hurricane is perhaps Earth's most devastating vortex. But even the deadliest hurricanes die out as they move away from warm waters that power them. Not so in the frictionless world of superfluids. When liquid helium is chilled to near absolute zero and agitated, it spawns tiny twisters that spin forever.

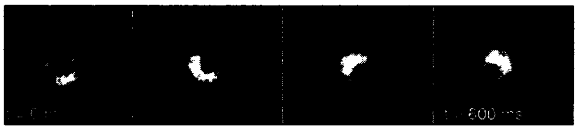
Now a team of physicists has stirred up and clocked such a vortex, a long-awaited step toward hands-on probing of this key feature of superfluidity. The action took place not in liquid helium, but in a dilute vapor of rubidium atoms, all in the same quantum state, called a Bose-Einstein condensate (BEC).

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.

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*.





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.

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

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