Found: Memories of gravitational waves

In the realm of Einstein's general theory of relativity, the curvature of space-time replaces the force of gravity. A massive body such as a star influences other objects not by acting on them directly but by warping the shape of space and time. Moreover, if such a body abruptly changes its motion or mass, space-time in its vicinity undergoes a corresponding convulsion. This disturbance travels outward as a gravitational wave that imperceptibly jostles any objects in its path.

Demetrios Christodoulou, a mathematician at New York University in New York City, has discovered a new wrinkle on gravitational waves tucked away in the intricacies of the equations that express general relativity. This unexpected mathematical result implies that a sufficiently strong, sharp burst of gravitational radiation will itself emit gravitational waves. The extra helping of gravitational waves would leave an imprint in the form of a permanent shift in the relative positions of test masses in an Earth-based gravitational-wave detector after the passage of a wave.

Christodoulou's finding has both theoretical and practical implications. "It's of considerable interest from the point of view of understanding the nature of gravity," says Kip S. Thorne of the California Institute of Technology in Pasadena.

"It's an exciting and unanticipated result," says astrophysicist Jeremiah P. Ostriker of Princeton University. Because current strategies for detecting gravitational waves focus on the observation of rapid oscillations, the idea that the passage of a wave may also cause a permanent displacement of objects opens up the possibility of developing simpler, less expensive detection techniques, he notes.

Christodoulou originally encountered this gravitational-wave effect as a mathematical formula derived from the Einstein equations describing gravitational fields located far from their sources. "I discovered this result in an abstract form [nearly two years ago], but I didn't know what it meant [physically]," Christodoulou says.

A year later, while reading to pass the time on a train commute between New York City and suburban New Jersey, he happened upon a magazine article about gravitational-wave detection. The article's discussion of the difficulties involved in observing rapidly fluctuating gravitational waves triggered a chain of reasoning that suggested his formula corresponded to some kind of permanent, potentially observable displacement of objects.

Subsequent discussions with Thorne and several other theorists gradually clarified the physical meaning of Christodoulou's result. "It took a long time for it to make sense to me and for us to understand what was going on," Thorne says. "It was entirely an issue of communication and translating from a language in one community [mathematics] to the language of another [astrophysics]."

Christodoulou describes his discovery and its implications in the Sept. 16 Physical Review Letters, and Thorne has prepared a paper that translates the results into language more accessible to astrophysicists.

A pair of orbiting, coalescing neutron stars or black holes represents the most likely source of gravitational radiation strong enough to produce an observable effect. As the two objects orbit each other, they emit gravitational waves and gradually draw closer together. Eventually the objects slam into each other, and the system sends out a final, intense burst of gravitational radiation. This, in turn, produces the secondary "Christodoulou signal."

An Earth-based sensor tuned to such an event would detect a slow, overall change in the local gravitational field superimposed on the rapidly fluctuating signal from the primary burst itself. Theorists predict that in some instances, the permanent displacement of masses in the detector – called the "memory" of the gravitational-wave burst – would be as large as the maximum displacement during the burst-generated fluctuations.

"The Christodoulou effect can yield measurable amplitudes and provides us with another way of looking at certain components of a gravitational wave from a coalescing black-hole binary," says astrophysicist Stuart L. Shapiro of Cornell University.

Although researchers have designed detectors, such as the proposed Laser Interferometer Gravitational Wave Observatory, without taking the Christodoulou effect into consideration, these devices should nonetheless detect both rapid fluctuations and permanent changes in a gravitational field. "If detectors are built sensitive enough to measure the previously estimated amplitudes from coalescing neutron stars, they will also be able to see this Christodoulou effect," Shapiro says.

"[The effect] can have some impact on the data analysis algorithm that one might use in a given situation," Thorne says. "There are also likely to be special cases where the secondary wave may turn out to be easier to detect than the primary burst of waves, but I think they will be rare." *– I. Peterson*

NASA inches toward smaller satellites

NASA is slowly backing away from its controversial plan to launch an expensive set of giant satellites in a project designed to monitor Earth's climate and resolve questions about global warming. Several scientific advisory panels, including one this week, have recommended that the agency fly its monitoring instruments on smaller, less expensive satellites that could go up several years before the larger crafts would be ready for launch.

Original plans for the Earth Observing System (EOS) called for a pair of orbiting observatories, EOS-A and EOS-B, each carrying a dozen sensors aimed at Earth's surface and atmosphere. NASA hoped to launch the first observatory in 1998 and the second one several years later.

But a key review panel of outside experts, assembled by NASA at the White House's urging, now concludes that the agency should redesign EOS in favor of smaller spacecraft. The use of small and intermediate-sized satellites could reduce costs, get instruments into orbit earlier and allow greater resiliency in case problems arise, says panel chairman Edward Frieman, director of the Scripps Institution of Oceanography in La Jolla, Calif. The panel released its report this week.

NASA officials say they are reconsidering the grand plan for EOS in light of the new report and important events that occurred this summer. "We're in the process of developing different alternatives to the implementation of EOS," says Shelby G. Tilford, director of NASA's earth sciences division in Washington, D.C.

Budget constraints are one factor forcing NASA to rethink the program's design. In recent months, both the Senate and House voted to make significant cuts in the proposed EOS budget for fiscal year 1992. And the Senate called on the agency to chop $5 billion off the $16 billion planned for EOS between now and the turn of the century. These cuts would make it impossible for NASA to meet the scope and timing of the project as originally conceived, the panel concludes.

Other recent developments offer NASA more flexibility in exploring alternatives. The Air Force told NASA this summer that it plans to adapt a facility at Vandenberg Air Force Base to launch Atlas rockets, which can carry intermediate-sized satellites. Launches from the California facility could send satellites into the polar orbits needed by EOS instruments. The Air Force decision thus provides an opportunity for distributing the instruments among six intermediate-sized satellites rather than grouping them on two large space platforms.

NASA had not considered the Atlas

option in the past, Tilford says, because "it's hard to plan on something that isn't there." EOS managers say they learned of the Air Force's Atlas intentions early this summer. However, a description of the Air Force plans appeared last February in public documents issued as part of the President's budget request.

NASA officials had long maintained that EOS' goals required orbiting the instruments on big platforms because certain sensors must monitor the same part of the Earth at the same time. But the review panel asserts that other options could also work. A smaller platform could hold instruments that truly need to make simultaneous measurements, while other sensors could make nearly simultaneous observations from small satellites orbiting in close formation.

Splitting up the instruments would allow NASA to launch the most important sensors as soon as possible and leave the less critical ones for later. Some might fly as early as the mid-1990s, says Frieman. He points out that government leaders need EOS data to help resolve pressing questions about climate change.

Smaller craft would make the program more resilient, he adds, because NASA could change the instruments on a later satellite to answer questions raised by data from early missions. Moreover, distributing the instruments among several satellites would provide better protection against mishaps such as the Challenger accident or the equipment glitches now hobbling the Hubble Space Telescope and the Galileo probe.

"People [on the review panel] were mindful of the fact that, when carrying an enormous number of instruments, if there's any difficulty, the whole mission can be destroyed," Frieman says.

The panel also calls on NASA to speed up its satellite development process. Recent NASA projects have typically taken nine years to move from chalkboard to launchpad, whereas the Defense Department has repeatedly designed, built and launched complex space experiments in less than two years, the panel notes.

NASA has considered splitting the single EOS-A payload onto two Titan rockets, but the review panel recommends going even smaller by using three Atlas rockets or a mixture of Atlas and even smaller rockets.

The idea of separating the instruments upsets some scientists, especially those whose research projects might not survive a program redesign. At the same time, many researchers and policymakers criticize NASA for holding on too long to the concept of flying large EOS satellites. While agency officials say they are considering new options, they appear to be "somewhat reluctant," says one member of an independent advisory committee charged with evaluating the future of the U.S. space program.

– R. Monastersky

Sizing up atoms with electron holograms

In their ongoing quest to see the all-but-invisible, physicists have developed a method for using patterns of scattered electrons to observe the three-dimensional atomic textures of materials. In this emerging technology, called electron holography, investigators exploit the wave-like properties of electrons to make their observations (SN: 10/15/88, p.252).

Now scientists have used a lensless electron projector to discern the arrangement of atoms in several types of materials. In the Sept. 16 Physical Review Letters, Hans-Werner Fink and Heinz Schmid of IBM's Zurich (Switzerland) Research Laboratory and their colleagues describe the technique and the calculations that helped them create holograms of carbon fibers and of thin gold films. Since doing that work, they have produced a holographic image of DNA – published here for the first time – demonstrating that the approach also works with biological materials.

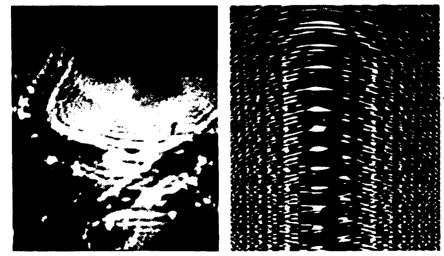
Fink and Schmid illuminate their samples with a beam of electrons emitted from an ultrathin tungsten tip similar to that used in scanning tunneling microscopy. By sharpening this tip to a width of one atom, they create a beam coherent enough to make atomic-scale holograms.

"Holograms are not direct pictures of objects; they are sort of smeared-out representations," explains Hans Jürgen Kreuzer, a physicist at Dalhousie University in Halifax, Nova Scotia. He and Dalhousie colleague Andrzej Wierzbicki worked with the IBM scientists to make a model for predicting the scattering patterns and to interpret experimental results. "We now have a theory that eliminates the guesswork," Kreuzer says.

But these researchers and others agree that the images still need work. The pictures display wavy patterns as well as hints of the real structure. "It's somewhere in between what you can see directly and a true hologram," says Dilano K. Saldin, a physicist at the University of Wisconsin-Milwaukee. "They claim that you can see atomic detail, but [the images] are not very clear."

Saldin and others rely on photoelectron and Auger spectroscopy data to reconstruct three-dimensional images (SN: 9/1/90, p.134). These images represent what most people think of as true holograms. Saldin expects Fink's group to develop comparable reconstruction schemes for the new technique.

One advantage of the electron projector, says Kreuzer, is that "you can fine-tune it depending on what you want to see." It can shoot out low-energy electrons for seeing overall shape and structure, and then high-energy electrons to resolve finer details. In addition, the scientists can adjust the distance between the tip and the sample.



Fink *et al.*/IBM, Dalhousie Univ.

Electron hologram of DNA (left) and simulated hologram of a double helix of carbon.

The electrons emitted by the projector pack far less power than those used in transmission or scanning electron microscopy, two common imaging methods involving electrons. "Therefore, the amount of beam damage is much smaller," says Saldin. The new technique thus enables researchers to make holograms of biological molecules, such as DNA, without having to replace carbon atoms with larger atoms like gold.

"We are quite convinced that within a few years there will be thousands of these instruments in materials science and biomedical laboratories," says Kreuzer. "It is very powerful." *– E. Pennisi*

Signs of early ozone loss

Researchers monitoring ozone levels over the South Pole report signs that the ozone hole may have started developing earlier than usual this year.

Balloon-borne sensors measured ozone values as low as 195 Dobson units during the second week of September, a week earlier than usual, says Samuel J. Oltmans of the National Oceanic and Atmospheric Administration in Boulder, Colo. He adds that the timing of the ozone depletion does not necessarily mean that this year's hole will be more severe than previous ones.

The ozone hole opens in September when sunlight returns to the extreme south, energizing reactions in which chlorine pollution breaks down ozone molecules in the lower stratosphere – between about 12 and 23 kilometers in altitude. The depletion progresses until early October, when warm winds invade the region and shut down the cycle of chemical destruction.

Although the balloon measurements hint that the hole might be opening early this year, these sensors probe only the region directly over the pole and cannot track the development of the entire hole. Indeed, satellite observations over a broad region show the hole forming essentially on schedule, says Arlin J. Krueger of NASA's Goddard Space Flight Center in Greenbelt, Md. □