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