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Home Menu | Local News | SportsDay | Business | ClassifiedCenter

Search
Go
DallasNews.com
The Archives

Break Room
City-by-City
Collin County
Columnists
Education
Entertainment
Health/Science
House/Garden
Lottery | Pets
Nation | World
Obituaries
Opinion/Letters
Photography
Punchbutton
Religion
Special Reports
Texas Living
Traffic
Texas | Politics
Travel | Food
Weather
Corrections
.com Store

ClassifiedCenter
Local ads from the paper and more!

HomeCenter
Cars.com
JobCenter
DatingCenter
TicketCenter
Other categories

Marketplace
Newspaper ads
New! Photo Store
Front Page Store
News Archive
Services for newspaper subscribers
Calling on America

My DallasNews.com
Register
Account information
My-Cast Weather
My-NetLink ISP
My Specials Direct
Make this my home page
My newsletters

Health/Science

New searches for old waves

Physicists seek evidence of gravitational ripples from cosmic events

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By SARAH GOFORTH / Special Contributor to The Dallas Morning News

Imagine if Earth's every drama – the breaking and shaping of continents, earthquakes and wars – were preserved in the sea. By watching waves lapping at the shore, scientists could describe the last great ice age, or the asteroid impacts that triggered mass extinctions. But no matter how big the splash, of course, water can carry a ripple only so far.

Space, on the other hand, can carry a wave forever. Spacetime, specifically, flutters and surges with the energy of its momentous occasions.

Such ripples in the very substance of the universe are known as gravitational, or gravity, waves. They are released whenever something very big does something very fast.

"Think of it: Gravity waves come to us from the edge of the universe, from the beginning of time, unchanged," says Wai-Mo Suen, a theoretical physicist at Washington University in St. Louis.

Sprawling observatories are now poised to catch these waves, which may provide a way to see elusive phenomena that have been mostly described through theory. For the first time, scientists now have a chance to see whether reality fits with the forecast.

Gravitational waves "carry completely different information than electromagnetic waves," such as the light seen through ordinary telescopes, says Dr. Suen. "Perhaps the most exciting thing about looking for ... [gravitational waves] is that we may well not know what we're going to observe. We think black holes, for sure. But who knows what else we might find."

Scientists at a specially built observatory have just begun a long hunt for gravitational waves, which are so slight that only this $300 million project (funded by the National Science Foundation) and the best minds in physics have any chance of catching them.

Two giant antennae in Washington and Louisiana make up the Laser Interferometer Gravitational Observatory, or LIGO. The scientists hope to "catch a wave" by simultaneously sending laser beams down both arms of an L-shaped building – if a gravity wave passes through the detector, the laser beams will be thrown slightly out of phase with each other. The discrepancy would be detectable when the laser beams recombined at the base of the L.

If catching gravity sounds counterintuitive, it might help to consider how Einstein described the famous force.

It is the curving of spacetime that buckles feet to the ground and pulls tides from shore to shore, Einstein said.

Spacetime, the three dimensions of space and the one dimension of time, is like a fabric on which everything in the universe sits.

Matter – the Earth, its moon, an apple, for example – dimples the fabric's surface where it rests, and spacetime curves in proportion to the object's mass.

Anything hanging around will naturally roll along the curve.

When something extraordinary happens – when two stars collide, for instance – the dimples become ripples that spread outward in every direction at the speed of light, without end.

What is now known of the cosmos is based mostly on observations of electromagnetic radiation – the ripples that form light (among other signals, including radio waves). But this knowledge has built-in limits, because electromagnetic waves are absorbed, scattered and dispersed by the matter they encounter in the trek through space.

Gravitational waves, on the other hand, can travel from the farthest reaches of the universe and arrive at Earth in pristine condition – diminished in strength, but identical in form.

"Gravity has been largely a theoretical field," says LIGO's director, physicist Barry Barish of California Institute of Technology. "The force is so weak that we have had to work very hard and long experimentally to start catching up with theory. LIGO becoming real was a sea change."

The information gleaned from LIGO's first run – which began Aug. 23 and lasted 17 days – will help engineers refine the instruments. But nobody expects to see any gravitational waves just yet.

LIGO is undergoing continual adjustments and is scheduled for a major upgrade in 2006. The refined LIGO – and a space-based successor called LISA – will be sensitive to signals the current LIGO cannot yet detect.

Wave-watchers following LIGO's progress may have some waiting to do, but Dr. Suen is looking for waves another way. He uses mathematical models to predict the gravitational wave "signatures" of astronomical events.

No single phenomenon, says Dr. Suen, warps spacetime better than a black hole – where a tremendous amount of matter has collapsed into such a small space that its gravity prevents even light from escaping. Black holes are famously massive and dense – qualities that make them likely sources of gravitational waves.

By intergalactic standards, black holes are common – one even churns in the center of the Milky Way. And most gravitational wave theorists believe that no event is more likely to produce detectable gravitational waves than the spiral-shaped waltz of two merging black holes.

"It's a very comforting source," says Lee Samuel Finn, director of the Penn State Center for Gravitational Wave Physics. "We know so much about them that it's kind of like the poster-child source for LIGO."

Since colliding black holes produce no light or radio waves, their behavior has, so far, only been inferred from theory. LIGO may pick up signals that confirm what physicists have surmised about black holes. They might find that Einstein was wrong. Either way, it will be a jackpot of information.

"The prospect for the first time to really study black holes observationally is the most exciting thing," says Kip Thorne, a leading gravitational wave theorist at Caltech. "But with LIGO and LISA, we will be able to see in great detail the tornadolike motion of space around a black hole, and make maps with accuracy."

Double black hole systems, such as the one recently discovered by the orbiting Chandra X-ray Observatory, aren't the only gravitational wave generators that physicists hope to see.

Systems of two neutron stars, or one black hole and one neutron star, also exist. Neutron stars, the remnant cores of some exploded stars, are as small as cities with more mass than the sun. Like black hole "binaries," neutron stars emit gravitational waves as they spiral inward.

In an observation that earned the 1993 Nobel Prize in physics, Russell Hulse and Joseph Taylor Jr. watched two neutron stars merging in a way that could only be explained if the stars were radiating gravitational waves. In fact, the spiraling pattern Drs. Hulse and Taylor saw by radio telescope exactly matched the predictions they derived from Einstein's relativity equations.

As stars in binary systems whirl more closely together, they release more gravitational waves. Just before the two stars collide, they will emit gravitational waves strong enough for detectors such as LIGO to pick up.

But it doesn't always take a couple to make magic on the dance floor.

Average-size stars end up as calm white dwarfs, as scientists expect the sun to in about 5 billion years. But massive stars explode when they die, spattering the universe with the particles inside them. These explosions, called supernovae and hypernovae, release gravitational waves in sudden surges.

The less-well-understood hypernovae, says Dr. Thorne, "are believed to occur when very heavy stars – 30 to 50 times the size of the sun – implode, whereas a supernova is believed to occur when a much smaller star, like 10 times the size of the sun, implodes."

Supernovae detonate in a flash as bright as 10 billion suns, but beyond that moment are difficult to see. In a galaxy the size of ours, the Milky Way, a supernova appears about twice a century. Gravitational waves from supernovae would only be detectable by LIGO if the event happened in the cluster of galaxies containing our own or in the nearby Virgo Cluster.

Another possible source of gravitational waves is a neutron star. A neutron star with an asymmetric spin probably releases waves as it wobbles. Single black holes, too, as they suck up nearby matter, will churn out gravitational waves if the matter is big enough.

But before there were any neutron stars or black holes, or for that matter before there were any stars at all, there was the big bang.

Everything that now makes up billions of galaxies was once confined to a very small, very dense spot, astronomers say. About 14 billion years ago, the universe exploded into being from that tiny space.

After the big bang, the universe was hot and violent, so much so that most forms of energy were scattered or absorbed. But around its 400,000th birthday, the universe had expanded and cooled enough for particles of light to fly freely, and they began the journey through space. Scientists see that light today as microwave radiation bathing the cosmos.

This cosmic microwave background carries a picture of the universe at that age. Gravitational waves, on the other hand, may allow scientists to see all the way back to the birth of the universe.

"Probably the most romantic and least determined source of gravitational radiation is the relic signal from the big bang itself," says Dr. Barish. "The cosmic microwave background signals are quite absorbed. ... So if you really want to understand the early part of the big bang, you have to probe with something else."

Gravitational wave experts agree that the first generation of LIGO will not be sensitive enough to allow researchers to see gravitational waves from the early universe. But future versions of LIGO, or the space-based LISA, might. Physics journals are already brimming with theories about what these signals might look like.

One idea is that gravitational waves emerged from cusps and kinks on cosmic strings in the early universe. A cosmic string, explains Dr. Thorne, "can be thought of as a linear crack in the fabric of spacetime, like a string or wire, but really a defect in the structure of space."

Cosmic strings are thought to have been created in the very early universe and are quite tense. "They vibrate like a stretched violin string," says Dr. Thorne.

Other murmurs from the early universe may help test some of the more bizarre-sounding theories – for example, those about extra dimensions of space.

"The most trendy picture about the early universe is that the world that we live in lives on a brane – you could think of it like a membrane," says Dr. Barish. In theory, this membrane prevents earthbound observers from seeing more than three dimensions.

Gravity, he says, exists beyond the membrane, and detecting gravitational waves from the "braneworld inflation" in the very first moments of the universe might reveal something about these extra dimensions.

It's possible too, says Dr. Thorne, that gravitational waves were produced as the universe's fundamental forces emerged.

"When the universe was very young and hot, electromagnetic and nuclear forces were uniform," he says. "When the universe was about a femtosecond [one-quadrillionth of a second] old, these two forces began to attain separate identities."

When that happened, distinct areas emerged where the forces were separate. It was like bubbles of vapor forming inside boiling water, Dr. Thorne says. When the walls of these "bubbles" collided, they created strange cracks in the structure of spacetime. These cracks, so-called Nambu-Goto walls, may have released gravitational waves.

Theories about cosmic strings and Nambu-Goto walls can sound crazy, admits Dr. Suen. But without such theories, looking for meaningful signals amid the experimental data "is not even like a needle in the haystack, because we don't know necessarily that we're even looking for a needle," says Dr. Finn.

Most gravitational wave experts agree that LIGO is likely to reveal surprises; inevitably, they say, the giant antennae will register signals no one has predicted. In the end, says Dr. Suen, "we'll look back and see that we were so naïve at this stage in 2002. We know so little about the universe."

Sarah Goforth is a Wisconsin free-lance writer.

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