Searching For The Golden Spike

Is there any hope of experimentally testing quantum gravity?

by KATE BECKER

Conference Idea: Is there any hope of experimentally testing quantum gravity? January 18, 2008

Remember the story of the golden spike from your American History class? (Don't worry, we'll get to physics in a minute.)

The golden spike—the final, ceremonial link in the United States' first transcontinental railroad—connected two parts of the country that, at the time, may as well have been different worlds. Getting from New York to San Francisco still required a ferry jaunt across the Mississippi, but many say that the driving of the golden spike was the beginning of the end for the American frontier.

LEE SMOLIN
Perimeter Institute

Today, physicists are working to unite a different kind of east and west. On one side of the divide is general relativity, Einstein's theory of space, time, and gravity, which successfully explains everything from why apples don't fall up to the precise timing of a binary pulsar. On the other side is quantum mechanics, the microscopic physics in which uncertainty and probability hold the reins, yet which describes its tiny domain at least as well as Einstein's relativity explains its realm.

Yet these two theories can be pushed to the breaking point. The equations of general relativity run aground when applied to the infinitely dense environment inside a black hole, or the "singularity" that birthed our universe. At the same time, physicists are still struggling to accept the baffling paradoxes of quantum mechanics. Can we swallow the idea that our universe is just one exceedingly complex probability distribution, forced into physical reality only by an observer's measurement?

Worse, general relativity and quantum theory have clashing notions about space itself. While the equations of quantum mechanics play out against a fixed background grid of space and time, general relativity dispenses with the notion of rigid geometry altogether. Further, general relativity and quantum mechanics

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>
> *- Louis Crane,*
> speculating on how to concentrate enough energy in a small enough volume to produce violent curvature on a quantum scale, to test quantum gravity

both have "defects that point to the existence of a deeper theory," writes Lee Smolin, a theoretical physicist from the Perimeter Institute in his recent book *The Trouble With Physics*. "But the main reason each is incomplete is the existence of the other."

That's why scientists are now racing to uncover this deeper theory, called "quantum gravity," in their quest to drive a "golden spike" between the gravity of general relativity and quantum mechanics, uniting two disparate tracks and conquering the greatest frontier of contemporary physics.

Quantum Gravity and its Discontents

Two leading theories of quantum gravity, string theory and loop quantum gravity, propose that if we could look at our universe on a small enough scale, we would see tiny structures—the eponymous strings and loops—which give rise to all the particles and forces we observe.

Loop quantum gravity depicts a sort of needlepoint universe in which space itself is stitched in a discrete weave, while string theory suggests that the universe is composed instead of "ultramicroscopic" strings that vibrate to take the form of matter and forces. String theory also predicts that our apparently

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four-dimensional universe (three spatial dimensions, plus time) actually conceals some number of extra "small dimensions." We may be able to move in these dimensions, but we have so little wiggle room that we never even notice they are there.

And while loop quantum gravity is about recasting Einstein's general relativity in a new unified theory, string theorists have bigger plans: "Loop quantum gravity takes the viewpoint that you just have to figure out a proper way to turn Einstein's theory of gravity into a quantum theory," explains Steve Giddings, a physicist at the University of California, Santa Barbara, "String theory, instead, proposes that Einstein's theory is part of a larger theory."

But these takes on quantum gravity have drawn criticism from scientists who claim that they make no testable predictions, or that they are so loosely defined that they can be endlessly rejiggered to address new discoveries that don't square with the meager predictions they do make.

LOUIS CRANE
Kansas State University

Louis Crane, a mathematician at Kansas State University, counts himself among the skeptics: "String theory cannot really be defined. The predictions people say they are making from string theory are only characteristics of some model or other, which is suggested by low energy approximations to string theory. It has an almost endless array of such models." String theory is a slippery animal, argues Crane. "Falsifying the predictions wouldn't falsify string theory, since one could just pick another model."

And that, says Smolin, isn't science. String theory and loop quantum gravity may be mathematically elegant and polished to perfection on the pages of a theorist's notebook, but to be true science, they must make predictions that can be falsified by real-world experiments.

"The empirical challenge is to somehow explain why we see the particles and forces we do," says Crane.

From Page to Stage

The best laboratory in which to test quantum gravity may turn out to be the universe itself. Using vast distances of space as a cosmic amplifier, scientists may be able to observe effects that would otherwise be too tiny to measure.

For example, if space is not continuous but made up of disconnected volumes, as loop quantum gravity predicts, it would leave a diffraction signature on particles and light waves that pass through it. A particle or light wave would have to traverse a huge distance for this effect to be observable, but Smolin thinks that astronomers might be able to spot it using ultra-high-energy cosmic rays (super-speedy particles spit out by active galactic nuclei) or gamma ray bursts (high-energy photons from tremendous extragalactic explosions). Both travel millions or billions of light-years before reaching Earth, ample distance for the diffraction effect to become observable.

Loop quantum gravity also makes the heretical prediction that the speed of light depends on its frequency. That prediction violates *special* relativity, Einstein's rule that light in a vacuum travels at a constant speed for all observers and at all frequencies. The theory predicts that high-energy (blue) photons should actually move the tiniest bit slower than lower-energy (red) ones, and although the difference would be small, coming from, say, a gamma-ray burst 10 billion light years away, it could be measurable.

"If an energy dependent speed of light is seen," says Smolin, "that would be dramatic confirmation of quantum gravity."

Indeed, scientists using the MAGIC telescope, which images the shower of photons set off when a gamma-ray hits Earth's atmosphere, think they may have already seen this effect, The GLAST gamma-ray telescope, set to launch in 2008, will provide another check on the results.

On the other hand, one experiment has already delivered a rebuke to theorists who predicted that special relativity would break down at high energies. At the Pierre Auger Cosmic Ray Observatory, a network of cosmic ray detectors, scientists have confirmed an energy "ceiling" above which they detect no cosmic rays—just as special relativity predicts. "This is important and exciting," says Smolin, and "strongly constrains" the degree by which special relativity might be flawed.

Could it one day be possible to test quantum gravity in a lab smaller than the visible universe? The challenge, says Crane, is "concentrating enough energy in a small enough volume to make violent curvature at a quantum scale."

"It's far beyond us now for practical reasons. A nuclear laser the size of an asteroid might eventually do it."

If you're not willing to wait for that giant nuclear laser to come on line, there is another possibility: Some string theorists predict that the Large Hadron Collider, currently under construction at the CERN particle physics lab near Geneva, may create mini black holes that could test quantum gravity.

"If we could make collisions that formed black holes, the observable results would give us information about quantum gravity," says Crane. But, he cautions, "The practical limits on observations appear long before we could reach this. Just knowing whether a small black hole decays or not would be important."

Crane quips: "Given the lack of success of string theory in predicting anything we already see, I think it unlikely."

So, will the next great leap in quantum gravity come from theory or from experiment? The scientists interviewed for this story answered along party lines—theorists for theory, experimentalists for experiment. But whoever eventually drives the golden spike between gravity and quantum theory may not merely close one frontier: He or she may open a new one.

GOLDEN SPIKE CEREMONY
May 10, 1869
Utah Territory