COSMOLOGY

Could a Pair of Cosmic Strings Open a Route Into the Past?

Time travel would seem a more appropriate topic for science fiction writers, philosophers, and Hollywood producers than mainstream scientists. Yet in recent months, the subject has been bandied about by a small group of theoretical physicists in the pages of such respected journals as *Physical Review Letters* and *Physical Review D*. Treating a seemingly frivolous concept with utter seriousness, these scientists are calling upon quantum effects, black holes, closed timelike curves, and cosmic strings (where's the kitchen sink?) to explain—or dismiss—a notion that has been capturing the public's fancy since H.G. Wells' 1895 story "The Time Machine."

Revisiting the Wells notion last year, Princeton physicist J. Richard Gott suggested in the 4 March 1991 *Physical Review Letters* that certain gravitational effects could warp space and time ("spacetime," in the language of Einstein's theory of relativity) enough to allow a spaceship to travel into the past. The speeds involved and other assumptions in the scenario made it unlikely that Delta Airlines would soon be offering bonus miles for trips back into history. But other theorists have been unnerved by the very possibility of time travel in a rational universe. In recent months, they have joined in an effort to restore sense to the cosmos. A consensus against the possibility of time travel has now emerged, but Gott doesn't give in easily.

The proposal that has so disquieted his colleagues depends on a notion derived from relativity and known to every science fiction buff: Clocks slow down as they approach the speed of light. By implication, time stops for objects traveling at the speed of light and runs backward if the cosmic speed limit is broken. That cosmic speed limit is supposed to be inviolable, of course, but if the "shape" of spacetime were sufficiently distorted, Gott speculated, a traveler might find shortcuts that could get him to his destination ahead of a light ray following the usual route through spacetime. Why couldn't such a shortcut lead a traveler back in time?

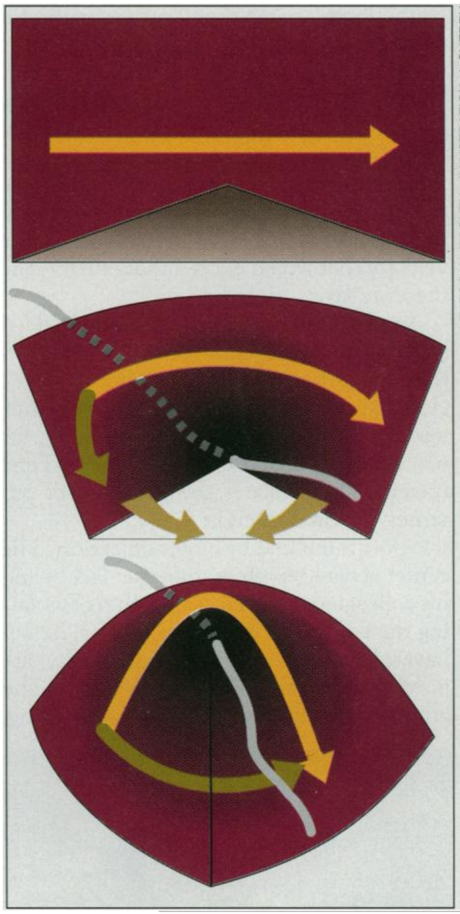
String theory. Precious few objects in the universe are massive enough to create the kind of shortcut Gott has in mind. So Gott started to play with the equations of general relativity, which describe the shape of spacetime, looking for an appropriately warped situation. He struck gold when he solved the equations for two infinitely long cosmic strings—thin streams of pure energy left over from the Big Bang—each moving at 99.999999992% the speed of light, hurtling past each other in opposite directions.

Okay, so that's not a situation likely to arise every day. But while cosmic strings are only theoretical objects, they're not outrageous ones by the standards of most astrophysicists. Since a single string's energy content, translated into mass, is the equivalent of 40 million billion tons per inch, it can distort any circular region of space centered on the string in a way analogous to cutting a wedge out of a paper disk to form it into a cone. By in effect slicing a wedge out of the surrounding space, the string's gravity opens up a potential shortcut in spacetime. One string isn't enough for time travel, Gott found, but send two of them toward each other at nearly the speed of light and spacetime will warp even further. The result: a closed timelike curve (CTC)—the technical term for a time machine. A spacecraft looping around the pair of strings could return to its starting point before it had left. Voilà, a quick jaunt into the past.

"It's an amazingly simple solution," says Massachusetts Institute of Technology (MIT) astrophysicist Alan Guth. "It doesn't take much physics to understand it." That's precisely what makes it so disquieting to Guth and other physicists. They know that any time travel plays havoc with the notion of cause and effect by opening the way for effects that precede—or even interfere with—their causes. Physicists have a "deep-seated belief that things should be causal," says Guth. To name one obvious problem: suppose you killed your grandfather before you were born.

> **"If we can understand how nature protects herself from time travel, we would understand space and time more fully."**
>
> **–Kip Thorne**

So, in no time at all, the race was on to erase Gott's argument. Even Gott, in his original paper, took a crack at his own brainchild by suggesting that, in most encounters of cosmic strings, wrenching gravitational forces might trigger the formation of a black hole. That way, any closed timelike curves that happened to form would be, if not prevented, at least sealed off from the rest of the universe.



SOURCE: ALAN GUTH ILLUSTRATION: J. CHERRY

A stitch in spacetime. The gravitational effects of a cosmic string warp spacetime, creating a shortcut *(olive)* along which a spaceship could outrace a light ray *(yellow)*.

Time out. That's not devastating enough for Guth, Edward Farhi of MIT, and Sean Carroll of the Harvard-Smithsonian Center for Astrophysics. They tried to undermine the Gott time machine by arguing, in the 20 January *Physical Review Letters*, that some plausible universes could not support it. They reached that conclusion by analyzing a simplified version of Gott's proposal in which each infinitely long cosmic string is represented as just a point mass in a two-dimensional universe. Through an analysis of the energy and momentum of such a system, they concluded that if the universe is open—if it doesn't contain enough mass to halt its expansion—and if its particles started out at rest, a Gott time machine is ruled out. There just isn't enough mass and energy to form Gott's cosmic strings and accelerate them to the needed speeds.

Gott has been quick to argue that this analysis may eliminate his time machine from certain universes—but not necessarily from our own. A more sweeping dismissal, though, appeared in the same issue of *Physical Review Letters*. The theoretical physics team of Stanley Deser of Brandeis University, Roman Jackiw of MIT, and Gerard 't Hooft of the Institute for Theoretical Physics in the

Netherlands argued that Gott's scenario for sneaking around the cosmic speed limit—the speed of light—is actually in flagrant violation of it. Jackiw and his colleagues determined the velocity of the strings' combined center of mass. Although you might expect their center of mass to be stationary, because the strings are moving in opposite directions, the warping of spacetime actually leads to a velocity that would exceed that of light, the theorists say.

In an interview with *Science*, Jackiw added a second broad objection, based indirectly on the grandfather paradox. Even though Gott's closed timelike curves would be rare, they would shatter the concept of causality, for which we have ample evidence, he says. Time travel simply violates the evidence of our senses, Jackiw contends.

Gott is unfazed by either objection. The center of mass representation that Jackiw and his colleagues rely on to accuse him of violating the cosmic speed limit is invalid, he believes, because the strings, individually, are moving at less than the speed of light. The group's argument, he says, amounts to saying, "We do not like what CTCs imply for physics, so CTCs are unphysical constructs."

As for Jackiw's other complaint, Gott concedes the point but insists it rules out closed timelike curves only in the present universe, not at some point in the past or future. To bolster his case, Gott points to a paper in the 15 January *Physical Review D* by Caltech physicist Curt Cutler. Cutler's paper shows, according to Gott, that a normal causal universe can briefly develop a closed timelike curve that then disappears, restoring sense to the universe.

While Gott fends off the published challenges, others are looming. Even now another paper by 't Hooft is circulating in the physics community as a preprint. The preprint argues that even in closed universes—where there is enough mass to halt expansion—closed timelike curves are impossible. In a closed universe, there would be no shortage of mass for building the time machine, but—in an ironical twist—there might not be enough time. The universe would collapse in a "big crunch" before a spaceship could travel around the strings and return to its starting point, 't Hooft claims.

Time tourists. Gott's scenario will also have to withstand the skepticism of Stephen Hawking, the noted theoretical astrophysicist at the University of Cambridge. Hawking has long argued against the possibility of time travel. For example, he drew upon quantum effects to dismiss a 1988 proposal by Caltech theoretical physicist Kip Thorne that wormholes—theoretical tunnels connecting distant points in spacetime—could serve as gates to the past. In an effort to prohibit time machines of any design, Hawking has just completed a manuscript, called "The Chronology Protection Conjecture," arguing that the laws of physics forbid closed timelike curves. Somewhat tongue-in-cheek, Hawking cites as "strong empirical evidence" for his conjecture the fact that "we have not been invaded by hordes of tourists from the future."

PRINCETON

Time-machine designer. Theoretical physicist J. Richard Gott has touched off a lively debate.

In a more serious vein, Hawking argues that, in general, closed timelike curves sow the seeds of their own destruction by creating a feedback loop in which small fluctuations in the energy of the vacuum travel back in time. At the end of the closed timelike curve, infinite energy builds up, distorting spacetime and disrupting the time travel mechanism. Thorne calls Hawking's work "a very powerful result" and explains the Catch-22 in time this way: "You kill [a closed timelike curve] the moment you create it."

Under this sort of withering assault, Gott's notion may finally collapse. But based on past experience, there's every indication that future generations of physicists will return to the Wells conceit time after time. As several physicists told *Science*, wrangling about such possibilities—or impossibilities—can sometimes lead to fresh insights about general relativity and, more generally, the nature of the universe. Remarks Thorne, "If we can understand how nature protects herself from time travel, we would understand space and time more fully." And after all, one physicist sheepishly admits, "There isn't a whole lot to do in fundamental physics right now."

–John Travis

PARTICLE PHYSICS

CERN's New Detectors Take Shape

When Carlo Rubbia presides over a physics meeting—as he did last month at Evian-les-Bains, France—he rules like a stern father at a family gathering. Physicists had come to Evian to display their proposals for the Large Hadron Collider (LHC), a European megaproject rivaling the United States' Superconducting Super Collider (SSC). The LHC will be built at CERN, in Geneva, in a tunnel that now houses an existing accelerator. And Rubbia, as director-general of CERN, was definitely the man to please if you wanted your proposal for doing science at the LHC to be included.

The contenders were grouped into four teams, each made up of hundreds of investigators collaborating on a single detector design. The CERN management, especially Rubbia and research director Walter Hoogland, insists that the teams were presenting only preliminary ideas, and that all the participating scientists will have an opportunity to get on an approved detector. But for many at the Evian meeting, the stakes were high. All knew that only two of the four proposals would be approved, a decision that will cause leaders to drop out and months of labor to go to waste. Rubbia promised to appoint a committee to do the winnowing, but he clearly will have a role in the decision himself.

So each team arrived at Evian with a spokesman to sell the merits of its particular design. The cast of protagonists included Peter Norton of England's Rutherford-Appleton Laboratory, Peter Jenni of CERN, Michael Della Negra of CERN, and Sam Ting of MIT.

The new particle detectors they were offering to build at LHC will be similar in concept to those at existing accelerators, but more sophisticated in design. These massive devices embrace intersections where bunches of speeding particles crash head-on from opposite directions, millions of times per second. Each collision sends out an explosion of energy and matter, and the detectors are supposed to capture and identify every shard of this debris. To do this, they employ thousands of tons of materials in an interlocking, Rube Goldberg arrangement of tricks and traps—liquid argon chambers, exotic crystals, and powerful electromagnets. A jungle of cables and wires connect the detectors to computers that sift the output for traces of exotic particles that may have lived for no more than a nanosecond.

The task of capturing these events will be