Charting the River of Time

General relativity suggests backward time travel is possible, given the right conditions. Now Ken Olum wants to know whether those conditions are possible.

by WILLIAM OREM

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I'm going to show that time travel is impossible," Ken Olum said, when asked for a simple explanation of his project.

Of course, there is also the more complex version. "In order to produce curved space we have to have some energy, but because of the curved space, we also get some negative energy. We're trying to show that the negative energy will always be much less than the original energy that was necessary to produce the space-time curvature."

What that amounts to is: no jaunts into the past. Such trips are not just improbable, Olum suspects, they are impossible—and he hopes to prove it.

Olum, a Research Assistant Professor at Tufts Institute of Cosmology, has received almost $86,000 over two years from The Foundational Questions Institute in support of his efforts to develop a mathematical proof that so-called exotic phenomena are forbidden in semi-classical theory.

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>
> *- Ken Olum*

"Semi-classical" means the universe as it is described by the best physics presently available, which has yet to integrate gravity into the Standard Model of particle interactions. Essentially, the semi-classical approach treats all fields as quantum except gravitational ones, fudging things in that respect until a compelling theory of quantum gravity can be developed. Meanwhile, "exotic phenomena" is the technical term for such darlings of science fiction as time travel, faster-than-light motion, and stable wormholes. Tantalizingly enough, Einstein's General Theory of Relativity rules none of these possibilities out.

"As far as the geometry goes, there is no problem with closed time-like curves," said Chris Fewster, a member of the Mathematical Physics group at the University of York in England, and co-author with Olum and Michael J. Pfenning of a recent *Physical Review* article on energy densities in limited regions of space-time. A "closed time-like curve" is a path through space-time in which the traveling object winds up where it started both in space and time. Leave the spot you are occupying right now on a closed, time-like trajectory, and you will arrive again just in time to watch yourself beginning this sentence. "However, the Einstein equations famously relate geometry to matter, and the problems begin when we try to work out what sort of matter distributions will allow closed, time-like curves to form," Fewster said.

This is where Olum comes in. It is well and good—indeed, fascinating—that General Relativity allows time travel in principle. Whether nature allows it in practice is a separate issue.

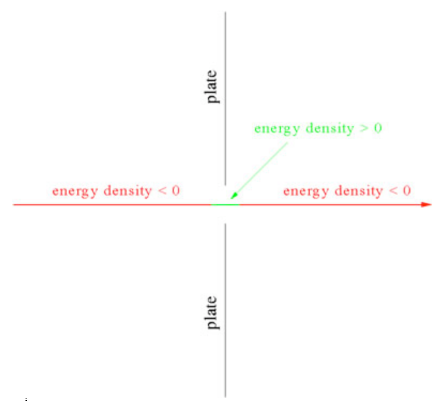
"Right now the question we face is whether a simple calculation might yield time travel," Olum said. "Nobody knows. Ruling that out is what we're trying to do."

Less Than Zero

Though it too sounds like the stuff of fiction, the negative energy in the complex version of Olum's project is already known to exist.

"There are situations where negative energy densities are predicted by quantum field theory," explained Fewster. "A well-known example is the Casimir effect, in which two uncharged plates are placed parallel close together in vacuum. Quantum field effects cause an attractive force between the plates, which has been measured in laboratory; the same theory also predicts that the energy density between the plates can be negative."

To understand how energy can be negative, set aside the classical interpretation of empty space, which is a vacuum with zero energy density. Instead, think of the vacuum as having only an *average* energy density of zero, in deference to the statistical fluctuations quantum mechanics says underlie fields. Given those vacuum fluctuations, zero energy is no longer the lowest energy state possible. Why? Because in order to average out to nothing, sometimes the vacuum must have tiny amounts of positive, and other times tiny amounts of negative, energy.



A PATH THROUGH A HOLE in a conducting plate has negative energy density far away, but larger positive energy density near the hole. The total is positive, so this geometry cannot be used for time travel. (The plate is oriented vertically in this diagram.)

The presence of Casimir plates affects the fluctuations, so that the negative energy density between extremely close plates compared to the positive energy density outside them leads to a measurable effect. Were we able to tease out an abundance of negative energy, all sorts of other surprising effects might be produced as well . . . including a quick trip to yesterday.

ANEC

But negative energy is hard to get and harder to keep. The cosmos is punctilious about balancing the energy books, a truth physicists recognize by referring to the ANEC, or Averaged Null Energy Condition. The ANEC essentially says that, though you can borrow a little negative energy on your route through space-time, you wind up paying it back with the positive type. Exotic phenomena are unlikely because they require some form of energy with a density that violates the ANEC—"they require that the total energy density be negative when we add up all the contributions over the complete path of the light ray," as Olum describes it.

Which is to say, a little trading in the energy margins is fine, but the end result will still be positive—or at least not negative enough, for long enough, over a large enough region to make any difference.

Along with Noah Graham, a Junior Faculty Fellow at Middlebury College, Olum has already shown that the ANEC still obtains between Casimir plates, even if you put holes in the plates so a photon can pass through in the most negative energy-friendly direction.

"What we found was the striking result that the region near the hole always contributed enough positive energy to overwhelm the ANEC violation," said Graham. "This result could be a coincidence of this particular system, but it certainly suggests there is a deeper principle at work."

With Fewster and Pfenning, Olum showed that there is such a principle at work in flat space, a finding confirmed by his work with Graham. If it applies to more complex systems as well, that principle may be the barrier to time travel.

"No collection of Casimir-type systems in flat space can violate the ANEC," Olum said. "This we succeeded in showing. So the next thing to do is to try this for interacting fields, and curved space."

Olum is skeptical of any exotic outcomes, however. There is no free negative-energy lunch in the special case and, he suspects, there isn't going to be one in the general case.

"I have tried to construct these exotic things before, using what seemed to be promising ideas, and I have not been able to construct them. So I think that it's impossible. And I have good reasons to think that it's impossible," he said.

"Without constructing the proof, though," he added, "one can't be certain."

Is Nature Paradoxical?

Notably absent from Olum's work is any concern with what might be called the "folk objection" to time machines. Backward time travel strongly violates our intuitive sense of how things must work, especially with its capacity to generate paradoxes. Suppose a particle emitted at 2:00 followed a closed timelike curve to emerge at the same location at 1:59:59, colliding with itself in such a way as to prevent itself from taking the initial trajectory. Where did the interrupting particle come from? Or, in the popular version of this argument, could a time traveler kill his grandparent (or parent, or himself as an infant), thus preventing himself from becoming a time traveler? The absurdities have led some to exclude the possibility *a priori*, but Olum is not among that number.

"I kind of prefer the paradoxes," Olum said. "Certainly, discovering time travel is more exotic than ruling out time travel. Of course, you're in trouble once you discover it because of all the paradoxes. But I personally am not motivated by that. I think it would be interesting if a paradoxical situation did arise. The reason I'm trying to prove the paradoxical situation doesn't arise is only that I'm trying to settle the issue one way or another."

And, as he pointed out, plenty of things have been ruled nonsensical in the past, later proven to be no such thing. Olum notes that he is still in possession of an old popular science book that dismisses black holes out of hand as a logical impossibility—reminding us that today's paradox may be tomorrow's physics.

But Olum is nonetheless cautious.

"My impression about the situation now is that the likely answer is that time travel is impossible," he said. "So I'm setting out to prove it. If I thought the likely answer was that it's possible, then I'd be setting out to do it."

Even If Semi-Classical Gravity Does Exclude Exotic Phenomena, They May Still Occur in Quantum Gravity

If Olum succeeds in constructing his proof, he will have ruled out exotic phenomena from the semi-classical universe. Such a description, however, is only provisional.

"We're doing the best we can in the arena we understand," Olum said. "If you really want to know everything about what is and isn't possible, you should of course have a complete Theory of Everything, and we don't have such a theory."

Einstein struggled to the end of his days to find a Theory of Everything, but neither he nor anyone since has been able definitively to provide it. Many physicists feel, though, that when the quantum nature of gravity is finally understood, it may turn out that exotic phenomena occur routinely – for very, very small things.

"On exceptionally small scales (not much bigger than 10^{-35} meters) the structure of space-time is quite probably very different from the smooth continuum that we imagine on larger scales," said Fewster. "Exotic phenomena on that scale might well be possible."

For example, wormholes of a subatomic size may open and close spontaneously in a quantized space-time, allowing nearby particles to slip into their own pasts.

"When you include quantum effects in the theory of General Relativity, you invalidate the known principles that prevent time travel," said Graham.

The danger of chronology paradoxes is an entirely different matter for quantum gravity systems, however. For example, all electrons are identical, a situation for which there is no macroscopic parallel. To say that two electrons are present at a given moment may therefore be indistinguishable from saying that the same electron is present in two locations. Further, an electron moving backward in time would from one perspective be equivalent to a positron moving forward.

Indeed, decades ago, such considerations motivated the theoretical physicist John Archibald Wheeler to wonder whether all electrons may in fact be the same particle, hopping endlessly about in space and time. Resolving temporal paradoxes at the quantum level may thus turn out only to be a matter of choosing a suitable frame of reference.