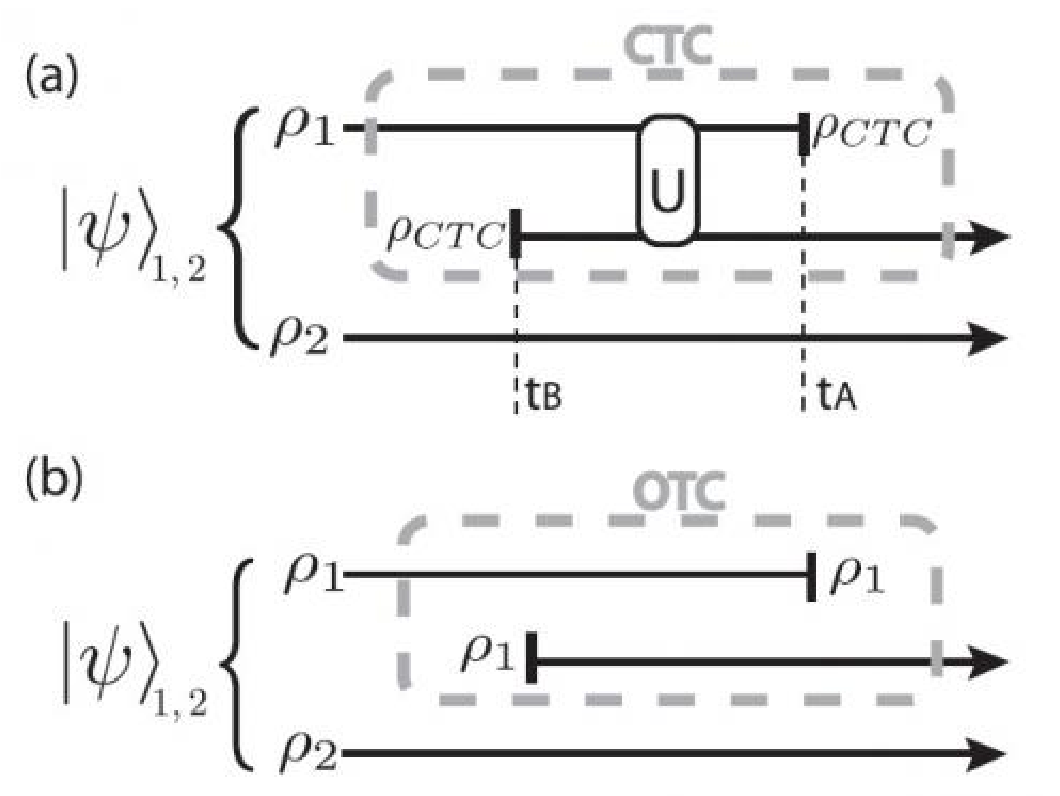
Curves in spacetime violate Heisenberg's uncertainty principle

February 19 2013, by Lisa Zyga



(a) A closed timelike curve, in which p2 is a chronology-respecting system, and p1 is a time-traveling system that can jump from point tA to the past point tB through a spacetime wormhole, has the ability to interact with itself in the past. (b) In an open timelike curve (OTC), the system cannot interact with itself in the past. In the new study, physicists have theoretically shown that OTCs can violate Heisenberg's uncertainty principle, provided p1 is entangled with p2. This proposal could be tested by performing experiments on entangled systems in Earth's gravitational field. Credit: J. L. Pienaar, et al. ©2013 American Physical Society

(Phys.org)—If an object traveling through spacetime can loop back in time in a certain way, then its trajectory can allow a pair of its components to be measured with perfect accuracy, violating Heisenberg's uncertainty principle. This new finding involves a particular trajectory called an open timelike curve (OTC), which is a special case of a closed timelike curve (CTC), a theoretical concept that has previously provoked controversy because it raises the possibility of traveling backwards in time.

According to Heisenberg's uncertainty principle, measurements of any pair of variables must have at least a minimum amount of error. The most well-known example of the pair of variables is position and momentum, but the principle applies to any two variables that have a mathematical relationship which makes them conjugate variables. The uncertainty principle is thought to be an inherent property of quantum systems due to their wave-particle duality, rather than any observational limitations. Although previous studies have found that CTC models can theoretically violate the uncertainty principle, nobody knew that this could happen for the special case of an OTC.

Now, physicists Jacques Pienaar, Tim Ralph, and Casey Myers at The University of Queensland in Australia have theoretically shown that OTCs can allow scientists to measure a pair of conjugate variables of a quantum state to an arbitrary degree of accuracy forbidden by the uncertainty principle. The finding could have implications for quantum gravity and change the way that scientists view quantum uncertainty.

"There is some speculation that the Heisenberg uncertainty principle might be different in a future theory of quantum gravity," Pienaar told *Phys.org*. "However, most of these studies suggest that quantum gravity will introduce more uncertainty. Our model suggests the complete opposite: that a theory of quantum gravity might actually remove the uncertainty of quantum mechanics."

This perfect measurement ability arises from the nature of OTC trajectories. As the physicists explain, OTCs are the simplest and most normal type of CTCs. Whereas CTCs form closed loops in time that allow systems to affect events in their own past, OTCs form open loops in time and do not allow systems to interact with previous versions of themselves. These interaction-free OTCs overcome some of the paradoxes associated with time travel, such as the grandfather paradox in which a time traveler kills their own grandfather, preventing their own existence.

Despite such paradoxes, CTCs in general are compatible with general relativity; however, they are not compatible with quantum mechanics. One way to make them compatible is to extend quantum mechanics in a way that resolves the paradoxical aspects of CTCs. An example of such an extension is the Deutsch model, which makes the mathematics of quantum mechanics nonlinear, allowing for CTCs. Previously, scientists have shown that this nonlinearity leads to some unusual properties, such as the possibility to build a super quantum computer that can quickly solve some complex problems called NP-complete problems, a task that would take trillions of years using today's computers.

In the new study, the physicists have shown that the Deutsch model's nonlinear mathematics also applies to OTCs, where there is no interaction between the past and present, provided that entanglement exists between the time-traveling system and an external system. To reach this conclusion, the physicists calculated what happens when quantum states travel through a quantum optics circuit that contains an OTC. In this theoretical situation, two quantum states are "squeezed" in orthogonal directions. After the states cycle through the circuit several times, the scientists found that they could measure the orthogonal components with arbitrary accuracy.

Another interesting feature of these OTCs is that they resemble time dilation in general relativity, in which two clocks measure different times under different gravitational conditions. In a similar way, OTCs create a time difference between two initially synchronized trajectories. As the scientists explain, this resemblance means that an experimenter observing an OTC system and a time dilation system might not be able to tell whether the time difference was due to the gravitational curvature of general relativity or to the trajectory of an OTC. This finding suggests that modeling gravitational time dilation as an OTC effect could have implications for a theory of quantum gravity.

"Deutsch's model describes the strange quantum effects that we might see in the presence of CTCs, within a future theory of quantum gravity," Pienaar said. "However, if there are no CTCs in the universe, then we would not expect to see the effects. But since the slowing of time due to gravity looks just like the effect of an OTC from the outside, and since OTCs still lead to strange effects (as we have shown), we suggested that these effects might turn up in strong gravitational fields, even without any closed loops in time. If so, then they would allow us to violate the Heisenberg uncertainty principle and clone coherent states of light without needing a full-blown time machine.

"Of course, the connection between OTCs and gravitational fields is still very speculative and might turn out to be wrong. We hope to flesh it out into a more complete theory in future research."

The physicists propose that testing this possibility—by testing the Deutsch model's nonlinear effects—could be done with current technology by performing experiments on entangled systems in Earth's gravitational field. As the scientists explain, this kind of experiment would serve as an alternative to experimenting with real OTCs, which are rather hard to come by.

"The circuit itself is easy to build; it's coming up with an OTC that's the problem!" Pienaar said. "Strictly speaking, we would require an actual time machine in order to build that circuit, which we obviously don't have. However, if our analogy between OTCs and gravity is correct, then we could make do with just an ordinary gravitational field like Earth's. In that case, the circuit certainly can be built; there is already a group working on sending entangled beams of light up to a satellite in orbit. This would then provide an experimental test that could either prove or disprove our claim about gravity behaving the same as an OTC."

More information: J. L. Pienaar, et al. "Open Timelike Curves Violate Heisenberg's Uncertainty Principle." *PRL* 110, 060501 (2013). DOI: 10.1103/PhysRevLett.110.060501

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