Quantum experiment in space confirms that reality is what you make it

By Adrian ChoOct. 27, 2017 , 5:15 PM

To test quantum theory, physicists used the Matera Laser Ranging Observatory in southern Italy, which usually tracks satellites to monitor tiny changes in Earth's shape.

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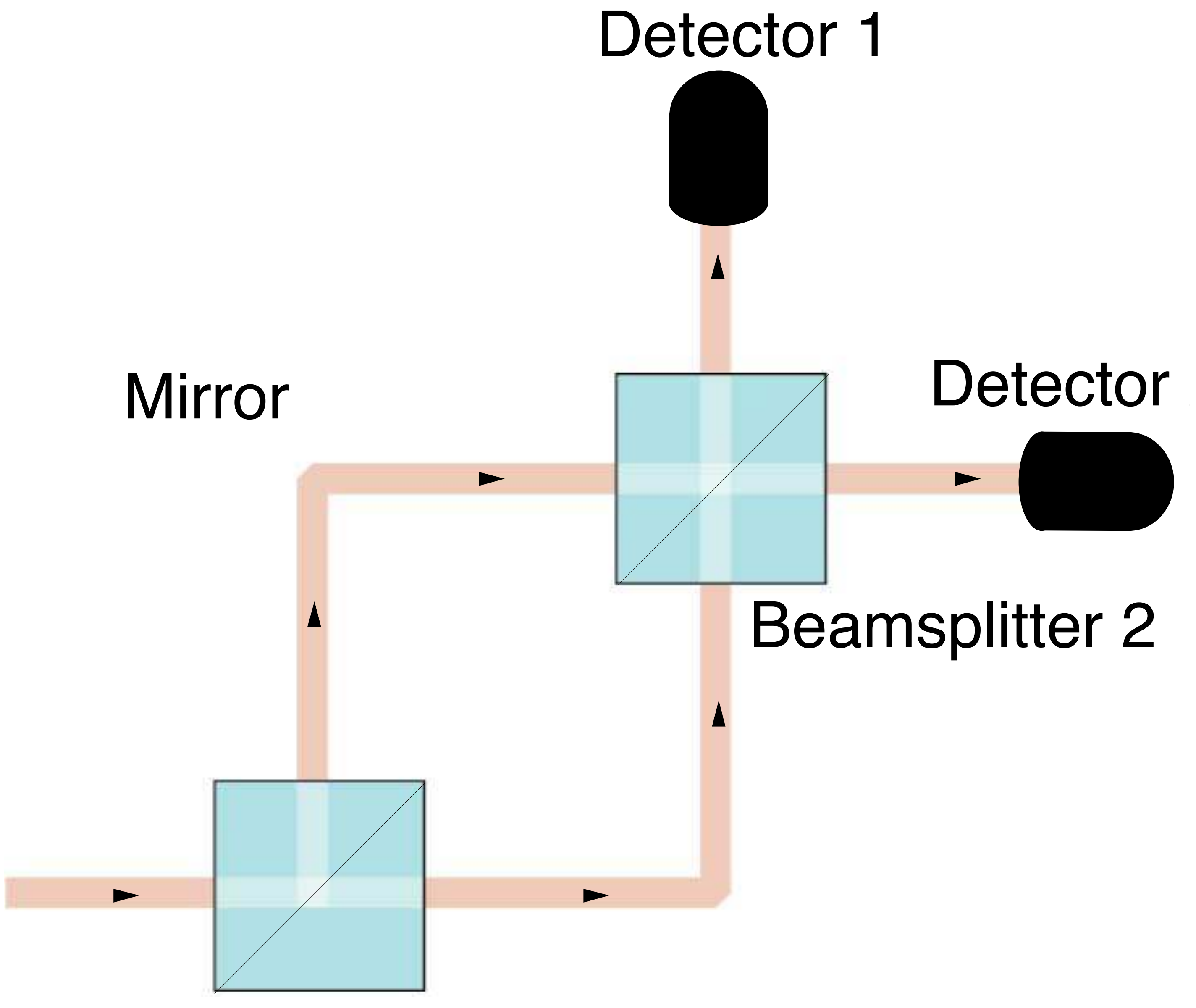
An odd space experiment has confirmed that, as quantum mechanics says, reality is what you choose it to be. Physicists have long known that a quantum of light, or photon, will behave like a particle or a wave depending on how they measure it. Now, by bouncing photons off satellites, a team has confirmed that an observer can make that decision even after a photon has made its way almost completely through the experiment—seemingly well past the point at which it would become either a wave or a particle. Such delayed-choice experiments might someday probe the fuzzy frontier between quantum theory and relativity, researchers say.

Other researchers have demonstrated the same counterintuitive effect in the laboratory. But the new work shows that a photon's nature remains undefined even over thousands of kilometers, says Philippe Grangier, a physicist at the Institute of Optics in Palaiseau, France, who collaborated on an earlier test. "It's a very nice experiment that demonstrates their ability to do quantum physics in space."

A photon can act like a bulletlike particle or rippling wave—but not both at once—depending on how experimenters decide to measure it. In the late 1970s, famed theoretician John Archibald Wheeler realized that experimenters could even delay the choice until the photon had made its way almost completely through an apparatus configured to emphasize one property or the other, thus proving that the photon's behavior isn't predetermined.

Wheeler imagined sending photons one at a time through a so-called Mach-Zehnder interferometer, which accentuates light's wave nature. Using a mirrorlike "beam splitter," the interferometer splits the entering photon's quantum wave in half and sends the two waves along different paths, like people walking opposite ways around the block. A second beam splitter then recombines the waves, which interfere with each other to shunt the photon toward either one of a pair of detectors. Which detector is triggered depends on the difference in the two paths' lengths, as expected for interfering waves.

A photon ordinarily takes both paths through a Mach-Zehnder interferometer, and wavelike interference can then shunt it toward one detector or the other. Remove the second beam splitter and, like a particle, the photon must take one path or the other and is equally likely to hit either detector.



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Remove the second beam splitter and interference becomes impossible. Instead, the first beam splitter sends the photon down one path or the other, like a particle. As the paths cross where the second beam splitter would have been, the detectors click with equal probabilities regardless of the paths' lengths. Wheeler realized that experimenters could even wait to remove the second beam splitter until after the photon had passed the first beam splitter. That assertion suggests, weirdly, that a decision in the present determines an event in the past: whether the photon split like a wave or took one path like a particle. Quantum theory avoids the issue by assuming that, until measured, the photon remains *both* a particle and a wave.

Now, a team led by Francesco Vedovato and Paolo Villoresi of the University of Padua in Italy has performed a version of the experiment using the 1.5-meter telescope at the Matera Laser Ranging Observatory in southern Italy to bounce photons off satellites thousands of kilometers away. At such distances, physicists cannot make light take two parallel paths, Villoresi notes, as the spreading beams would overlap and merge. Instead, they send a photon through a Mach-Zehnder interferometer on Earth that has paths of very different lengths. The difference in path lengths splits the single pulse into two, separated in *time* by 3.5 nanoseconds, which the telescope then shoots skyward.

Once the pulses return, the experimenters run them back through the interferometer. The apparatus can either undo the time shift so that the two pulses overlap and interfere like waves or double it so that no interference is possible. Of course, the physicists must choose which thing happens. When the pulses first leave the interferometer, they have different polarizations. To undo the time shift, physicists must first use a very fast electronic polarization to change their polarization in a certain way. To double the time shift, they simply leave their polarizations alone.

When experimenters make the pulses overlap, the photon triggers one detector or another with a probability that depends on the satellite's recession speed, as expected for interfering waves. When the pulses cannot interfere, then the photon, like a particle, ends up in either detector with a 50-50 probability regardless of the satellite's speed. Crucially, physicists choose which measurement to make after the light pings off the satellite halfway through its 10-millisecond round-trip, they report 25 October in *Science Advances*. Again, the delayed decision seems to reach back in time, defining how the photon behaved after it left the first beam splitter.

The experiment isn't the most stringent test of Wheeler's idea, notes Jean-François Roch, a physicist at the École Normale Supérieure in Paris, who in 2007 led a more faithful test. For example, to see the light at all over such long distances, Villoresi and colleagues must fire pulses containing many photons, instead of the individual photons Wheeler specified. Still, Roch says, the experiment is a noteworthy example of taking "quantum optics" out of the lab and into space. In May, physicists in China used a satellite to establish a weird quantum connection called entanglement between two photons sent to widely separated cities.

Delayed-choice experiments could help probe the boundary between relativity—which requires that cause precede effect—and quantum theory, Roch says. Even though, strictly speaking, the effect does not violate causality, it still raises a tension by suggesting that a measurement in the present shapes what can be inferred about the past. "This area where you mix quantum mechanics and relativity is still relatively unexplored," Roch says, "and this is the sort of experiment that raised the possibility of probing the link" between the two.