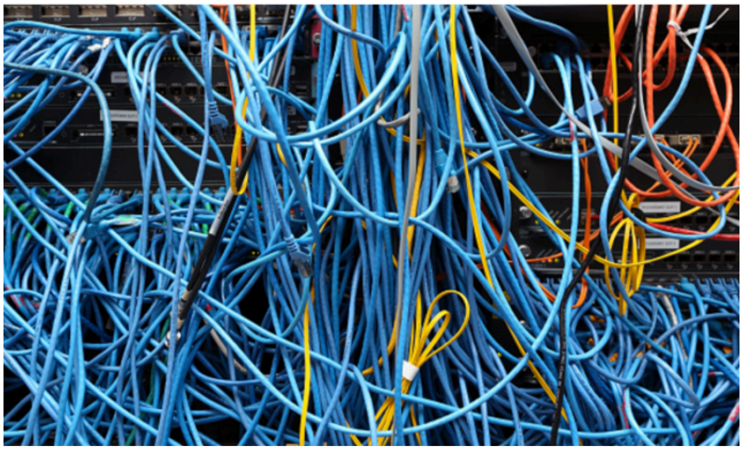
HIGHLY UNLIKELY —

Starlight-controlled entanglement experiment makes shared history unlikely

Entanglement is real, or device settings were determined 600 years ago by a star.

CHRIS LEE - 2/16/2017, 12:28 PM



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We're talking a slightly higher level of entanglement, here.

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Quantum entanglement is one of the most difficult concepts in physics to grasp. In fact, I would go so far as to say that most physicists don't fully grasp it. That's not ideal, given that entanglement and tests of entanglement are key to understanding the Universe as we know it.

Entanglement and the non-deterministic nature of quantum mechanics also make people uncomfortable; a lot of people have hoped entanglement can be explained by some underlying deterministic physics. But new tests have pretty much burned the last of the get-out-of-jail-free cards for those who really, really don't like entanglement.

The question that underlies all of this is surprisingly philosophical in nature. Are we living in a world where all is predetermined? If the world followed the rules of Newton (and, later, Einstein), then we'd have to say yes. Given the starting

conditions of the Universe, everything unfolds in a deterministic and predictable manner. Sure, we might not be able to predict every detail, but that would be due to our lack of knowledge about the starting conditions or a limited ability to compute.

If the Universe follows the rules of quantum mechanics, however, then the Universe is not predictable even in principle. Tests of entanglement are actually the best way to look for hidden determinism in the Universe. Those tests are hard, because there are a number of tricks that the Universe could play on us to make it look like things aren't deterministic. To play the game, it's not enough to know the rules—you also have to know how to cheat.

The rules

Since this particular bit of research uses polarization, I'll describe entangled photons in those terms. Imagine a single photon with its electric field oscillating up and down in space as it travels. We would say that this photon is vertically polarized. I cannot actually measure the polarization of the photon, but I can ask it if it is vertical or horizontal. In this case, I would get vertical as an answer with absolute certainty.

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Polarization

I could also set my measuring device at a 45-degree angle. A measurement under these circumstances is uncertain. That is, there is a 50 percent probability of observing that a single photon is at +45 degrees or - 45 degrees. Critically, I cannot determine from this measurement that the photon was *vertically* polarized. The only way to calculate the outcome of a measurement is to assume that the photon is simultaneously +45 and -45 degree polarized. This is called a superposition state.

FURTHER READING
Quantum superposition

Now we can get to entanglement: imagine a single photon that, for reasons we won't go into, splits into two photons. This can happen as long as certain properties are conserved—between them, the two photons have to have the same energy, momentum, and angular momentum as the original photon. Angular momentum, in the case of a photon, is polarization. So, if we have one photon that is vertically polarized, we cannot, after splitting the photon, have two photons that are vertically polarized. Instead, their resulting polarizations should sum to one vertically polarized photon.

FURTHER READING
Quantum entanglement

That puts both photons into a

different polarization state, called circularly polarized. In fact, both photons end up in a superposition of two circularly polarized states. Now, a simultaneous measurement of the polarization state of both photons cannot result in just any value—if both photons were measured as vertically polarized, conservation of momentum would be violated. Thus, if one photon is measured to be in a vertically polarized state, the other cannot have any vertical polarization—it must be in a horizontal state. If the measurement is simultaneous, it cannot be thought of as two independent random choices. There is only one random choice, which is applied to both photons.

This may seem weird. You might think that the polarization states were set from the start. You might think that there is no entanglement: each photon has a predetermined state that conserves angular momentum.

But this is not so.

We can make the experiment more complicated by choosing the orientation of the measurement device. I can randomly choose orientations of my instruments and make simultaneous measurements of both photons. If the particles were in a specific state when they were created (a state that would look entangled), I would expect my measurements to result in polarization correlations that were only due to random chance. If they were in this undefined entangled state, I expect stronger polarization correlations. The correlations we observe are stronger than that expected from random chance. So, the entangled state really does seem to exist.

Does Nature cheat?

Are there other ways to explain this correlation? If the two measurement devices are close enough together, it is possible that there is classical communication between the hardware that ensures correlated measurements. Wait, you say—the measurements are simultaneous. They are, but only to within a certain time window. It takes time for a random number generator to choose a setting and apply that setting to the physical device. That means there are usually a few nanoseconds for nature to mess with us.

This type of cheating was eliminated by separating the measurement locations and delaying the decision about measurement settings until the last possible moment. This eliminated light-speed communication between measurement locations. The correlations remained.

Nature has other tricks up her sleeve. For instance, no experiment is perfect: my entangled photon emitter might emit 1,000 photons per second, but my detectors might only detect 70 of them.

Maybe the detector isn't fair and is rejecting photons that are (due to random chance) uncorrelated. In this case, I would measure a correlation only because the lost photons were all uncorrelated.

That's also something we can measure and check. We now have experimental data for cases where we know that sampling was fair, and the correlation remains.

That leaves the process of randomly choosing the device measurement settings. We say they are random. And by every test of randomness that we possess, they look random. But what if each "random" choice was predetermined by a previous event?

Imagine that I have my two detectors, one in Paris, and one in Washington. In both cases, I use a radio antenna to generate a random number based on the amplitude of the electromagnetic white noise in the vicinity of the detector. This should be random. However, you can imagine that a strong radio emitter somewhere in the Atlantic Ocean could, conceivably, correlate the two random number generators.

That would be man-made interference. But to be more general, we have to consider the possibility that our sources of randomness are correlated because they are linked by shared historical events.

Flickering starlight

To test this, researchers went to extremes. They separated their two detectors by about a kilometer. And the device settings weren't randomized using any random number generating hardware. Instead, random settings were generated by measuring the light from a pair of stars elsewhere in the Milky Way. Yes, the researchers purchased a couple of small telescopes and pointed them in opposite directions toward bright stars, and they used their photons to provide randomness. So, the stars are not only several light years from Earth, but the light emitted from them enters the atmosphere from different directions.

To eliminate most other sources of interference, the researchers didn't use the absolute brightness of the stars but instead divided the starlight into red and blue bands. They then used "red" photons to signal one device setting and "blue" photons to trigger the second settings. Since the color of a photon is set when it is generated, this places the moment at which the random number was generated back at the time when the light was emitted. And to influence that, the controlling event had to be such that it could influence *both* stars.

Taking into account the stellar separation, the researchers showed that the random number generated could only be driven by a deterministic event that was some 600 years in the past.

This particular experiment is not perfect. Unlike lab experiments, the researchers do not have the possibility to ensure that the detectors attached to their telescopes are not biased. So, although they can show that they can probably make random choices, they can't be sure that their detector wasn't throwing away a select group of photons. However, considering that other experiments have shown this is not the reason for the correlation, I think it is fair to say that this is unlikely to be generating the correlation in this case, as well.

We also can't absolutely eliminate the possibility that nothing is random, because it could be that the Universe is unfurling in a completely deterministic way that just *looks* random to us. In this case, even using cosmic microwave background radiation would yield "random" numbers that would be correlated. On the other hand, I'm pretty happy taking the view that if it passes every randomness test that we can realistically apply, we might as well call it random.

Physical Review Letters, 2017, DOI: 10.1103/PhysRevLett.118.060401
