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ENTANGLEMENT

Ancient Starlight Just Helped Confirm the Reality of Quantum Entanglement

“The real estate left over for the skeptics of quantum mechanics has shrunk considerably."

By **Daniel Oberhaus** | Aug 21 2018, 7:38am

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On Monday, a group of researchers from MIT **published the results** from recent experiments that used the light from stars emitted 7.8 billion and 12.2 billion years ago to help confirm the reality of quantum entanglement.

These results help settle a long standing debate in physics about whether entanglement is just an illusion that can actually be explained using principles of classical physics. These new results suggest that entanglement actually occurs because if it didn't exist the universe would somehow have to have "known" 7.8 billion years ago that these MIT scientists would perform these experiments in 2018.

QUANTUM LOOPHOLES

Quantum entanglement is the theory that particles can be connected in such a way that measuring one particle can instantaneously convey information about that measurement to the other particle, regardless of the distance between them. It almost sounds like magic, which is probably why it received a healthy dose of criticism from the physics community when the theory was first proposed nearly 100 years ago.

Albert Einstein was a particularly vocal critic of entanglement, which he famously described as "**spooky action at a distance**." Part of Einstein's beef with the quantum mechanics crowd was that he believed that particles have definite qualities that exist before they are measured and that two particles distant in space and time can't affect one another instantaneously since they are limited by the speed of light—a viewpoint known as local realism.

Under quantum mechanics, however, the properties of a particle don't exist independently of measurement used to determine those properties. Moreover, when it comes to entangled particles, the measurement of one particle will instantaneously influence the properties of the other entangled particle. This means that the values of these properties will be highly correlated—so highly correlated, in fact, that the degree of coincidence in their values can't really be explained without recourse to quantum mechanics.

Nevertheless, local realism has continued to haunt the development of quantum physics. In the 1960s, the physicist John Bell calculated the upper limit on the degree of correlation between two particles if their relationship was governed by local realism rather than quantum mechanics—a value known as Bell's inequality.

> “As strange as quantum mechanics may seem, it continues to match every experimental test we can devise.”

In the past half-century, however, numerous experiments have demonstrated values in excess of Bell’s inequality, which created a serious theoretical dilemma. Either these experiments demonstrated the reality of quantum entanglement or there were some “loopholes” unintentionally introduced into the experiments that could explain the results through classical physics without invoking quantum mechanics.

One of the most pernicious loopholes is known as the “freedom of choice loophole.” This is the idea that the way a researcher sets up an experiment—from the choice of particles used to the way properties of these particles are measured—can influence the results of the measurement in unforeseen ways. In order to truly demonstrate quantum entanglement, critics argue, it is necessary to negate this freedom of choice loophole in quantum experiments.

A COSMIC SOLUTION TO FREEDOM OF CHOICE

In May, a group of researchers led by physicists from the Institute for Photonic Sciences in Spain published the results from the largest experiment to tackle the freedom of choice loophole. This experiment involved **over 100,000 people from around the world playing a video game** and the results of their gameplay were used in the experiment. The idea was that because the actions of these 100,000 people could not be predicted in advance, this would effectively remove any bias introduced into the experimental set up by researchers and thus close the “freedom of choice” loophole in the experiment.

> ***Read More:*** ***The Results of a 100,000 Person Quantum Experiment Seem to Violate Einstein’s Theory of Local Realism***

Around the same time these researcher were collecting their data from participants, however, a group of physicists led by researchers from MIT were also exploring how to close the freedom of choice loophole in quantum mechanics. Yet rather than search for solutions on Earth, these physicists turned to the cosmos to eliminate human bias.

In the past, physicists have tried to close the freedom of choice loophole by generating entangled particles from a single source and then sending these entangled particles to detectors at two different locations. In the instant before the particle arrives, the detectors would use a random number generator to decide what property of the particle to measure (spin, polarity, etc.) in an effort to eliminate human bias. The problem, however, was that even this random number generator could technically be influenced by hidden, non-quantum variables that affect the measurement.

To eliminate the influence of hidden variables, the researchers from MIT ditched the random number generators in favor of stars. In their experiment, the MIT researchers trained telescopes at two detector sites on various stars at least 600 light years away and used the photons from these stars to determine which measurements would be conducted on entangled particles at the detectors. The theory was that using 600 year-old starlight would help close the freedom of choice loophole because any hidden variables in the experiment would have to have been set in motion before the photons left their host star over 600 years ago.

"The real estate left over for the skeptics of quantum mechanics has shrunk considerably," MIT physicist David Kaiser said in a **statement** shortly after the results of the experiment were published last year. "We haven't gotten rid of [the freedom of choice loophole], but we've shrunk it down by 16 orders of magnitude."

In research published in ***Physical Review Letters*** on Monday, the same team of MIT physicists made some wild improvements on their previous measurements and reduced the freedom of choice loophole even more. The new experiment is more or less the same, but instead of using normal stars as their source of randomness for quantum measurements, the researchers used light from two ancient quasars that were 7.8 and 12.2 billion light years away.

"The Earth is about 4.5 billion years old, so any alternative mechanism different from quantum mechanics that might have produced our results by exploiting this loophole would've had to be in place long before even there was a planet Earth, let alone an MIT," Kaiser said in a **statement**. "So we've pushed any alternative explanations back to very early in cosmic history."

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Quasars are basically dense clouds of gas that surround the massive black holes that can be found at the center of most galaxies. As the gas from the quasar falls into the black hole it emits strong bursts of energy that are smeared across the electromagnetic spectrum. In the most recent experiment, the researchers used incredibly sensitive telescopes to measure the wavelength of photons—particles of light—emitted by the quasars.

At the same time, a station between the two telescopes generated thousands of entangled photons which were then sent to detectors at the telescope. For each pair of entangled photons, the detectors would measure the wavelength of incoming interstellar photons relative to some baseline metric and use this value to determine what measurement would be performed on the incoming photons.

In total, the researchers performed this measurement on just shy of 30,000 entangled photon pairs. The correlation between the measurements performed on the photons far exceeded Bell's inequality, which suggested that the particles were experiencing quantum entanglement. In fact, Kaiser and his colleagues calculated that the odds that this degree of correlation was the result of classical rather than quantum physics was about one in one hundred billion billion. According to MIT physicist Alan Guth, the research makes it "unbelievably implausible that a local realistic theory could be underlying the physics of the universe."

Despite the overwhelming results in favor of quantum entanglement, there's still the (incredibly) small possibility that local realism can account for these effects. To reduce these uncertainties even more, Kaiser, Guth and their colleagues are considering experiments that look even further back in time for a source of randomness, such as the cosmic microwave background. Performing these experiments, however, would involve overcoming a host of significant technical challenges.

"It is fun to think about new types of experiments we can design in the future, but for now we are very pleased that we are able to address this particular loophole so dramatically," Kaiser **said**. " Our experiment with quasars puts extremely tight constraints on various alternatives to quantum mechanics. As strange as quantum mechanics may seem, it continues to match every experimental test we can devise."

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