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Is entanglement real or is there a super-deterministic cosmic conspiracy?

Researchers use quasars to kill off the last of the quantum hidden variables.

by **Matthew Francis** - Feb 21 2014, 9:05am PST

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Composite optical and X-ray image of quasar 3C 186, one of the most distant yet observed. Two such quasars on opposite sides of the sky could close a loophole in interpreting quantum entanglement experiments.

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Entanglement is one of the stranger aspects of quantum mechanics. Once two particles are entangled, you can separate them by any distance, and measurements of one will instantly set the state of the second.

Because this behavior is so weird, researchers have been trying to find out if there might be some classical behavior going on that is masquerading as quantum physics. One possibility they've considered is that the detectors are interacting with quantum systems in a hidden way to fool us into thinking entanglement is real. Admittedly it's an unlikely proposition, but one that is difficult to dismiss entirely.

It may be that we're limited to making only certain measurements because there is some sort of cryptic information exchange between particles and the devices measuring them. If this is the case, then human researchers have far less choice than they think they have when it comes to performing experiments. One way to test this is to arrange an entanglement experiment that will produce different outcomes based on whether these hidden interactions exist or not.

That's the premise of a new paper by Jason Gallicchio, Andrew S. Friedman, and David I. Kaiser. They proposed using light from quasars on opposite sides of the sky to set the detector configurations in entanglement experiments. Since quasars—powerful jets from black holes—are extremely distant, any pair sufficiently far apart in the sky would never have interacted during the lifetime of the Universe.

That provides a measure of independence for entanglement tests: if any hidden interactions exist, then detectors configured via quasar would produce different results than detectors configured by ordinary randomization procedures.

Entanglement involves two quantum systems prepared such that some of their properties are not independent. The common type of experiment creates two photons that have opposite polarization orientations. The experimenter cannot know the polarization state (to use the quantum terminology) of either photon without performing a measurement. Yet finding the polarization of one photon affects the result of any measurement taken on the other photon—no matter how far the two detectors are separated. Experimenters sometimes even randomize the configuration of both detectors to ensure their independence, but the measurements they make are still correlated.

A tangled subject

Quantum entanglement is a tangled subject, inspiring both nonsense and astounding experimental creativity. Over the last several decades, researchers have entangled eight photons, performed quantum erasure between islands, and showed entangled systems don't depend on the order measurements are taken.

That's all in accordance with the predictions of quantum theory, but it need not be that way. For example, a number of researchers have proposed alternative models involving "hidden variables," properties of quantum systems that are not directly accessible to experimenters. The hidden variables would produce most of the same entanglement effects, but avoid the weird bits.

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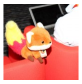

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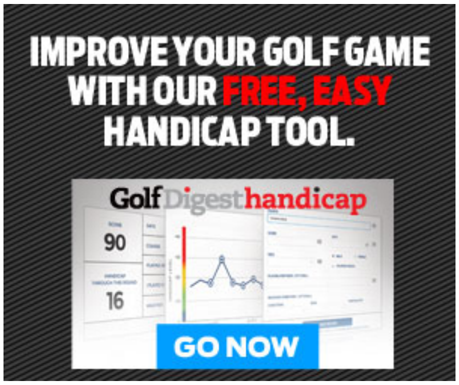

Some of these models preserve "local realism," the notion that hidden variables are not shared by the two halves of an entangled system. To get the correlations we see in experiments, information must have passed either between the two measurement devices, or between the devices and the particle they're about to measure. (Another possibility is "non-local" hidden variables, including something known as Bohmian mechanics, but that's unimportant for now.)

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However, local hidden variables have definite deviations from the behavior predicted by standard quantum theory. John S. Bell derived a number of mathematical relations known now as the "Bell inequalities," which quantify the differences between the various models. All experiments thus far have upheld the "no local hidden variables" version of quantum mechanics, but there are still a few very narrow loopholes left.

If a detector has some correlation with the hidden variables of the particles being measured, then the two detectors don't act independently. That's true even if only a very tiny amount of information is exchanged less than a millisecond before measurements take place. The interaction would create the illusion that the particles are entangled in a quantum sense, when in fact they are influencing the detectors, which in turn dictate what measurements are being taken. This is known as the "detector settings independence" loophole—or somewhat facetiously as the "free will" loophole, since it implies the human experimenter has little or no choice over the detector settings.

The amount of information required to preserve the illusion of quantum physics is very tiny, so it would be difficult for conventional entanglement experiments to sniff them out. The millisecond needed for this effect, after all, is short by human standards, but incredibly long in quantum terms.

12 billion light years of separation

Using two quasars separated by billions of light-years would eliminate the problem: instead of milliseconds, the hidden variables would have had to have been present for the entire existence of the Universe. The authors proposed picking two quasars at least 12 billion light-years away from Earth (of which astronomers have observed a plethora), and at least 130° apart on the sky. (Ideally the separation should be 180°, but it's impossible to simultaneously observe two objects precisely opposite on the sky from the same location on Earth.)

That's enough to ensure those quasars could never have interacted since the Universe was little more than a disorganized swarm of particles, and therefore could never have shared any quantum information. Any hidden variable exploiting the detector settings independence loophole would not be able to correlate over that long a time frame.

The proposed experiment would use photons from one quasar to set the orientation of one polarization filter; much of the paper was devoted to explaining how this could be done. Entangled photons produced in the usual way would pass through those filters and the results compared. If there are any local hidden variables, then the results from the two filters should be uncorrelated—in strong violation of the predictions of quantum mechanics.

Of course, even quasars might not completely close the loophole. For that reason, the authors also discussed the possibility of using photons from the cosmic microwave background (CMB), again from points on the sky separated as far as possible. Any correlation between two such photons would have to have occurred at the time of inflation, a tiny split second after the Big Bang. However, the authors pointed out that practical considerations could limit the usefulness of this approach, since there's too much noise to ensure ant particular photon originated from the CMB.

And it's also possible that the outcome of every entanglement experiment was set before the Big Bang via local hidden variables, which the authors refer to as a "super-deterministic cosmic conspiracy." In that case, every experiment would produce the same results whether hidden variables or quantum mechanics are true, and we could never tell. Think of this as a hyper-control-freak deity or an extreme version of the cosmic simulation hypothesis.

Ultimately it seems unlikely that the free will loophole will stand in light of quantum mechanics' other overwhelming successes, but a practical experiment using quasars might be the best way to close it. As long as the nagging doubt about hidden variables exists, clever ideas like this will continue to be necessary.

Physical Review Letters, 2014. DOI pending (About DOIs).

The arXiv. Abstract number: 1310.3288" (About the arXiv).

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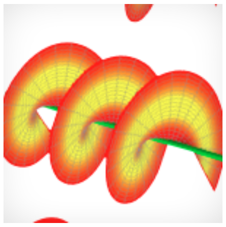

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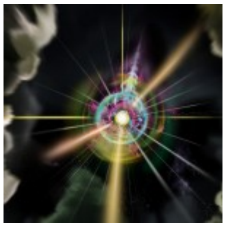

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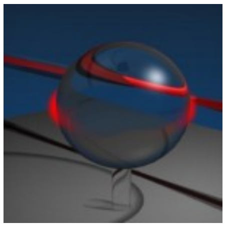

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