

PHYSICS TODAY

Cosmic experiment is closing another Bell test loophole

Extra Dimensions: A new experiment combines nanoscale measurements and interstellar distances to demonstrate quantum nonlocality.

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For decades, physicists have performed versions of John Stewart Bell's famous test to confirm that quantum mechanics is indeed as strange as it appears to be. None of those Bell tests have required telescopes staring into the heavens—until now.

By using light from stars in the galaxy to determine the measurements performed on pairs of entangled photons, researchers have demonstrated a violation of Bell's

inequality. The results appear in a study that was posted 21 November on arXiv but that has not yet been accepted for publication.

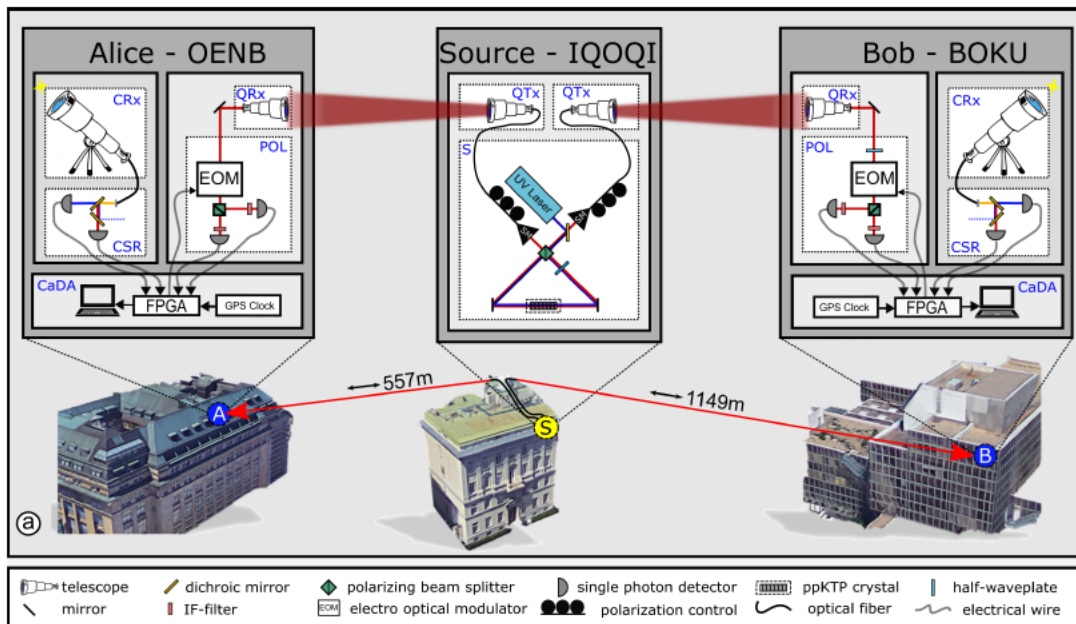
The clever experiment builds on the already overwhelming evidence that quantum mechanics is not secretly rooted in the classical concept of local realism. It also adds an important safeguard: Unlike previous experiments, the cosmic Bell test ensures that the choices of measurement settings are free of influence from causally connected events that occurred just before the test.

Last year, separate teams at the Delft University of Technology in the Netherlands, NIST, and the University of Vienna performed loophole-free Bell tests, which eliminated what many physicists considered the two major limitations of prior experiments. The researchers measured their entangled particles with detectors spaced far enough apart that a speed-of-light signal couldn't inform one detector of the measurement performed by the other. The scientists also used detectors that were efficient enough to ensure that the measured particle properties were representative of all the particles in the experiment, detected and undetected.

Yet as Jason Gallicchio, Andrew Friedman, and David Kaiser explained in a 2014 *Physical Review Letters* paper, even so-called loophole-free tests are not immune to the setting-independence, or free-will, loophole. Even if the detectors can't communicate with each other, the trio noted, hidden variables may influence the choice of detector settings. Most Bell experimenters have used quantum random number generators to determine which measurement a detector makes on an entangled particle. The shared history of those number generators, the detectors, or both could, at least in theory, bias a Bell test.

The cosmic Bell test required two stations (A and B) equipped with telescopes to observe starlight and instruments to capture and measure entangled photons from the source station (S). Credit: J. Handsteiner et al./arXiv 2016

Ruling out that unlikely yet plausible prospect requires setting the detectors via causally disconnected sources, wrote Gallicchio, Friedman, and Kaiser. Their solution: Use the light from quasars located on opposite sides of the visible universe to determine the detector settings. If such a cosmic test revealed a violation of Bell's inequality, then the only way hidden variables could be involved is if they conspired to rig the detector settings billions of years ago



—long before the formation of the planet on which the detectors reside.

The scientists haven't yet used quasars in a Bell test, but they have used Milky Way stars. Working with Anton Zeilinger's quantum optics group at the University of Vienna, the team set up telescopes spaced about 1.5 km apart and pointed them at stars located on opposite sides of the sky. Meanwhile, the researchers beamed entangled photons toward the two telescope stations. The color of the stellar photon collected by each telescope (either red, with a wavelength greater than 700 nm, or blue) determined which setting the station's detector would have when an entangled photon arrived. Because, the authors argue, the wavelengths

of stellar photons are determined at the time of emission and don't change en route to Earth, those photons cannot conspire at the last moment to rig the measurements.

Like the results of every other published Bell test, the cosmic version revealed a violation of Bell's inequality. But this new finding demonstrates that if hidden variables intervened in the measurements, they did so at least 575 years ago because the closest star observed in the experiment is roughly 575 light-years away. As the researchers write in the arXiv paper, their work "represents the first experiment to dramatically limit the space-time region in which hidden variables could be relevant."

The researchers say that in addition to tracking quasars, future experimenters could rely on patches of the cosmic microwave background or primordial gravitational waves to set their detectors. The farther those intrepid scientists push back, the more we can be confident that the universe follows the probabilistic set of rules that have left physicists scratching their heads since the development of quantum theory a century ago.

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