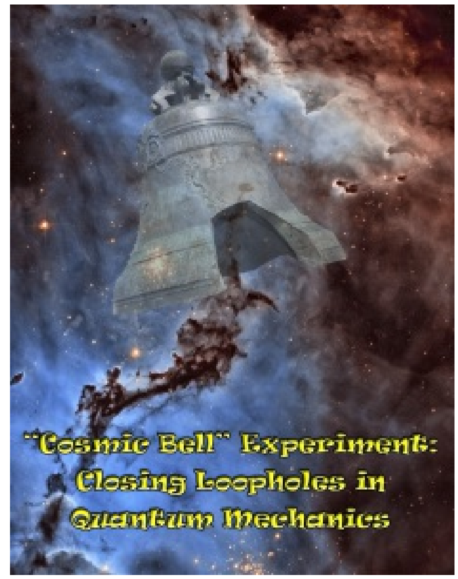
# Closing Loopholes in Quantum Mechanics

By Warren Huelsnitz October 16, 2013

## Violations of Bell's Inequalities and Loopholes in Quantum Mechanics




Recall that, in 1935, Einstein, Podolsky, and Rosen wrote their famous paper that became known as the EPR paradox. In it, they pointed out the bizarre consequences of the mathematics of quantum mechanics. If two particles were in an entangled state, then measurement on one of the particles would immediately affect the results of a measurement on the other particle, even if the two particles were arbitrarily far apart at the time of the measurements. This non-locality was later called "spooky action a distance" by Einstein.

In the 1960′s, John Bell came up with a set of equations, inequalities, that quantified the disagreement between the predictions of quantum mechanics and that of a purely local theory (i.e. one that assumed the distant measurement could not affect the local measurement). Since then, violations of these inequalities have been experimentally verified on numerous occasions. Thus, the inescapable conclusion is that nature *does* make use of non-locality, some how. However, this conclusion is based on the assumption that *nothing else unusual or unexpected* is happening during the experiment.

### Scrutinizing Loopholes in Observed Violations of Bell's Inequalities

Many different variations of the experiments have been done. See, for example, my discussion at *Quantum Weirdness: The unbridled ability of quantum physics to shock us*. Many more, different types of experiments have also been done. In some of these experiments, the violation is more dramatic – not just a matter of the frequency of apparently correlated outcomes. These experiments are go or no-go; they are designed to look for an event that would not happen under a purely local theory. See *Do We Really Understand Quantum Mechanics?* or *Do we really understand quantum mechanics? Strange correlations, paradoxes, and theorems* for more in-depth discussions.

Given that the implication of these experiments is so profound, scientists have gone to great lengths to ensure that there is not some more benign, classical, local, or deterministic explanation that has been missed. One possibility is that, since we do not detect every photon due to limitations in detector efficiency, we are detecting a special subset of events. Another possibility is that the detector settings are not actually independent or random. Typically, detector settings are chosen randomly; for example, by a quantum random number generator. But if there were even some slight correlations between the choice of detector settings and some sort of local hidden variables in the system being tested, then the observed violations of Bell's inequality could be explained without resorting to non-locality.

## Closing the Settings-Independence Loophole

Physicists at the Kavli Institute for Cosmological Physics in Chicago, and at MIT, have come up with a brilliant (*and FUN*) way to avoid the settings-independence loophole and also potentially further quantify non-locality. See their paper *Testing Bell's Inequality with Cosmic Photons: Closing the Settings-Independence Loophole*.

Their idea is to use distant quasars or the Cosmic Microwave Background (CMB) to determine detector settings.

They would chose two distant quasars on opposite regions of the sky, or two separate patches of the CMB with sufficient angular separation.  Photons from these sources would be coming from events whose past light cones do not overlap.  These photons would then be used to determine the detector settings.


Fig. 1 from http://arxiv.org/abs/1310.3288; Schematic of the proposed "Cosmic Bell" experiment. Cosmic sources are used to determine detector settings in a Bell-type experiment.

This experiment will close the settings-independence loophole (assuming the results remain consistent with QM and non-locality!).  If something unexpected is seen, it will enable mapping non-local correlations as a function of the overlap between light cones of the two independent photon sources.

Of course, the experiment will not be without some challenges.  The authors refer to a potential "noise loophole". They have to ensure that the cosmic photon detectors are not triggered by more local sources of photons, such as light pollution, scattered star light, zodiacal light, etc.  They also need to account for the impact of the intergalactic medium and Earth's atmosphere on the cosmic photons.  It will be interesting to see where this leads in the coming years!