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I write about physics, science, academia, and pop culture.

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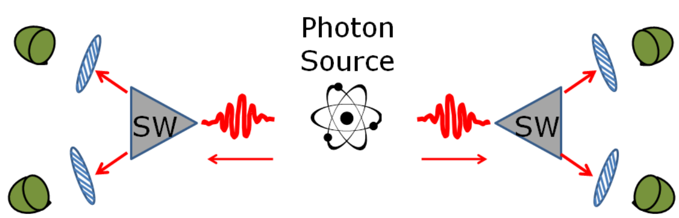
Quantum Loopholes And The Problem Of Free Will

The "extreme deep field" image from the Hubble Space Telescope, showing extremely distant galaxies. Image from NASA. http://www.nasa.gov/mission_pages/hubble/science/xdf.html

Last week's post about dark matter and ordinary atoms was prompted by a question from a colleague in the psychology department. That question, in turn, originated in an argument he was having with someone else, who was arguing that exotic physics could provide justification for "free will." This is one of those big philosophical questions that crop up a lot around the edges of physics — Sabine Hossenfelder at Backreaction has written about this at length.

Weirdly, this week brings another reason to talk about these kinds of issues, not from the psych department, but from the arxiv: a new paper titled Cosmic Bell Test: Measurement Settings from Milky Way Stars. This is an experiment by Anton Zeilinger and company in Austria testing an idea floated by David Kaiser and colleagues at MIT to do a test of quantum non-locality that would close what's sometimes called the "freedom-of-choice loophole" by using distant astronomical sources to determine their detector settings.

I referenced the proposal in a football context last year, and my fellow Forbes blogger Brian Koberlein has written about the new paper. This frees me up to talk less about the technical details, and more about What It All Means (which may or may not be a good thing…).

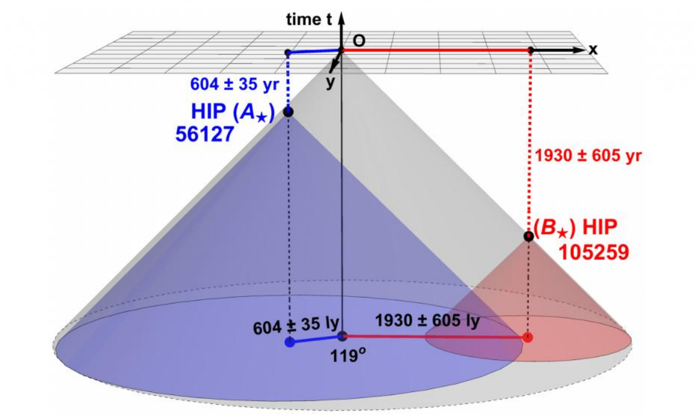


Schematic of the third Aspect experiment testing quantum non-locality. Entangled photons from the source are sent to two fast switches, that direct them to polarizing detectors. The switches change settings very rapidly, effectively changing the detector settings for the experiment while the photons are in flight. (Figure by Chad Orzel)

The basic experiment is a "Bell test," which looks for correlations between the well-separated measurements of the polarization of a pair of photons. These photons are created in an "entangled state" where the individual photon polarizations are indeterminate, but we know that the *pair* of photons are correlated. John Bell showed in the mid-1960s that if you do just the right measurements, you can find correlations in this sort of state that cannot be explained by any theory in which the photons have definite states determined in advance. I talked a bit about how these experiments work when a "loophole-free" test was published a couple summers ago, and about a puzzle-game analogy this past summer.

In the description of the experiment, "loophole-free" gets put in quotes not because it's a jargon term, but because it's not *really* free of loopholes. What it does is to close two specific loopholes: the "fair-sampling" loophole (which says that detectors with finite efficiency might just happen to fail to register enough photons of the right polarizations to make the correlation look stronger than it is) and the "locality" loophole (which allows for a message to pass between the photon source to the detector and arrange for the proper combination of photon polarization and detector settings to make the correlation look quantum). The former is closed by using high-efficiency detectors, the latter by using random-number generators to rapidly switch detector settings and putting the two detectors far enough apart that any message passing between source and detectors would need to travel faster than the speed of light.

Of course, if you're a particularly stubborn physicist with a philosophical bent, it's not hard to find an additional loophole, namely the "freedom-of-choice" loophole. This one points to the random-number generators used to determine the detector settings, and argues that these might not be *truly* random, but might be correlated in some way dating back to before the start of the experiment. While the individual sequences of numbers they generate pass the statistical tests for randomness that we know how to do, some common factor between them means that their lists of numbers are correlated with each other in just the right way to make the experiments seem to violate the classical limit Bell found.



A light cone diagram showing the range of influence possible for the cosmic EPR experiment. Credit: Johannes Handsteiner, et al.

This is related to the question of "free will" in an obvious way: If random-number generators can be correlated thanks to their common history, then everything else around them must also be predetermined, too. The current experiment and the proposal it's based on are an attempt to address this loophole by using "random-number generators" that have no recent common history: specifically, two widely separated stars. The experiment's random-number generation is based on the color of light from two stars in different parts of the Vienna sky, one a bit more than 600 light-years from Earth, and the other around 1900 light-years away. If these photons were somehow to share a common influence that determines how they'll be detected on Earth and used to set polarizers in a physics experiment, that influence must be more than 600 years in the past, back before the invention of the printing press, let alone physics blogs or parametric downconversion experiments on polarization-entangled photon pairs.

The experiment, like every other one before it, confirms that the photons are correlated with each other to a degree of statistical certainty that even particle physicists can't quibble with — better than seven standard deviations. The more random random-number generators used here don't make any difference in the core result: the photon states behave as quantum physics says they should, and not the way a more classical theory would prefer.

While I generally like Brian's story about the experiment, though, I have to dissent a bit from his clever title ("Quantum Physics Tells Us Our Fate Is Not Written In The Stars"). In the end, this experiment doesn't really have much direct impact on the question of "free will." I mean, it's an impressive bit of work, and cool that they've pushed the possible extent of influence back six centuries (they claim this is a 16-order-of-magnitude improvement on past limits, which must've been a fun sentence to put in a paper). But in the end, if you're willing to accept the idea of random-number generators being influenced by their common history in a way that leads to correlations in their output that might explain Bell test experiments, I'm not sure why it would be any less plausible to believe that that influence extends back over 600 years into the past. If your model of physics is sufficiently deterministic to have all the many experimental contingencies working out in exactly the right way to produce the illusion of quantum correlations on a time scale of microseconds, I don't think expanding to a time scale of years should be a deal-breaker.

Of course, this is, ultimately, only a proof-of-concept experiment, using relatively nearby stars because it's convenient. There's a note in the paper that the duration of the experiment was constrained by the fact that the telescopes used were simply pointed out the windows of the labs containing the detectors, and thus could only see a limited patch of sky. You could certainly imagine doing a more sophisticated test, using professional-grade astronomical observatories to look at more widely separated objects.

And, indeed, that was the idea of the original proposal for which this is a proof-of-concept: if you used big radio telescopes rather than small optical ones, you could conceivably point them at quasars on opposite sides of the sky that are separated by a distance greater than light could cover in the current age of the universe. In which case, those photons should be truly free of any common history at all, thus completely closing the freedom-of-choice loophole.

(Maybe, anyway. It wouldn't surprise me if, when they eventually do that experiment (because now that the idea is out there, *somebody* will actually do it...) some philosophically-inclined physicist will invent a new objection involving a shared history that predates the Big Bang. I suspect that, on some level, this particular loophole is fundamentally un-close-able.)

If they do that, what will it tell us about the nature of "free will?" I can't really say, because there really isn't a clear enough definition of what "free will" really means to say how it would be affected by quantum non-locality. If somebody develops a more concrete definition, I have every confidence that some bright person in quantum foundations will be able to work out the implications. For the moment, though, the question of "free will" remains as unanswerable as it's ever been, dating back even farther than the light used in this new experiment.

Chad Orzel is a physics professor, pop-science author, and blogger. His latest book is [Eureka: Discovering Your Inner Scientist]() (Basic Books, 2014).