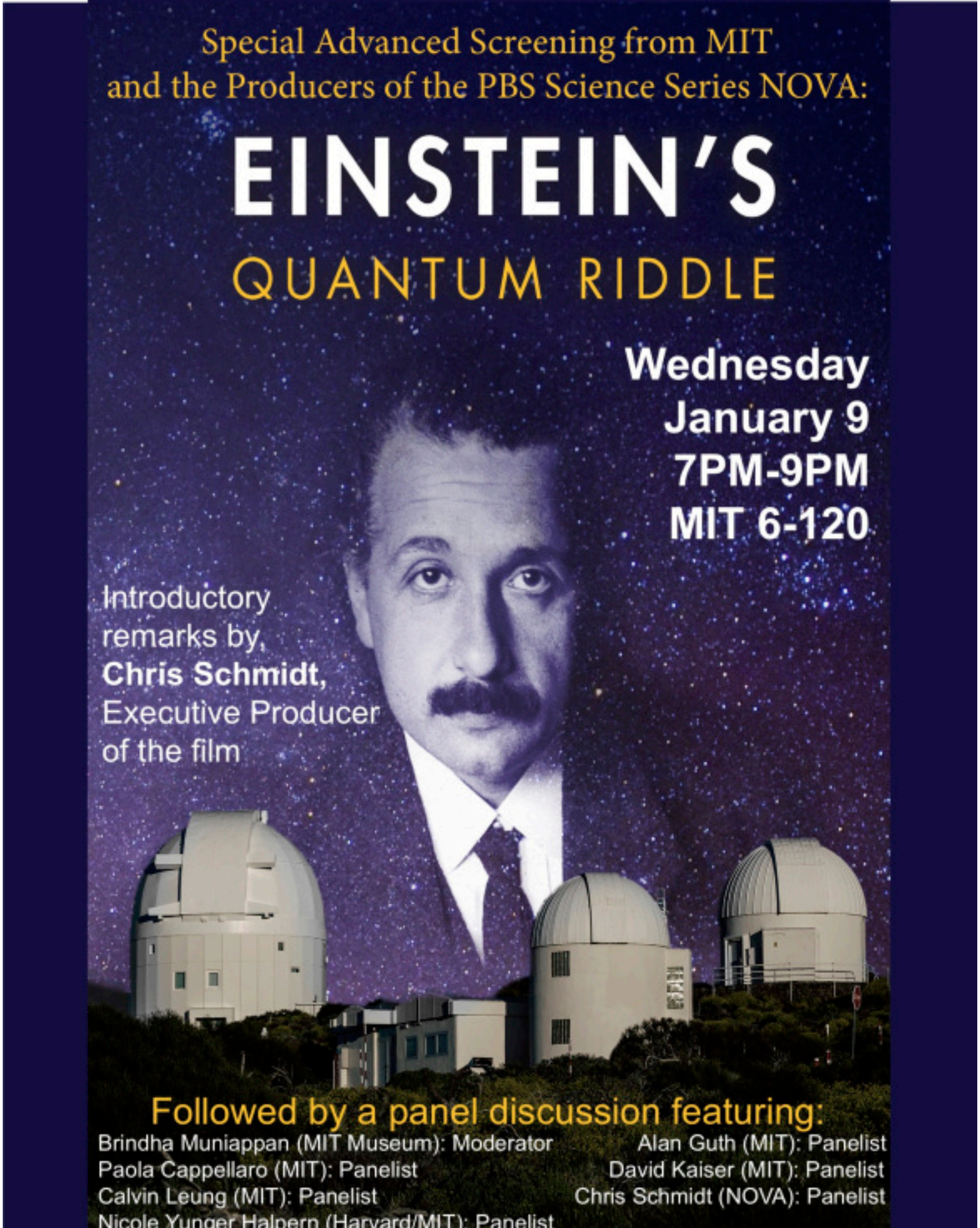
Humans can intuit quantum physics.

Posted on **January 27, 2019** by **Nicole Yunger Halpern**

One evening this January, audience members packed into a lecture hall in MIT's physics building. Undergraduates, members of the public, faculty members, and other scholars came to watch a film premiere and a panel discussion. NOVA had produced the film, "Einstein's Quantum Riddle," which stars entanglement. Entanglement is a relationship between quantum systems such as electrons. Measuring two entangled electrons yields two outcomes, analogous to the numbers that face upward after you roll two dice. The quantum measurements' outcomes can exhibit correlations stronger than any measurements of any classical, or nonquantum, systems can. Which die faces point upward can share only so much correlation, even if the dice hit each other.

MIT DEPARTMENT OF PHYSICS



National corporate funding for NOVA is provided by Draper. Major funding for NOVA is provided by the David H. Koch Fund for Science, the Corporation for Public Broadcasting, and PBS viewers. Major funding for *Einstein's Quantum Riddle* is provided by the Gordon and Betty Moore Foundation and the John Templeton Foundation with additional funding from Margaret and Will Hearst and The Montgomery Family Foundation.

WGBH NOVA PBS.

Dice feature in the film's explanations of entanglement. So does a variation on the shell game, in which one hides a ball under one of three cups, shuffles the cups, and challenges viewers to guess which cup is hiding the ball. The film derives its drama from the Cosmic Bell test. Bell tests are experiments crafted to show that classical physics can't describe entanglement. Scientists recently enhanced Bell tests using light from quasars —ancient, bright, faraway galaxies. Mix astrophysics with quantum physics, and an edgy, pulsing soundtrack follows.

The Cosmic Bell test grew from a proposal by physicists at MIT and the University of Chicago. The coauthors include David Kaiser, a historian of science and a physicist on MIT's faculty. Dave co-organized the premiere and the panel discussion that followed. The panel featured Dave; Paola Cappellaro, an MIT quantum experimentalist; Alan Guth, an MIT cosmologist who contributed to the Bell test; Calvin Leung, an MIT PhD student who contributed; Chris Schmidt, the film's producer; and me. Brindha Muniappan, the Director of Education and Public Programs at the MIT Museum, moderated the discussion.

— I *think* that the other panelists were laughing with me.

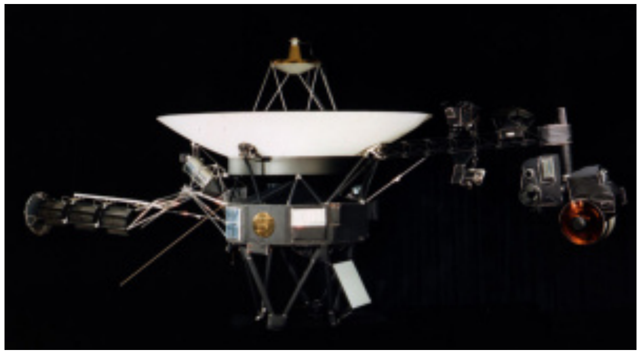
Brindha asked what challenges I face when explaining quantum physics, such as on this blog. Quantum theory wears the labels "weird," "counterintuitive," and "bizarre" in journalism, interviews, blogs, and films. But the thorn in my communicational side reflects quantum “weirdness” less than it reflects humanity’s self-limitation: Many people believe that we can’t grasp quantum physics. They shut down before asking me to explain.

Examples include a friend and *Quantum Frontiers* follower who asks, year after year, for books about quantum physics. I suggest literature—much by Dave Kaiser—he reads some, and we discuss his impressions. He’s learning, he harbors enough curiosity to have maintained this routine for years, and he has technical experience as a programmer. But he’s demurred, several times, along the lines of “But…I don’t know. I don’t think I’ll ever understand it. Humans can’t understand quantum physics, can we? It’s too weird.”

Quantum physics defies many expectations sourced from classical physics. Classical physics governs how basketballs arch, how paint dries, how sunlight slants through your window, and other everyday experiences. Yet we can gain intuition about quantum physics. If we couldn’t, how could we solve problems and accomplish research? Physicists often begin solving problems by trying to guess the answer from intuition. We reason our way toward a guess by stripping away complications, constructing toy models, and telling stories. We tell stories about particles hopping from site to site on lattices, particles trapped in wells, and arrows flipping upward and downward. These stories don’t capture all of quantum physics, but they capture the essentials. After grasping the essentials, we translate them into math, check how far our guesses lie from truth, and correct our understanding. Intuition about quantum physics forms the compass that guides problem solving.

Growing able to construct, use, and mathematize such stories requires work. You won’t come to understand quantum theory by watching NOVA films, though films can prime you for study. You can gain a facility with quantum theory through classes, problem sets, testing, research, seminars, and further processing. You might not have the time or inclination to. Even if you have, you might not come to understand why quantum theory describes our universe: Science can’t necessarily answer all “why” questions. But you can grasp what quantum theory implies about our universe.

People grasp physics arguably more exotic than quantum theory, without exciting the disbelief excited by a grasp of quantum theory. Consider the Voyager spacecraft launched in 1977. Voyager has survived solar winds and -452º F weather, imaged planets, and entered interstellar space. Classical physics—the physics of how basketballs arch—describes much of Voyager’s experience. But even if you’ve shot baskets, how much intuition do you have about interstellar space? I know physicists who claim to have more intuition about quantum physics than about much classical. When astrophysicists discuss Voyager and interstellar space, moreover, listeners don’t fret that comprehension lies beyond them. No one need fret when quantum physicists discuss the electrons in us.



— Voyager spacecraft

Fretting might not occur to future generations: Outreach teams are introducing kids to quantum physics through games and videos. Caltech's Institute for Quantum Information and Matter has partnered with Google to produce QCraft, a quantum variation on Minecraft, and with the University of Southern California on quantum chess. In 2017, the American Physical Society's largest annual conference featured a session called "Gamification and other Novel Approaches in Quantum Physics Outreach." Such outreach exposes kids to quantum terminology and concepts early. Quantum theory becomes a playground to explore, rather than a source of intimidation. Players will grow up primed to think about quantum-mechanics courses not "Will my grade-point average survive this semester?" but "Ah, so this is the math under the hood of entanglement."

Sociology restricts people to thinking quantum physics weird. But quantum theory defies classical expectations less than it could. Measurement outcomes could share correlations stronger than the correlations sourced by entanglement. How strong could the correlations grow? How else could physics depart farther from classical physics than quantum physics does? Imagine the worlds governed by all possible types of physics, called "generalized probabilistic theories" (GPTs). GPTs form a landscape in which quantum theory constitutes an island, on which classical physics constitutes a hill. Compared with the landscape's outskirts, our quantum world looks tame.

GPTs fall under the research category of quantum foundations. Quantum foundations concerns why the math that describes quantum systems describes quantum systems, reformulations of quantum theory, how quantum theory differs from classical mechanics, how quantum theory could deviate but doesn't, and what happens during measurements of quantum systems. Though questions about quantum foundations remain, they don't block us from intuiting about quantum theory. A stable owner can sense when a horse has colic despite lacking a veterinary degree.

Moreover, quantum-foundations research has advanced over the past few decades. Collaborations and tools have helped: Theorists have been partnering with experimentalists, such as on the Cosmic Bell test and on studies of measurement. Information theory has engendered mathematical tools for quantifying entanglement and other quantum phenomena. Information theory has also firmed up an approach called "operationalism." Operationalists emphasize preparation procedures, evolutions, and measurements. Focusing on actions and data concretizes arguments and facilitates comparisons with experiments. As quantum-foundations research has advanced, so have quantum information theory, quantum experiments, quantum technologies, and interdisciplinary cross-pollination. Twentieth-century quantum physicists didn't imagine the community, perspectives, and knowledge that we've accrued. So don't adopt 20th-century pessimism about understanding quantum theory. Einstein grasped much, but today's scientific community grasps more. Richard Feynman said, "I think I can safely say that nobody understands quantum mechanics." Feynman helped spur the quantum-information revolution; he died before its adolescence. Besides, Feynman understood plenty about quantum theory. Intuition jumps off the pages of his lecture notes and speeches.

— Landscape beyond quantum theory

I've swum in oceans and lakes, studied how the moon generates tides, and canoed. But piloting a steamboat along the Mississippi would baffle me. I could learn, given time, instruction, and practice; so can you learn quantum theory. Don't let "weirdness," "bizarreness," or "counterintuitiveness" intimidate you. Humans can intuit quantum physics.

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About Nicole Yunger Halpern

I'm an ITAMP Postdoctoral Fellow at the Harvard-Smithsonian Institute for Theoretical Atomic, Molecular, and Optical Physics (ITAMP). Catch me at ITAMP, in Harvard's physics department, or at MIT. Before moving here, I completed a PhD in physics at Caltech's Institute for Quantum Information and Matter. I write one article per month for Quantum Frontiers. My research consists of what I call "quantum steampunk" (https://quantumfrontiers.com/2018/07/29/so-long-and-thanks-for-all-the-fourier-transforms/): I combine quantum information with thermodynamics and apply the combination across science. I like my quantum information physical, my math algebraic, and my spins rotated but not stirred.

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4 THOUGHTS ON “HUMANS CAN INTUIT QUANTUM PHYSICS.”

KC LEE

on **January 27, 2019 at 9:05 pm** said:

0 0 Rate This

On string theory, lacking observational data, one intuits based in no small part on the beauty of its mathematics. In strong contrast, on quantum physics, one has had no choice, since the days of Planck and Einstein, but to intuit based solely on actual observations.

The weirdness of quantum physics stems from frustrated expectations when observations disagree with the biases built into our classical physics based experience. Bearing that in mind may help guide our intuition to better understand quantum reality?

Boon Tee Tan
on **January 27, 2019 at 9:30 pm** said:

0 0 Rate This

Classical physics is inadequate in fully explaining quantum phenomena, nor astronomical ones between or among galaxies. Could it be plausible that we need three different sets of physics laws?

On Mon, Jan 28, 2019 at 12:25 PM Quantum Frontiers wrote:

> Nicole Yunger Halpern posted: “One evening this January, audience members > packed into a lecture hall in MIT’s physics building. Undergraduates, > members of the public, faculty members, and other scholars came to watch a > film premiere and a panel discussion. NOVA had produced the film, “” >

KC LEE
on **January 27, 2019 at 9:54 pm** said:

0 0 Rate This

Certainly possible three sets of physical laws are needed.
Occam’s razor would discourage.
In the opposite direction, in Nicole’s “Theoretical physics has not gone to the dogs”, a comment made on November 28 (12:06 am) happens to suggest a possible scheme relying on only one set of laws, based on a thought experiment that in theory could be performed.

Paul Hayes

on **January 28, 2019 at 7:32 am** said:

0 0 Rate This

“Quantum foundations concerns why the math that describes quantum systems describes quantum systems, reformulations of quantum theory, how quantum theory differs from classical mechanics,…”

Primarily of course it differs from classical mechanics by being probability theory rather than physics (mechanics) theory. 🙂