UC SANTA BARBARA

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The Theory of Everything

In 1974, British theoretical physicist Stephen Hawking showed that quantum mechanics — which governs the very small — and general relativity — which governs the very large — make for conflicting predictions about black holes. This ignited a battle that continues to this day: Either quantum mechanics must break down or our understanding of space-time must be wrong. The challenge over the last 40 years has been to find a theory that unifies quantum mechanics and relativity.

UC Santa Barbara's Joseph Polchinski brought to bear his own expertise when he delivered the 59th Faculty Research Lecture in the university's Corwin Pavilion. Speaking to a full house, Polchinski, a professor of physics and a permanent member of the campus's Kavli Institute for Theoretical Physics, gave a talk titled "Space-Time versus the Quantum."

"There are places where the theories get along," said Polchinski, "but the places where these two theories conflict is where we have something to learn."

Polchinski guided the audience through the evolution of the current conundrum. That history is full of paradoxes, each leading to new and more interesting discoveries. He described how each step in the unification process led to unexpected findings.

For example, exploring quantum mechanics and special relativity, which deals with things moving near or at the speed of light, British theoretical physicist Paul Dirac

improved an existing equation. In so doing, he identified twice as many solutions as expected. Polchinski explained that the extra solutions represented antiparticles and antimatter, which were actually discovered two years later.

Even though special relativity and quantum mechanics fit together without conflict, general relativity and quantum mechanics are much harder to reconcile, in part, Polchinski pointed out, because something that is both very massive and very small is difficult to find. “We have to go to extreme environments to find situations where both are important,” he said. “One such environment is the early moments of the Big Bang; another is the event horizon of a black hole.”

According to Polchinski, two conflicts exist with regard to black holes: the entropy puzzle and the information paradox. “Quantum mechanics says empty space is not so empty,” he noted in discussing the information paradox. “Particle-anti particle pairs are popping in and out of existence. One of the pair falls below the event horizon and is lost and the other gets out. Yet quantum mechanics does not allow information to be destroyed. However, for the information to escape, it would have to travel faster than the speed of light.”

According to Hawking, in order to resolve the paradox, the rules of quantum mechanics have to be modified. “A new place where things don’t fit in the way we thought they did has led us to a lot of new ideas,” Polchinski said.

In 2012, Polchinski and three other physicists proposed the black hole firewall as a possible solution. They posited that the entanglement linking the particle to its anti-particle must somehow be broken, a process that would release vast amounts of energy. In turn, this would create a black hole firewall at the event horizon — a solution that violates Einstein’s equivalence principle, which is a basic postulate of general relativity.

Other physicists have taken the idea further. In particular, Polchinski mentioned Argentine physicist Juan Maldacena. Although still a work in progress, his analysis of the black hole firewall paradox argues that the paradox can be resolved if entangled particles are connected by tiny wormholes.

High-energy physicists remain divided as to the solution to the paradox. “It’s far too soon to say because we don’t know the answer or what we have to give up and what will be part of a more complete theory,” Polchinski concluded. “We’re trying on a lot of different crude pictures to see how this theory will eventually look. It’s an

extremely interesting time to work on this subject.”

Established in 1955, the Academic Senate selects one faculty member per year as the Faculty Research Lecturer. Candidates are nominated by their peers, and the final selection is made by a committee consisting of previous Faculty Research Lecturers. Polchinski is the recipient the 59th award, considered the highest honor bestowed by the university faculty on one of its members.

About UC Santa Barbara

The University of California, Santa Barbara is a leading research institution that also provides a comprehensive liberal arts learning experience. Our academic community of faculty, students, and staff is characterized by a culture of interdisciplinary collaboration that is responsive to the needs of our multicultural and global society. All of this takes place within a living and learning environment like no other, as we draw inspiration from the beauty and resources of our extraordinary location at the edge of the Pacific Ocean.