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Justin Eure/MEDILL
The mechanics of violin strings vibrating offer a gateway into understanding quantum theory.

Quantum string links black holes and violins

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Quantum mechanics may bring the essence of black holes into the laboratory, breaking the biggest beast in the cosmos down into the smallest subatomic bits imaginable. The subtle, almost mystical uncertainty at the heart of quantum theory provides the common thread.

The same mathematics that allow quantum vibrations to seemingly conjure something out of nothing applies as readily to superconducting circuits on earth as to the forces that anchor galaxies into the fabric of space and time. That's according to a new analysis by researchers at the Riken Advanced Science Institute in Japan posted this week on Cornell University's Arxiv.org.

“The idea of bringing the physics of black holes down to Earth in the form of a tabletop experiment was too intriguing to pass up,” said Paul Nation, a physicist at the Riken Institute and an author of the new study.

The energies near a black hole’s event horizon, the final threshold before all mass and energy tumble irretrievably into the abyss, present an obvious challenge to experimentalists.

But similar quantum phenomena occur in the superconducting circuits used in quantum computing research. Essentially, researchers apply a magnetic field in the laboratory to a quantum particle and make the particle jump between energy levels. This “stretching and pulling,” Nation said, generates the kind of oscillation that triggers a photon to "pop" into existence.

It is here that the spontaneous generation of particles occurs: something appears to pop out of nothing.

The Riken Institute collaborators' analysis proposes experimental methods to “amplify these feeble vacuum fluctuations, boosting their energy to the extent that they become real and detectable,” said physicist Robert Johansson, also of the Riken Institute.

These controlled, local fluctuations provide a much friendlier way to explore quantum vacuum activity than at the perilous edge of a black hole.

“The vacuum state of a quantum field is the closest to nothing that one can get,” said Johansson. But even that vacuum seldom stays quiet, he said. Space is never empty, suggesting the potential for quantum creation of something out of seemingly nothing.

“Let us first consider a violin string,” Nation said.

This metaphor can take us from familiar experience down into imperceptible quantum phenomena. Just follow the vibrations.

Plucking that violin string produces vibrations and their amplitude directly relates to the force applied. Essentially, pluck harder and the noise is louder and more easily observed.

“However, even when not being played, the string is still vibrating ever so slightly,” Nation said.

The molecules in the air surrounding the violin whiz around and bombard the string to produce subtle vibrations. The little atoms, driven by heat, don’t carry the force of a plucking finger, but it is enough to generate motion.

Moving the violin into an air-free, sealed vacuum chamber helps further limit the potential vibrations in the string. Nation proposed dropping the temperature down to near absolute zero, or -459.67 degrees Fahrenheit, a cold so extreme that atomic motion slows to a halt.

“Now comes the big step,” Nation said.

Einstein demonstrated with his famous formula E=mc2 that mass itself is intrinsically energy. So to remove any lingering vibrations, the violin itself and all its ringing strings must be removed from the chamber.

What remains in that sealed vacuum? “Naively, the answer is nothing,” Nation said. “However, there is something left, and it is called a field.”

A field is not as exotic or unfamiliar as it may sound. The electromagnetic field, for example, manifests as photons, the particles that carry light throughout the universe.

The field remains in otherwise empty space. Nation compared it to those same violin strings, which when plucked produce motion that manifests as particles. Only these quantum fluctuations are plucked by chance and probability. No purposeful hand sparks the vibrations on the quantum level.

The uncertainty principle, as proposed by physicist Werner Heisenberg in 1927, governs this supremely shaky ground. This study helps expose the unlikely and far-reaching harmony produced by quantum uncertainty.

The work needs to move into an experimental phase and hunt such elusive phenomena as Hawking radiation, a bizarre quantum effect of black holes proposed by Stephen Hawking in 1974.

Niels Bohr, often called the sage of quantum theory, famously encapsulated the quagmire of quanta early in the last century: “If you think you can talk about quantum theory without feeling dizzy, you haven't understood the first thing about it.”

Bohr was not exaggerating. The uncertainty at the heart of quantum mechanics dethroned determinism in atomic science and offered a portrait of reality balanced precariously upon probabilities.

The clear, deterministic cause and effect that fueled science for centuries crumbled against the uncertainty principle that sits at the eye of the quantum storm.

Albert Einstein, among others, challenged the assertion that nature at a fundamental level obeyed only the rules of chance. In fact, he spent much of his later life seeking to quell the quantum revolution and find a meaningful current underneath its experimental accuracy.

Despite Einstein's understandable reservations, the revolution surged forward. Practical application of quantum mechanics may now be the most accurate and elegant link between the mysteries of the cosmos and the laboratory.