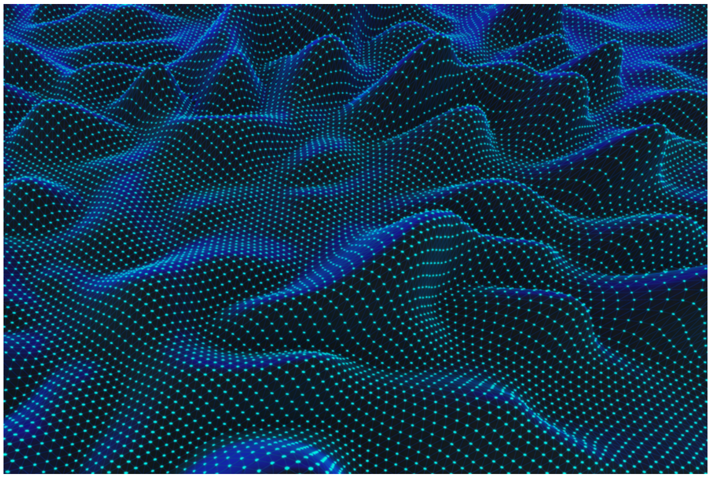
New Strategy in the Hunt for Quantum Gravity

Predictions of theories that combine quantum mechanics with gravity could be observed using highly sensitive photon detection in a tabletop experiment.

By **Michael Schirber**

Quantum-gravity theories attempt to unite gravity and quantum mechanics. A proposed tabletop experiment called Gravity from the Quantum Entanglement of Space Time (GQuEST) would search for a predicted effect of such theories using a new type of interferometer—one that counts photons rather than measuring interference patterns. The GQuEST team has now calculated the sensitivity of their design and shown that it can recover the predicted signal 100 times faster than traditional interferometer setups [**1**].

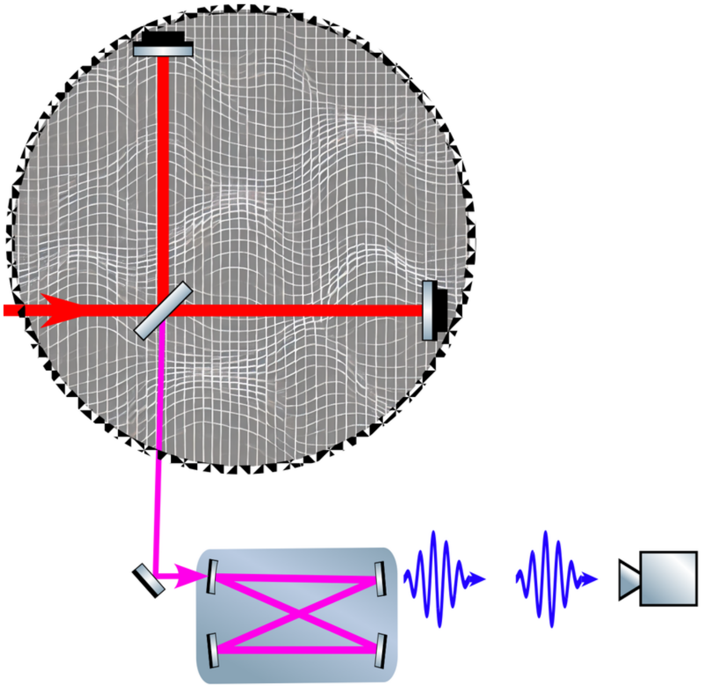
Quantizing gravity implies that spacetime is not continuous—it becomes “pixelated” when you look at scales as small as 10^{-35} m, far too small to be probed in any experiment. However, certain quantum-gravity models predict that spacetime can fluctuate—a kind of spontaneous stretching and squeezing in the spacetime fabric that might produce observable effects [**2**]. “You couldn’t detect a single pixel, but you could detect the coherent fluctuations of many pixels,” says Caltech theorist Kathryn Zurek. She has formulated a “pixellon” model, which predicts that collective fluctuations inside an interferometer can cause a detectable frequency change, or modulation, in the interferometer’s output light [**3**].



Pixel perception. The GQuEST experiment proposes to detect fluctuations in the fabric of spacetime that would be a signature of quantum theories of gravity.
Credit: stock.adobe.com/ec0de

This prediction is what Zurek and her colleagues plan to test using GQuEST, a preliminary version of which is currently being built at Caltech. The basic layout of the experiment is that of a classic Michelson interferometer, in which light is split into two paths and then recombined to produce an interference pattern. Experiments such as LIGO monitor such patterns, looking for variations caused by gravitational waves. However, this measurement strategy is not practical for detecting pixellon-induced modulations, says Lee McCuller of Caltech, the GQuEST team leader. “In LIGO, the power is constantly fluctuating up and down due to the shot noise, so it’s very difficult to resolve a little bit of extra fluctuations, as expected from the pixellon model,” he says.

To search for a quantum-gravity signal, McCuller and his colleagues are developing a photon-counting interferometer. The idea is to measure the output of the interferometer at a “sideband” frequency—one offset from the 200-THz laser frequency by 17 MHz. Sideband frequencies are familiar from AM radio signals, as they correspond to modulations in the carrier wave amplitude. Interferometers respond similarly to



Keeping count. The GQuEST design resembles a classic Michelson interferometer, with a laser beam (red) striking a beam splitter and dividing into two paths with mirrors at their ends. The prediction is that some of this light will interact with quantum-gravity fluctuations, producing a modulated signal in the output light (pink). Rather than searching for this modulation in the interference pattern, the GQuEST team plans to filter the light with a mirrored cavity and count the number of photons (blue) that come out at an offset frequency.
Credit: S. Vermeulen/Caltech

noise and other environmental effects, but the amount of sideband light generated is typically negligible at an offset as large as 17 MHz. However, a laser photon could have its frequency changed significantly by an interaction with a pixellon fluctuation. “Rather than getting zero light leaking out, you get a little bit,” McCuller says.

The team chose this particular sideband frequency to align with an expected peak in the pixellon fluctuations, explains Caltech’s Sander Vermeulen. To be sure that any detected light is from pixellon effects, the researchers will use optical cavities to filter out all nearby frequencies. If successful, the amount of light leakage should be extremely small—the team estimates about one modulated photon every 12 minutes, or a rate of 10^{-3} Hz. To detect such a weak signal, the researchers will install a superconducting-nanowire sensor, which can detect single photons with a very small dark-count (false-signal) rate.

There are other effects that might cause photons to leak out of the system, such as thermal noise in the mirrors. The researchers have computed the expected level of noise for their experimental design. They found that their photon-counting interferometer design can detect whether a signal is present 100 times faster than a traditional interferometer setup that detects shifts in the interference signal.

The researchers are currently building a 1-m-scale demonstration experiment. If it goes well, they plan to construct the full-scale experiment, which would be 7 m on a side. They also project building two interferometers next to each other, which could provide a further check against background noise.

“The conversion from an interferometric readout to a single-photon detector is really an ingenious idea,” says Stefan Ballmer, a gravitational-wave specialist from Syracuse University, New York. He says the design avoids some quantum uncertainty limits that affect traditional measurement approaches, but the GQuEST researchers will face challenges in filtering their output sufficiently.

The GQuEST strategy “will result in significant improvements in sensitivity to small signals,” says quantum-metrology expert Aaron Chou from the University of Chicago. The photon-counting method benefits from the improved dark-count rates of 10^{-5} Hz in the best superconducting-nanowire detectors. “This low measurement noise allows the experimenters to focus on reducing other sources of noise in their apparatus,” Chou says. Both he and Ballmer imagine this photon-counting design being applied to the search for other signals, such as gravitational waves from the early Universe.

Michael Schirber is a Corresponding Editor for ***Physics Magazine*** based in Lyon, France.

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