"We think there are spacetime fluctuations that may perturb the light beams," she says. "We want to design an apparatus where spacetime fluctuations kick a photon out of the beam of the interferometer, and then we would use single-photon detectors to read out that spacetime perturbation."

### Emergent spacetime

"Gravity is a hologram," says Monica Jinwoo Kang, a Sherman Fairchild Postdoctoral Fellow in Theoretical Physics at Caltech, when explaining the holographic principle, a key tenet of Zurek's model. This principle, which was realized using string theory in the 1990s, implies that phenomena in three dimensions, such as gravity, can emerge out of a flat two-dimensional surface.

"The holographic principle means that all the information in a volume of something is encoded on the surface," Kang explains.

More specifically, gravity and spacetime are thought to emerge from the entanglement of particles taking place on the 2-D surface. Entanglement occurs when subatomic particles are connected across space; the particles act as a single entity without being in direct contact with each other, somewhat like a flock of starlings. "Modern perspectives on quantum gravity inspired by string theory suggest that spacetime and gravity materialize out of networks of entanglement. In this way of thinking, spacetime itself is defined by how much something is entangled," says Kang.

In Zurek and Adhikari's proposed experiment, the idea would be to probe this 2-D surface, or what they call the "quantum horizon," for graviton fluctuations. Gravity and spacetime, they explain, emerge out of the quantum horizon. "Our experiment would measure the fuzziness of this surface," says Zurek.

That fuzziness would represent the pixelation of spacetime. If the experiment succeeds, it will help redefine our concept of gravity and space at the most fundamental, deepest levels.

"If I drop my coffee mug and it falls, I'd like to think that's gravity," says Adhikari. "But, in the same way that temperature is not 'real' but describes how a bunch of molecules are vibrating, spacetime might not be a real thing. We see flocks of birds and schools of fish undertake coherent motion in groups, but they are really made up of individual animals. We say that the group behavior is emergent. It may be that something that arises out of the pixelation of spacetime has just been given the name gravity because we don't yet understand what the guts of spacetime are." [C]

# In Memoriam

Read more about their lives at **magazine.caltech.edu/post/in-memoriam**

**David Grether**
1938–2021

David Grether, the Frank Gilloon Professor of Economics, Emeritus, passed away on September 12. He was 82. Grether was trained in econometrics, a field that applies statistical methods to economic data to determine economic relationships. His research into individual decision-making helped develop what was then a new field, experimental economics, which examines economic questions through the use of experiments of auctions, games, and markets.

**Felix H. Boehm**
(MS '51, PhD '54)
1924–2021

Felix H. Boehm, the William L. Valentine Professor of Physics, Emeritus, and a pioneering nuclear physicist, passed away on May 25 at the age of 96. Boehm was among the first to use nuclear physics techniques to do fundamental research on weak interactions and the nature of neutrinos (nearly massless subatomic particles). He initiated the first experiment at a nuclear reactor to look for neutrino oscillations, spontaneous changes of a neutrino's "flavor."

**Stephen D. Bechtel, Jr.**
1925–2021

Stephen D. Bechtel, Jr., senior director of Bechtel Group Inc. and a life member of the Caltech community, passed away on March 15. He was 95 years old. In 1957, Bechtel founded the S. D. Bechtel, Jr. Foundation, which supports education and environmental programs in California. The construction of Caltech's 211-bed Bechtel Residence, which opened in 2018, was supported by that foundation and the building is named in Bechtel's honor.

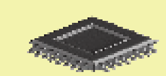
# QUANTUM PHYSICS in Your Kitchen

*Presented by the*
Caltech science exchange

**While ubiquitous quantum computers may seem far off, quantum principles are already at work in many technologies available today.**

**A common kitchen appliance demonstrates one of the phenomena that led to the founding of quantum science:**
Inside our toasters, there are metallic elements that glow red when they heat up. Heat any material to the same temperature and the same thing will happen: if you get them hot enough, all materials, metal or not, will glow red, then yellow, then white as they get hotter. This observation provided insight into the field of quantum science. Physicists in the late 1800s and early 1900s proposed that energy emitted from these heated elements was restricted to certain wavelengths, each producing a different visible color. This restricted range is due to the fact that light delivers energy in discrete packets, or "quanta."

## Interested in more examples?



*Hint: one is probably in your office ceiling, and another is in your phone.* Visit **scienceexchange.caltech.edu/quantum** and click on the toaster.

**Dive into the quantum realm on the Caltech Science Exchange, and learn why the smallest objects in nature hold the keys to understanding the universe and delivering groundbreaking technology.**