Learning about quantum vacuum by studying atoms

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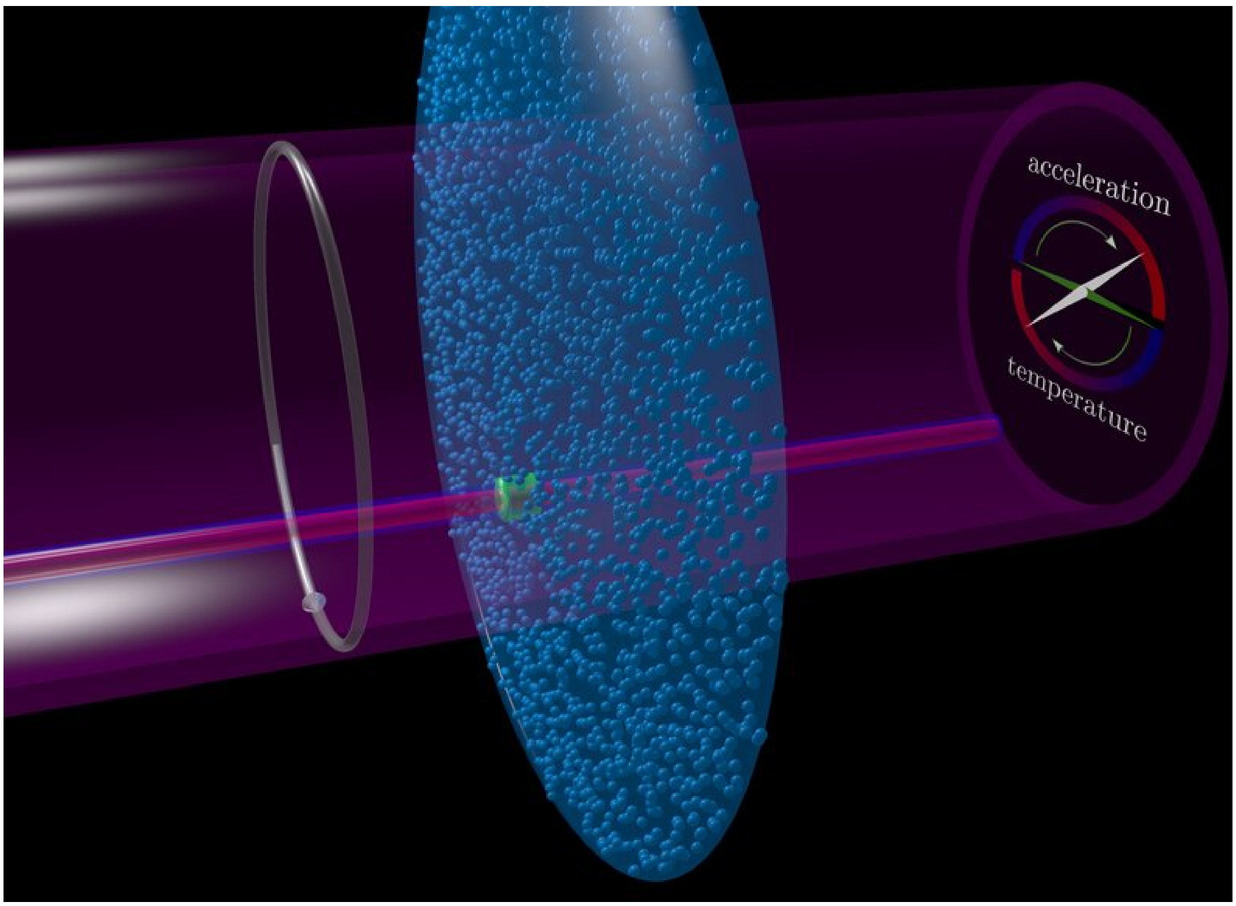

A laser beam hitting a cloud of ultra cold atoms. Credit: Vienna University of Technology

The Unruh-effect connects quantum theory and relativity. Until now, it could not be measured. A new idea could change this.

Is the vaccum of space really empty? Not necessarily. This is one of the strange results obtained by connecting quantum theory and the theory of relativity: The Unruh effect suggests that if you fly through a quantum vacuum with extreme acceleration, the vacuum no longer looks like a vacuum: rather, it looks like a warm bath full of particles. This phenomenon is closely related to the Hawking radiation from black holes .

A research team from TU Wien, the Erwin Schrödinger Center for Quantum Science and Technology (ESQ) and the University of Nottingham's Black Hole Laboratory in collaboration with University of British Columbia has shown that instead of studying the empty space in which particles suddenly become visible when accelerating, you can create a two-dimensional cloud of ultra-cold atoms (Bose-Einstein condensate) in which sound particles, phonons, become audible to an accelerated observer in the silent phonon vacuum. The sound is not created by the detector, rather it is hearing what is there just because of the acceleration (a non-accelerated detector would still hear nothing).

The vacuum is full of particles

One of the basic ideas of Albert Einstein's theory of relativity is: Measurement results can depend on the state of motion of the observer. How fast does a clock tick? How long is an object? What is the wavelength of a ray of light? There is no universal answer to this, the result is relative—it depends on how fast the observer is moving. But what about the question of whether a certain area of space is empty or not? Shouldn't two observers at least agree on that?

No—because what looks like a perfect vacuum to one observer can be a turbulent swarm of particles and radiation to the other. The Unruh effect, discovered in 1976 by William Unruh, says that for a strongly accelerated observer the vacuum has a temperature. This is due to so-called virtual particles, which are also responsible for other important effects, such as Hawking radiation, which causes black holes to evaporate.

"To observe the Unruh effect directly, as William Unruh described it, is completely impossible for us today," explains Dr. Sebastian Erne who came from the University of Nottingham to the Atomic Institute of the Vienna University of Technology as an ESQ Fellow a few months ago. "You would need a measuring device accelerated to almost the speed of light within a microsecond to see even a tiny Unruh-effect -we can't do that." However, there is another way to learn about this strange effect: using so-called quantum simulators.

Quantum simulators

"Many laws of quantum physics are universal. They can be shown to occur in very different systems. One can use the same formulas to explain completely different quantum systems," says Jörg Schmiedmayer from the Vienna University of Technology. "This means that you can often learn something important about a particular quantum system by studying a different quantum system."

"Simulating one system with another has been especially useful for understanding black holes, since real black holes are effectively inaccessible," Dr. Cisco Gooding from the Black Hole laboratory emphasizes. "In contrast, analog black holes can be readily produced right here in the lab."

This is also true for the Unruh effect: If the original version cannot be demonstrated for practical reasons, then another quantum system can be created and examined in order to see the effect there.

Atomic clouds and laser beams

Just as a particle is a "disturbance" in empty space, there are disturbances in the cold Bose-Einstein condensate—small irregularities (sound waves) that spread out in waves. As has now been shown, such irregularities should be detectable with special laser beams. Using special tricks, the Bose-Einstein condensate is minimally disturbed by the measurement, despite the interaction with the laser light.

Jörg Schmiedmayer explains: "If you move the laser beam, so that the point of illumination moves over the Bose-Einstein condensate, that corresponds to the observer moving through the empty space. If you guide the laser beam in accelerated motion over the atomic cloud, then you should be able to detect disturbances that are not seen in the stationary case—just like an accelerated observer in a vacuum would perceive a heat bath that is not there for the stationary observer."

"Until now, the Unruh effect was an abstract idea," says Professor Silke Weinfurtner who leads the Black Hole laboratory at the University of Nottingham, "Many had given up hope of experimental verification. The possibility of incorporating a particle detector in a quantum simulation will give us new insights into theoretical models that are otherwise not experimentally accessible."

Preliminary planning is already underway to carry out a version of the experiment using superfluid helium at the University of Nottingham. "It is possible, but very time-consuming and there are technical hurdles for us to overcome," explains Jörg Schmiedmayer. "But it would be a wonderful way to learn about an important effect that was previously thought to be practically unobservable."

Provided by Vienna University of Technology