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PRESS RELEASE (2026/04/15)

Does gravity follow the rules of quantum mechanics?

A recent approach by researchers could pave the way for experimental validation of the quantum nature of gravity

Fukuoka, Japan—In quantum physics, objects can exist in multiple states at the same time—a phenomenon known as quantum superposition, where a particle does not have a single definite value of position or momentum until it is measured. A major open question is whether gravity, one of the fundamental forces, also follows the quantum rule. One way to examine this is through gravity-induced entanglement, in which two objects that interact only via gravity become quantum mechanically linked. Now, researchers led by Professor Kazuhiro Yamamoto at the Faculty of Science and Quantum and Spacetime Research Institute, Kyushu University, have proposed a way to enhance the quantum superposition of a mirror's position in systems in which two mirrors interact via gravity, thereby making the resulting entanglement signal easier to detect. Their findings, published in the journal *Physical Review Research* on April XX, 2026, represent a crucial step toward experimentally testing whether gravity is fundamentally quantum.

Gravity-induced entanglement suggests that if gravity follows the quantum mechanics, then two objects interacting only through gravity should become entangled. This is a natural prediction of the quantum nature of gravity. Detecting this effect, however, is challenging as gravity is weak at small scales.

One way to make such effects observable is to carefully control relatively large objects so that they are in the quantum regime. This is achieved by cooling the large objects near their lowest-energy state, called the quantum ground state, **not only through cryogenic cooling but also through an optimal filtering technique.** At this point, random thermal motion is minimized. In this state, quantum behavior becomes easier to detect. The object's position and momentum are then governed by the Heisenberg uncertainty principle, which states that neither property can be known with perfect precision.

Using this approach, the research team including Ryotaro Fukuzumi, Kosei Hatakeyama, Daisuke Miki, along with their colleagues from Kyushu University, Japan, and the California Institute of Technology, USA, have proposed a method to enhance gravity-induced entanglement by creating a momentum-squeezed state in movable mirrors.

In quantum mechanics, squeezing reduces uncertainty in one property, such as momentum, while increasing uncertainty in another, such as position. In the momentum-squeezed state described in the study, the mirror’s momentum becomes very precise, while its position becomes more spread out. As a result, the mirror exists in a quantum superposition over a larger region of space.

“We demonstrated that using this momentum-squeezed state significantly broadens the quantum superposition of the mirror’s position, thereby greatly amplifying the signal of quantum entanglement generated by gravity. This represents a new strategy that will be advantageous for future experiments to verify the quantum nature of gravity,” says Yamamoto.

The researchers achieved this state in a cavity optomechanical system, a setup in which a mirror's motion can be controlled with high precision using laser light trapped in an optical cavity. By continuously measuring the outgoing light and carefully processing the signal to reduce thermal noise (or optical quantum filtering), the researchers showed that a momentum-squeezed state can emerge under suitable conditions.

Placing two such mirrors close together can lead to stronger entanglement signals via their gravitational interaction. When momentum is made more precise, the mirror’s position becomes less certain and spreads out over a larger area. This wider spread strengthens the measurable signature of gravity’s quantum effects, making the entanglement easier to detect.

The researchers note that while this work is still theoretical, the conditions required to create the momentum-squeezed state itself are within reach of current technology. “In particular, it is believed that the possibility of generating and detecting gravity-induced entanglement will be further enhanced by utilizing low-noise environments such as extremely low-temperature and high-vacuum settings or outer space,” says Yamamoto.

If future experiments succeed in detecting gravity-induced entanglement using this approach, it will provide direct evidence that gravity obeys the rules of quantum mechanics. Thus, this study may pave the way for answering a long-standing question in physics about how gravity fits into the quantum world.

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For more information about this research, see "Momentum squeezed state realized via optimal filtering in optomechanics: Implications for gravity-induced entanglement”, Ryotaro Fukuzumi, Kosei Hatakeyama, Daisuke Miki, and Kazuhiro Yamamoto, *Physical Review Research*, https://doi.org/10.1103/zrs2-sk28.

About Kyushu University

Founded in 1911, Kyushu University is one of Japan's leading research-oriented institutions of higher education, consistently ranking as one of the top ten Japanese universities in the Times Higher Education World University Rankings and the QS World Rankings. Located in Fukuoka, on the island of Kyushu—the most southwestern of Japan’s four main islands—Kyushu U sits in a coastal metropolis frequently ranked among the world’s most livable cities and historically known as Japan’s gateway to Asia. Its multiple campuses are home to around 19,000 students and 8,000 faculty and staff. Through its VISION 2030, Kyushu U will “drive social change with integrative knowledge.” By fusing the spectrum of knowledge, from the humanities and arts to engineering and medical sciences, Kyushu U will strengthen its research in the key areas of decarbonization, medicine and health, and environment and food, to tackle society’s most pressing issues.

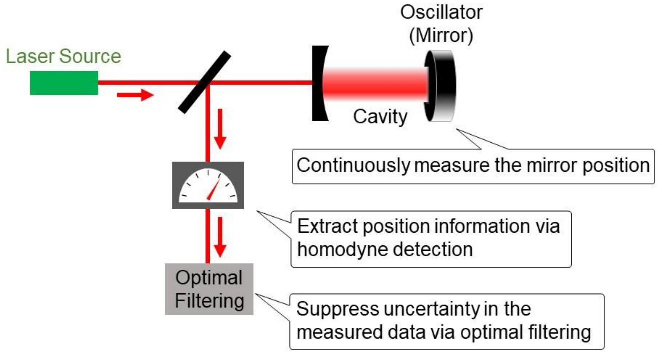

FIG.1 Continuous position measurement of a mirror using light and the filtering process
Laser light is injected into an optical cavity to continuously measure the position of a movable mirror. The output light is read out by homodyne detection, and the measurement data are analyzed using optimal filtering to estimate the quantum state of the mirror with high precision.

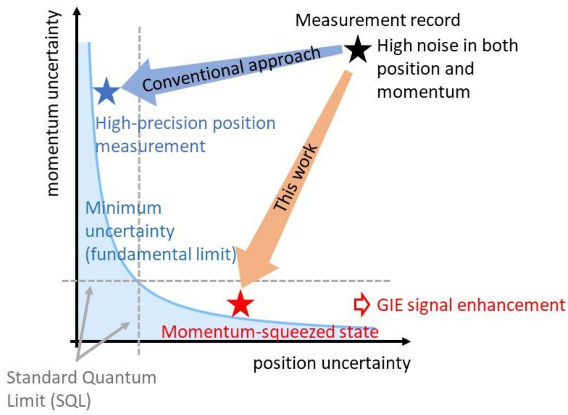

FIG.2 A new method based on quantum measurement to suppress momentum uncertainty
In quantum mechanics, position and momentum cannot be simultaneously determined with arbitrary precision. Conventionally, position uncertainty is reduced to improve estimation accuracy. In this work, by adjusting detection conditions, we demonstrate a momentum-squeezed state where momentum uncertainty is strongly suppressed while position uncertainty increases, enhancing gravity-induced entanglement signals.

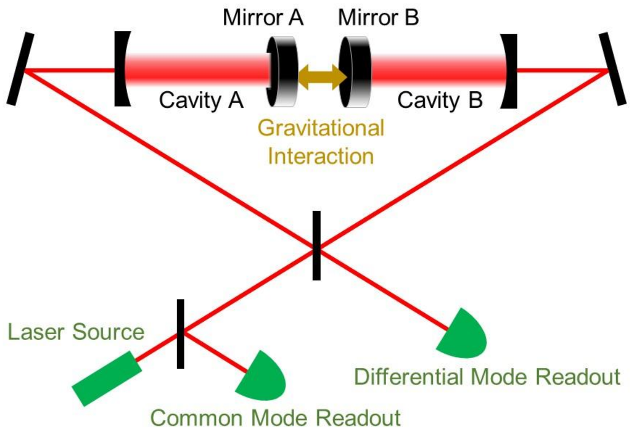

FIG.3 Conceptual diagram of an experiment to test gravity-induced entanglement using optomechanical systems
Two optomechanical systems arranged as shown, where the cylindrical mirrors A and B interact via gravity. The interaction affects only the differential mechanical mode associated with their relative displacement, generating quantum entanglement between the mirrors.

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