From burglar alarms to black hole detectors: Super sensors as possible outputs of a quantum gravity experiment

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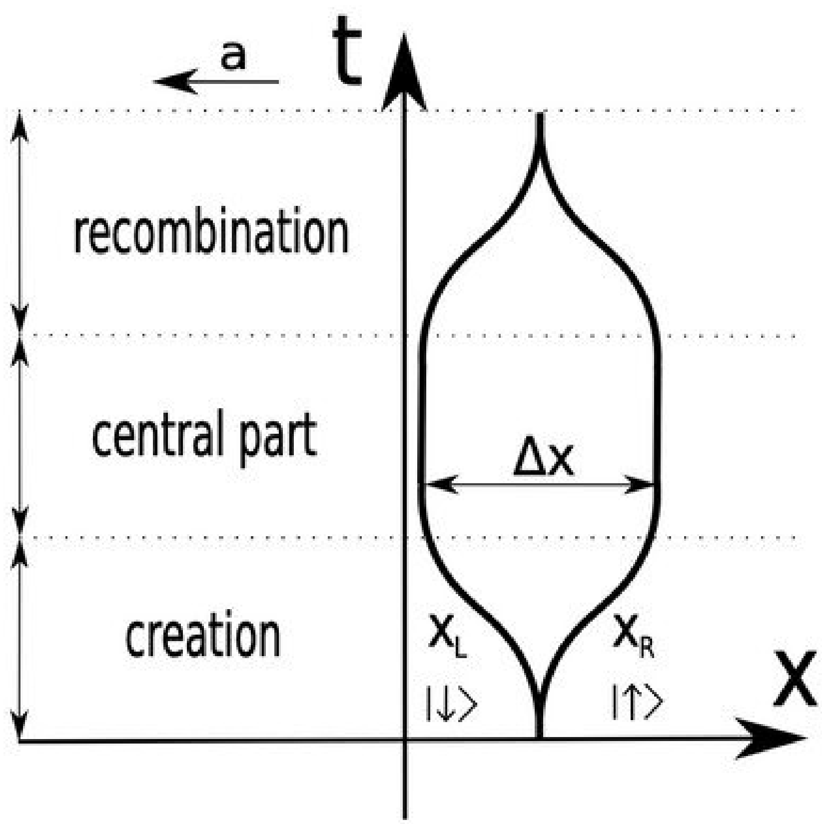

Schematic of the proposed experiment: A beam is split into two (bottom) and subsequently recombined, creating an interference pattern (top). Credit: Anupam Mazumdar

Last year, Anupam Mazumdar, a physicist from the University of Groningen, together with colleagues from the UK proposed an experiment that could conclusively prove whether gravity is a quantum phenomenon. This experiment would focus on observing two relatively large, entangled quantum systems in free fall. In a new article, published on 4 June in *Physical Review Research*, the scientists describe in more detail how two types of noise could be reduced. They suggest that quantum interference could be applied in the production of a sensitive instrument that could detect movements of objects ranging from butterflies to burglars and black holes.

Central to this experiment is a minuscule diamond, just a few nanometers in size, in which one of the carbon atoms has been replaced by a nitrogen atom. According to quantum physics, the extra electron in this atom would either absorb or not absorb the photon energy of a laser.

Diamond

Absorption of the energy would alter the electron's spin value, a magnetic moment that can be either up or down. "Just like Schrödinger's cat, which is dead and alive at the same time, this electron spin does and does not absorb the photon energy, so its spin is both up and down," Mazumdar explains. This process results in quantum superposition of the entire diamond. By applying a magnetic field, it is possible to separate the two quantum states. When these quantum states are brought together again by turning off the magnetic field, they will create an interference pattern.

This diamond is small enough to sustain this superposition, but it is also sufficiently large to be affected by the pull of gravity. When two of these diamonds are placed next to each other under conditions of free fall, they only interact via the gravity force between them. The experiment was originally designed to test whether gravity itself is a quantum phenomenon. Simply put, as entanglement is a quantum phenomenon, the entanglement of two objects that interact only through gravity would serve as proof that gravity is a quantum phenomenon.

Collision

Any moving mass will have an effect on this very sensitive quantum system. In their latest paper, Mazumdar and colleagues describe how these disturbances can be reduced. However, it is also apparent that this system could be used to detect moving masses. The first source of noise is the collision of gas with the experimental capsule in free fall. Even the impact of photons can create a disturbance. "Our calculations show that these effects are minimized by placing the experimental capsule inside a larger container, which creates a controlled environment," Mazumdar explains.

Inside such an outer container, this noise is negligible at a pressure of 10^{-6} Pascal, even at room temperature. Requirements for conditions within the experimental capsule are more stringent. Currently, the scientists estimate a required pressure of 10^{-15} Pascal at around 1 Kelvin. Given the current state of technology, this is not yet feasible, but Mazumdar expects it could well be possible within around 20 years.

Space debris

Moving objects, even as small as a butterfly, located near the experimental site constitute a second source of noise. Calculations reveal that this noise can also be mitigated relatively easily by limiting access to the experimental site. People should maintain a distance of at least 2 meters from the experimental site, and cars should maintain a minimum distance of 10 meters from the site. Passing planes at a distance of more than 60 meters from the experimental site would not pose a problem. All of these requirements can be accomplished easily.

Once the experiment is up and running, its scope could be extended beyond an investigation of quantum gravity, according to Mazumdar. "You could put it in a spacecraft, where it is in free fall all the time. Then, you could use it to detect incoming space debris. By using several systems, it would even be possible to get the trajectory of the debris." Another option is to place such a system in the Kuiper belt, where it would sense the movement of our solar system in space. "And it could detect any nearby black holes," Mazumdar adds.

Back on Earth, the quantum system would be capable of detecting tectonic movements and perhaps providing early warnings of earthquakes. And, of course, the quantum system's sensitivity to any movement occurring in proximity to it would make it an ideal, if somewhat complex, movement sensor and burglar alarm. But for now, the focus over the next few decades is on determining whether gravity is a quantum phenomenon.

More information: Marko Toroš et al, Relative acceleration noise mitigation for nanocrystal matter-wave interferometry: Applications to entangling masses via quantum gravity, *Physical Review Research* (2021). DOI: 10.1103/PhysRevResearch.3.023178

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