Does gravity create reality? A shocking path to a theory of everything

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Sometimes, you work tirelessly on a problem, only to realise you have been going about it all backwards. Imagine trying to fit a massive antique piano through a tiny doorway. You have tried everything – rotating it, removing the legs, forceful shoving – but you just can't get it to fit. Eventually, you realise it is easier to construct a room to house the piano where it already sits.

Now, some physicists are grappling with a similar rethink. For decades, the accepted route to an ultimate theory of everything has involved taking our best theory of gravity and squeezing it into the frame of quantum mechanics. Given that quantum theory is wildly successful in describing the other three of the four fundamental forces of nature, it is an understandable approach. Yet, almost a century later, scientists still haven't managed to make gravity fit.

That's why a few mavericks have championed an alternative strategy. They suggest that tweaking the equations of quantum mechanics – constructing a new room for gravity – helps explain how the strange world of particles gives rise to our everyday reality.

Various experimental avenues are opening up to probe this approach, involving everything from levitating diamonds and glowing metals to swinging pendulums and ticking clocks. The tests promise to shine a light on how the quantum world operates and guide the search for a more complete understanding of the universe. "This is like going into the open ocean: we have no clue where to go," says Angelo Bassi, a physicist at the University of Trieste in Italy. "But maybe … by going in the wrong direction, we'll discover the right thing."

The world as we know it is definite. Your books rest solidly on their shelf, your clock ticks steadily forward and your cat is demonstrably alive. In the realm of atoms, however, nothing is certain. Quantum mechanics allows us to describe certain properties of particles, like their position, only in terms of likelihood. You can predict – with great success – the odds of finding a particle in one of many places, but where it will be observed in a given test is completely unknowable. Before that measurement happens, the object exists in a wave-like blur of all those possibilities at once, which we describe mathematically with something called a wave function.

This leaves us with two big conundrums that lie at the heart of quantum theory. For one, it is unclear how and when the fuzzy quantum world gives rise to classical concreteness. The other problem is that this probabilistic description clashes with Albert Einstein's classical understanding of gravity. Efforts to recast Einstein's work on gravity into the language of forces and particles have resulted in constructions such as string theory that are cumbersome and practically untestable.

A long-standing assumption has been that, deep down, everything is quantum. But a century after the inception of quantum mechanics, physicists are still struggling to make a cohesive story out of it. "There must be something else going on, and we have to understand what," says Bassi. "The important step is to push quantum mechanics to its limits."

One route to finding these limits involves one of the many oddities of quantum mechanics: the principle of superposition. Scientists today routinely put a single particle into a mixed state of being in two distinct locations, a trick they can verify with interference patterns from those interacting possibilities. But once they measure where the particle is, it collapses into one definitive state: either left or right, say.

There are many possible explanations of what happens when a measurement occurs – as evidenced by the variety of interpretations of quantum mechanics. The many-worlds interpretation says that each possible scenario plays out in a different branch of reality, while the Copenhagen interpretation says, essentially, to trust the maths.

Some physicists want to adapt quantum mechanics to include the classical force of gravity

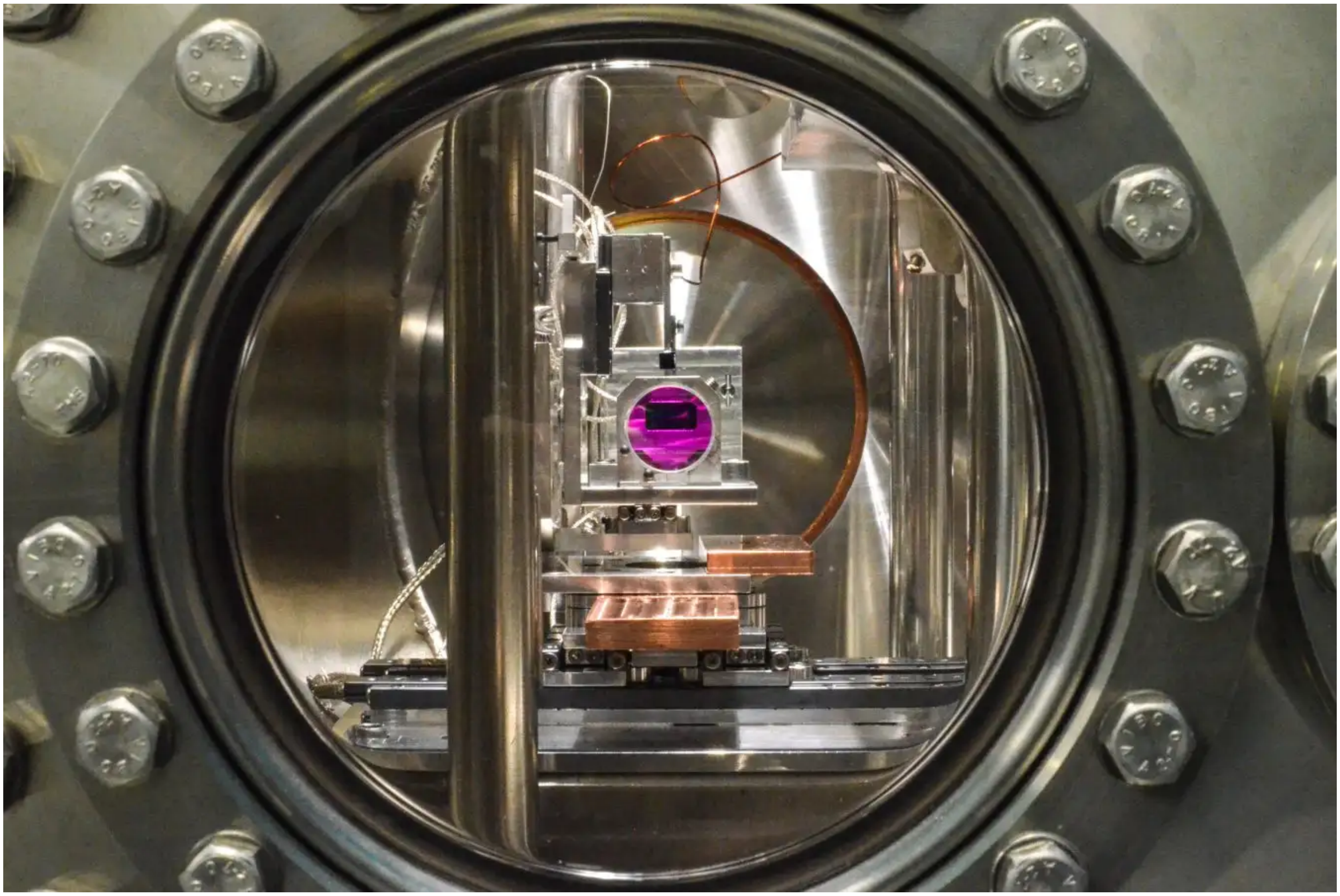
Hans Berggren/Getty Images

Another group of explanations searches for a physical solution. In the 1980s, physicists Giancarlo Ghirardi, Alberto Rimini and Tullio Weber proposed that some invisible process was tampering with quantum waves, causing them to suddenly collapse. In the following years, physicist Lajos Diósi at the Wigner Research Centre for Physics in Hungary and University of Oxford mathematician Roger Penrose proposed that gravity could be a culprit for this mysterious process. Essentially, the Diósi-Penrose model argues that, in the battle between quantum and gravity, quantum cracks first. The basic premise the pair set out was that putting a large mass into a superposition would force space-time to curve in two different ways – something it cannot permit. They proposed that the integrity of space-time prevails and causes the quantum waves to collapse.

If this is the case, superpositions would have a lifetime that is inversely proportional to the square of their mass. Quantum objects could live in a superposition for very long periods of time, but the larger the object was, the faster it would collapse. This would explain why we never see larger objects in superposition – because their substantial gravitational tug would instantly force a collapse. It also tackles the thorny problem of measurement, because any device large enough to detect and relay information about a quantum system would become part of that system and disturb it gravitationally. This idea moved the discussion away from merely interpreting quantum theory and instead towards revising it.

Ever-larger superpositions

Over the past 20 years, physicists have begun to build ever-larger superpositions in the hopes of verifying – or refuting – these predictions. Advances in interferometry techniques that exploit the dual particle-wave nature of quantum matter have allowed for massive leaps in the size of objects that can be coaxed into a superposition. Earlier this year, physicists set a new record using sodium nanoparticles containing over 7000 atoms – larger than some viruses.



The experimental setup that recently broke the record for the size of an item in a superposition

S. Pedalino/QNP/University of Vienna

A recent experiment from Penrose and his collaborators shows that such experiments are, in principle, able to test his collapse proposal. In a paper yet to be peer-reviewed, posted online in December 2025, a team led by Ron Folman at Ben-Gurion University of the Negev in Israel put a rubidium atom into a superposition of two states: one levitating in place and the other in gravitational freefall. Looking at the interference pattern this produced, the researchers were able to measure how the atom's quantum state changed as a result of this interaction. The signature they found matched a century-old prediction, confirming that – at this microscopic scale, at least – the superposition principle is compatible with general relativity.

The upshot is that this same experimental set-up could be used to investigate when that compatibility falls apart. Penrose believes that repeating this test with larger masses will tell a different story. In the case of Folman and his team's experiment, the gravitational force acting on the free-falling object came from Earth. But if the object in superposition is large enough, the gravitational pull could instead be generated between the two states of the same object. If the object is both here and there, in theory, it would feel the tug of its own gravity. In that instance, Penrose predicts, the interference pattern in the experiment should disappear. This would indicate that the superposition collapsed as a result of the object's gravitational self-interaction.

Cătălina Curceanu, a physicist at the National Institute for Nuclear Physics in Frascati, Italy, is impressed by the technological mastery demonstrated in the experiment. "It's absolutely fascinating," she says. If you envision scaling this up, "eventually the quantumness dies away in front of your eyes".

Folman is already preparing for follow-up experiments using tiny diamonds with more than a billion times more mass than the rubidium atoms he used previously. If he and his team can manage to create a superposition of those diamonds and separate them by 2 micrometres, they predict that gravitationally induced collapse would occur in less than a second. He suspects these experiments will be feasible in the next five years.

Others are less optimistic about the timeline. "Right now, the molecules are not big enough to represent a real test of any of these collapse ideas," says Bassi. "The day will come, but it will be a long journey."

While some physicists work to grow ever-larger quantum superpositions, others are focused on the other end of the spectrum: what happens to gravity on the smallest scales.

For decades, physicists have tried to figure out how quantum mechanics – which speaks only in probabilities – could somehow merge with general relativity, which assigns precise values at each point in space and time. Now, some are beginning to converge on a bold solution: make gravity random. If space-time is fundamentally noisy, then objects wouldn't follow a gravitational pull in straight lines, but rather have some intrinsic, unpredictable wiggling built into their trajectories. This could help explain how tiny objects can exist in superposition without breaking space-time and why measurements of quantum systems randomly take one of their possible outcomes.

Random gravity

In 2023, Jonathan Oppenheim at University College London solidified this idea in what he calls a "post-quantum" theory, which is a hybrid framework that allows the microscopic and macroscopic scales to function differently but still interact. "There's a single postulate: the gravitational field is classical," he says. "Everything else follows."

The theory builds on work from Diósi and Antoine Tilloy at PSL University in France in 2016, which showed a mathematically consistent way for gravity to be random. Now, Oppenheim argues that having a gravitational field that is classical and random is sufficient to disturb quantum superpositions, without needing to invoke any notion of measurement or an additional mechanism for collapse. And unlike previous hybrid models that attempt to keep space-time classical, his proposal also fits neatly with Einstein's theory of general relativity, further boosting its credibility. Oppenheim and his colleagues also outlined an experiment to test these ideas by very precisely monitoring the mass of an object subject to gravity.

Not everybody likes the idea of making gravity random, though. Ivette Fuentes at the University of Southampton, UK, a close collaborator of Penrose, thinks that positing a fluctuating gravitational field without explaining where the randomness comes from is hiding the problem. "Although I disagree with what he does, I really like it," she says. "He finds an alternative way and proposes an experiment to test it."

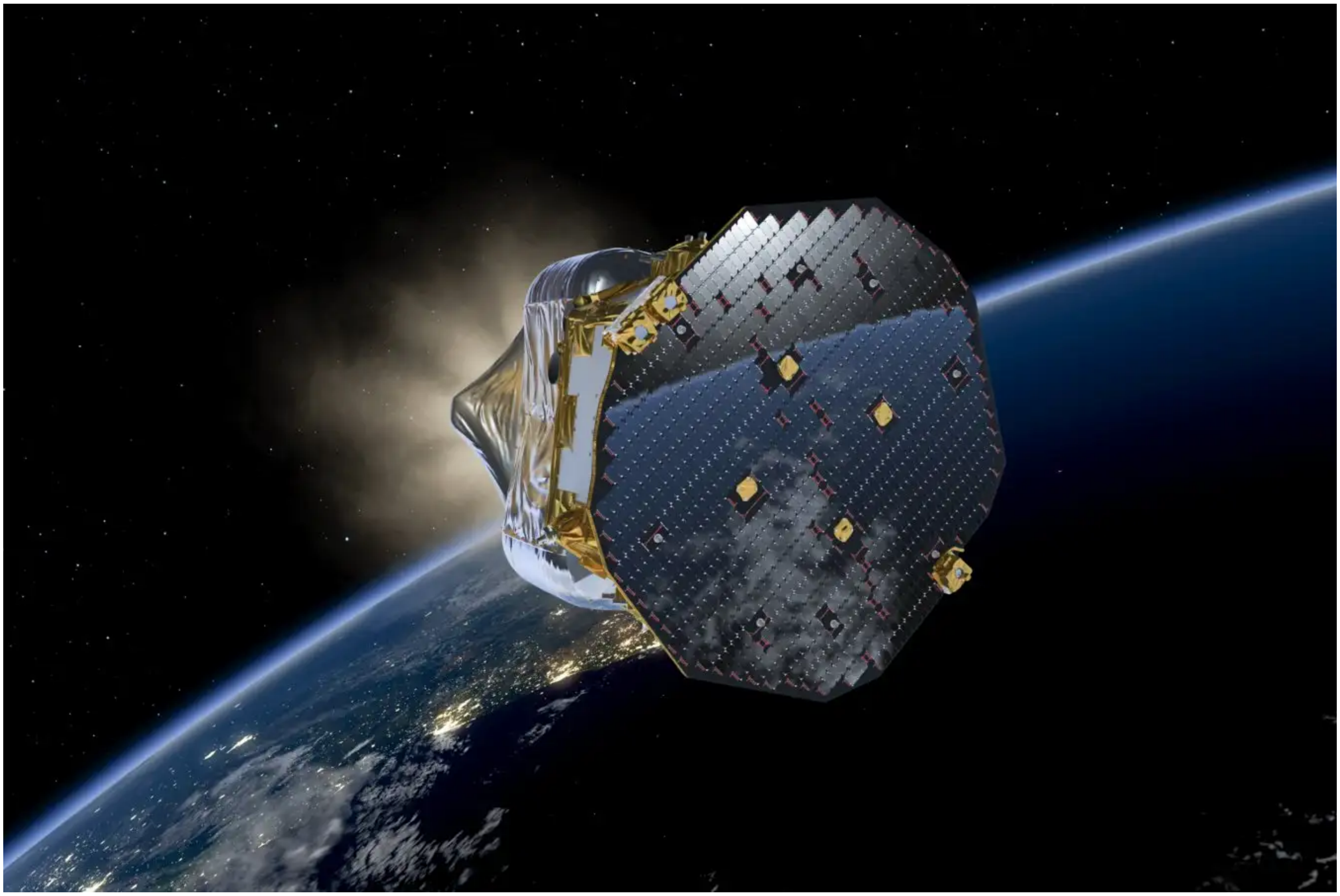
Furthermore, post-quantum gravity is now helping to probe gravitational collapse models more generally. Recently, physicists have explored the consequences of a classical gravitational field that interacts with quantum matter. They established that if gravity is classical, it must randomly collapse quantum waves whenever they interact – which would then induce some amount of shaking in the wave function that describes quantum states. In the past year, separate studies led by Bassi and Daniel Carney at Lawrence Berkeley National Laboratory in California calculated the minimal size of those fluctuations. Their analyses open new windows for testing these models.

New experiments

Over the past few years, three main channels of experiment have emerged in the search for signs of randomness in the gravitational field.

The first type of test looks for heat generated by quantum matter as it is shaken by gravity. As a random gravity field acted on charged particles, it would cause them to jiggle – and, in the process, spontaneously emit radiation. Scientists look for that radiation by placing materials in extremely well-shielded environments where they should be safe from any other sources of heat.

Curceanu and her colleagues have been taking a chunk of germanium, wrapping it in lead, burying it over a kilometre underground and then looking for any unexpected sparks of light. Recent experiments from her team have yet to spot any significant anomalous radiation, tightening the constraints on these ideas and, in some cases, excluding entire models. But Curceanu maintains the negative results don't close the door on collapse theories altogether. "When you eliminate the simplest models," she says, "the real work can start."



Artist's impression of LISA Pathfinder, which has provided some of the tightest constraints yet on gravitational randomness

ESA/ATG medialab

Another channel focuses on oscillating pendulums, looking for subtle swerves in their movement caused by gravitational randomness. Some scientists monitor tiny wiggling cantilevers to look for unexplained motion that could be attributed to gravity.

Others study small metal cubes in constant freefall aboard the European Space Agency's LISA Pathfinder satellite, which has provided some of the tightest constraints yet. Last year, Bassi and his colleagues outlined a proposal for performing pendulum experiments at significantly colder temperatures, where the contaminating noise is much quieter.

Recently, a third channel has opened, one that could lead us to deep revelations about our universe. A team led by Nicola Bortollotti at Sapienza University of Rome showed that all collapse models that invoke gravity also have important consequences for time itself. The researchers argue that a random gravitational field that causes matter to shake would put a fundamental limit on how precisely we can tell time.

The ultimate time limit

This limit is many orders of magnitude larger than the Planck time, which physicists previously believed to be the smallest measurable time interval. "The ultimate fuzziness of time may not require extreme quantum gravity, but can arise from more accessible physics," says Curceanu, who co-authored the paper.

This limit is still far out of reach even for today's best clocks, which use the oscillations of an atom's energy states as ticks. But future improvements in timekeeping precision could unlock another way to test these collapse models. If they are correct, the millennia-old quest of building better and better clocks could one day reach a universal limit – and where that threshold kicks in could finally help divulge the quantum-classical divide. Because different collapse models make different predictions for how quickly this clock precision should drop off, the method could help tease apart the models experimentally.

"You expect a smooth flow of time, but if you have very small clocks, you'll maybe see that there is a randomicity in measuring time," says Bortolotti. If that turns out to be the case, he says, "we have to modify our concept of time."

Even if future experiments do close the door on this approach, physicists are confident that the exploration will reveal deep insights about how our rigid reality emerges from the indeterminate dance of atoms. "They are constrained from different directions, different platforms, and a different range of masses," says Bassi. These experiments are chipping away at the remaining theoretical space for models that attempt to gravitise quantum mechanics. "Either they together shrink it to zero, and that's the end. Or they will find something."