

TWO QUESTIONS FOR THE BICENTENNIAL



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Quantum mechanics was born in the summer of 1925, when the young physicist Werner Heisenberg retreated to the island of Helgoland in northern Germany to escape the allergies that plagued him. Over the past hundred years, the theory has given rise to countless applications. Quantum electrodynamics, one of its generalizations, has shown an agreement between predictions and measurements of astonishing precision, better than one part in a trillion [1].

And yet, the foundations of the theory still elude understanding. This is due to two properties that radically distinguish quantum mechanics from its classical counterpart: superposition and entanglement. The first means that any linear combination of quantum state vectors is a quantum state; the second allows for correlations whose explanation seems to require instantaneous action at a distance. Both properties are essential to the development of quantum computers, which have been widely discussed since Peter Shor [2] demonstrated their speed in prime number factorization.

We could accept superposition if it only applied to microscopic systems, such as an electron. Since, however, the theory has universal value, microscopic superposition implies macroscopic superposition, as in the case of Schrödinger's cat. Different interpretations of quantum mechanics (Bohm and de Broglie's pilot wave [3], Everett's many worlds [4], or Rovelli's relational reality [5], for example) attempt to reconcile macroscopic superposition with what is observed. A very different solution, dating back to Dirac and von Neumann [6], consists in asserting that macroscopic superposition is impossible, i.e., that beyond a certain scale, quantum theory is no longer valid.

Quantum theory accounts for the microscopic world, while the large-scale structure of the universe is described by the theory of general relativity. To date, this theory has never been proven wrong. General relativity is a classical theory, incompatible with quantum mechanics. Most researchers believe that this incompatibility will be resolved once a quantum theory of gravity has been developed. Others, such as Roger Penrose [7], believe that the principle of superposition does not apply to the gravitational field, and that this field is responsible for the reduction of the state vector.

Building a high-performance quantum computer poses enormous challenges. The entanglement of "qubits" must be maintained despite disturbances from the environment. But the challenge is not only technical. If quantum mechanics no longer applies above a certain scale, the size and power of quantum computers are limited. In this sense, building increasingly powerful quantum computers is a severe test of quantum theory.

These considerations raise many questions, which can be summarized by two fundamental ones:

1. Will the development of quantum computers one day be hindered by a fundamental limitation in the validity of quantum theory?
2. Does the gravitational field (Figure 1) satisfy the principle of superposition and, if so, how can a quantum version of it be elaborated?

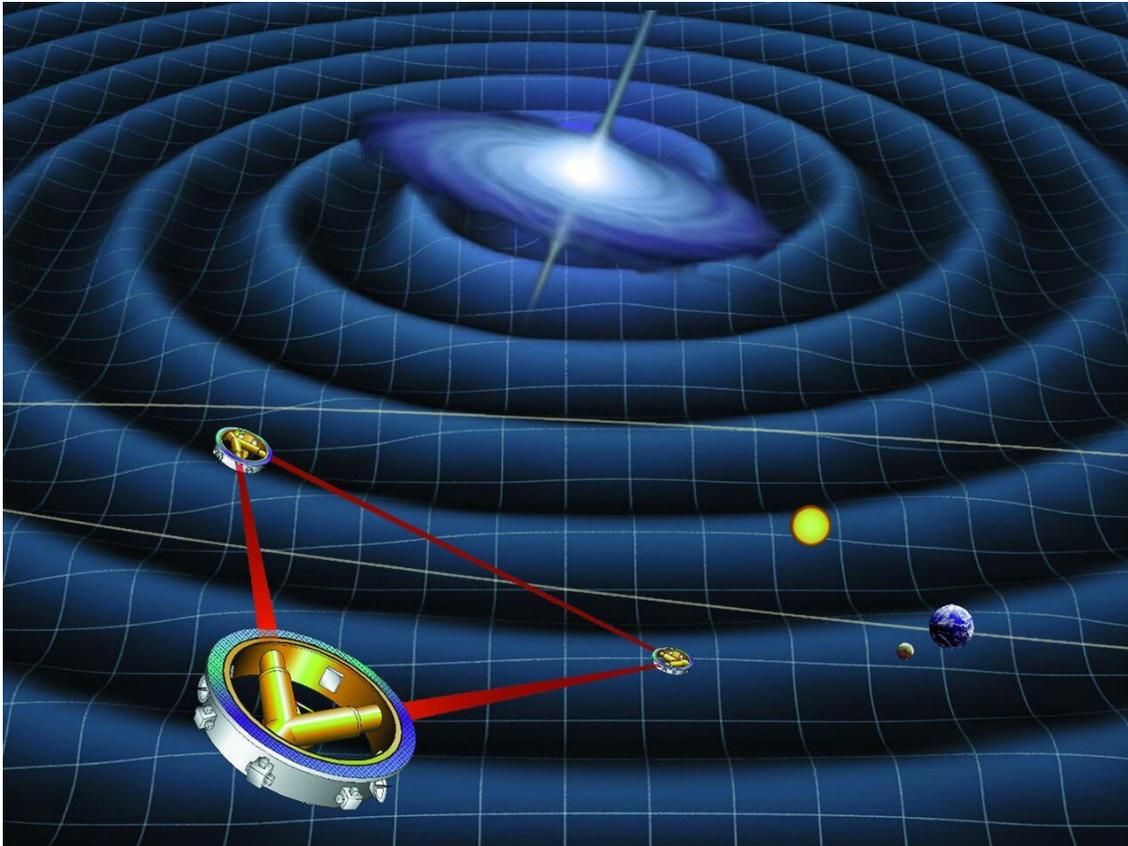


Figure 1. LISA, a triangular interferometer planned by the European Space Agency for 2035, could detect signs of quantum gravity in gravitational waves produced during the merger of black holes or in the early moments of the universe. (Source: Wikimedia Commons.)

These questions, in one form or another, have accompanied us for several decades. Will the answers come anytime soon? In any case, I would quickly ask them if I came back to Earth in 2125, celebrating the bicentennial of quantum theory.

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