Einstein's theory of relativity reaffirmed, despite doubts from quantum physicists

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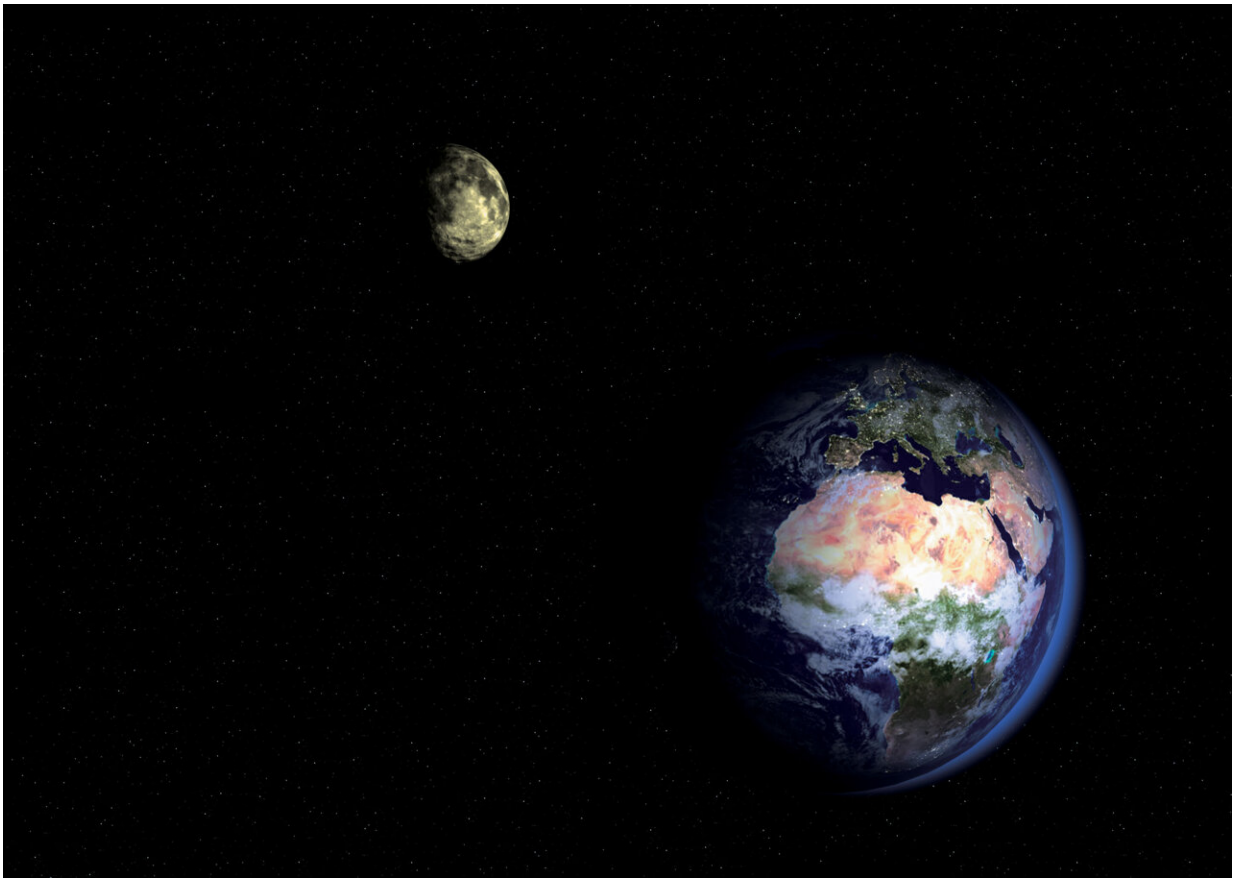

Binary system Earth-Moon. Credit: AEOS Medialab, ESA 2002

One of the most basic assumptions of fundamental physics is that the different properties of mass—weight, inertia and gravitation—always

remain the same in relation to each other. Without this equivalence, Einstein's theory of relativity would be contradicted and our current physics textbooks would have to be rewritten. Although all measurements to date confirm the equivalence principle, quantum theory postulates that there should be a violation.

This inconsistency between Einstein's gravitational theory and modern quantum theory is the reason why ever more precise tests of the equivalence principle are particularly important. A team from the Center of Applied Space Technology and Microgravity (ZARM) at University of Bremen, in collaboration with the Institute of Geodesy (IfE) at Leibniz University Hannover, has now succeeded in proving with 100 times greater accuracy that passive gravitational mass and active gravitational mass are always equivalent—regardless of the particular composition of the respective masses.

The research was conducted within the framework of the Cluster of Excellence "QuantumFrontiers." Today, the team published their findings as a highlights article in *Physical Review Letters*.

Physical context

Inertial mass resists acceleration. For example, it causes you to be pushed backwards into your seat when the car starts. Passive gravitational mass reacts on gravity and results in our weight on Earth. Active gravitational mass refers to the force of gravitation exerted by an object, or more precisely, the size of its gravitational field.

The equivalence of these properties is fundamental to general relativity. Therefore, both the equivalence of inertial and passive gravitational mass and the equivalence of passive and active gravitational mass are being tested with increasing precision.

What was the study about?

If we assume that passive and active gravitational mass are not equal—that their ratio depends on the material—then objects made of different materials with a different center of mass would accelerate themselves. Since the moon consists of an aluminum shell and an iron core, with centers of mass offset against each other, the moon should accelerate. This hypothetical change in speed could be measured with high precision, via "Lunar Laser Ranging."

This involves pointing lasers from Earth at reflectors on the moon placed there by the Apollo missions and the Soviet Luna program. Since then, round trip travel times of laser beams are recorded. The research team analyzed "Lunar Laser Ranging" data collected over a period of 50 years, from 1970 to 2022, and investigated such mass difference effects.

Since no effect was found, this means that the passive and active gravitational masses are equal to approximately 14 decimal places. This estimate is a hundred times more accurate than the best previous study, dating back to 1986.

LUH's Institute of Geodesy—one of only four centers worldwide analyzing laser distance measurements to the moon—has unique expertise in assessing the data, particularly for testing general relativity. In the current study, the institute analyzed the Lunar Laser Ranging measurements, including error analysis and interpretation of the results.

More information: Vishwa Vijay Singh et al, Equivalence of Active and Passive Gravitational Mass Tested with Lunar Laser Ranging, *Physical Review Letters* (2023). DOI: 10.1103/PhysRevLett.131.021401

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