A NEW TEST OF GRAVITY CONFIRMS EINSTEIN'S GENERAL RELATIVITY

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A new study confirms Lorentz invariance, the principle on which general relativity and the standard model of elementary particles are founded. The study, led by INAF researchers from the SaToR-G collaboration and funded by INFN, places strong constraints on possible violations.

Albert Einstein's theory of general relativity has passed a new and rigorous test, achieving one of its most accurate experimental verifications in the weak gravitational field regime. The result confirms a fundamental principle of general relativity, *Local Lorentz Invariance* (LLI): the laws of nature remain identical regardless of the speed or orientation with which an observer moves through space. This principle is mathematically summarised by a particular parameter, called PPN α_1, which is strictly zero if LLI holds, and consequently if general relativity holds. The new result improves the previous experimental limit, which had stood for around thirty years, by more than a factor of four, and was published on 27 July 2026 simultaneously in two of the most prestigious international journals in the field: *Physical Review Letters*, which presents the main result, and *Physical Review D*, where the result is discussed within the framework of a theoretical analysis and a rigorous characterisation of statistical and systematic errors.

The study was carried out by a collaboration led by researchers from the National Institute for Astrophysics (INAF), with the participation of researchers from the University of Rome Tor Vergata, the Institute of Information Science and Technologies of the CNR (ISTI-CNR), the British Geological Survey (United Kingdom), and the Instituto Geográfico Nacional (Spain). The project, known as SaToR-G, was funded by National Scientific Commission 2 of the National Institute for Nuclear Physics (INFN).

In search of new physics Local Lorentz invariance is a pillar of modern physics, a true cornerstone supporting both general relativity and the standard model of particle and field physics: as such, it lies at the foundation of our deepest understanding of spacetime. Many theories that seek to extend Einstein's theory or unify gravity with quantum mechanics predict the possible existence of a preferred reference frame in the Universe (typically identified with that of the cosmic microwave background), in contradiction with the principle of local Lorentz invariance. Such a violation would leave a measurable signature in the motion of artificial satellites. The PPN α_1 parameter quantifies precisely this possible deviation. In general relativity its value is exactly zero: therefore, any non-zero value would constitute evidence of new physics. The analysis established a new limit, according to which the value of PPN α_1 is compatible with zero with an uncertainty of less than two parts in one hundred thousand: this is the most stringent limit ever obtained for this parameter in the weak-field gravity regime, improving the previous experimental limit by more than a factor of four, a limit obtained in 1996 from Lunar Laser Ranging measurements of the Earth-Moon distance.

"Einstein's theory of General Relativity continues to prove itself extraordinarily robust", comments **David**

Lucchesi, INAF researcher associated with INFN and national coordinator of the experiment. “With this measurement – Lucchesi continues – we have pushed the limit on a possible violation of local Lorentz invariance to a level of accuracy never previously achieved in a weak gravitational field such as the Earth’s. Breaking a scientific record that had stood for thirty years, established by the historic laser measurements of the mirrors left on the lunar surface by the Apollo and LunoKhod missions, demonstrates that fundamental physics still has a great deal to discover and verify even ‘in our own backyard’, by studying circumterrestrial space around our planet”.

Thirty years of observations To obtain this result, the researchers analysed approximately thirty years of Satellite Laser Ranging measurements carried out on the geodetic satellites LAGEOS I and LAGEOS II, two passive satellites specifically designed for studies of geodesy and gravitational physics. Covered with hundreds of retroreflectors, the satellites are continuously illuminated by laser pulses from stations of the International Laser Ranging Service, including the Matera station of the Italian Space Agency. By measuring the time taken for light to travel to the satellite and back to Earth, it is possible to determine its distance with millimetre precision and reconstruct its orbit with centimetre accuracy. A possible violation of Lorentz invariance would produce a tiny annual oscillation in the satellites’ orbits. Detecting such a weak signal, however, requires distinguishing it from the many perturbations that continuously affect their motion.

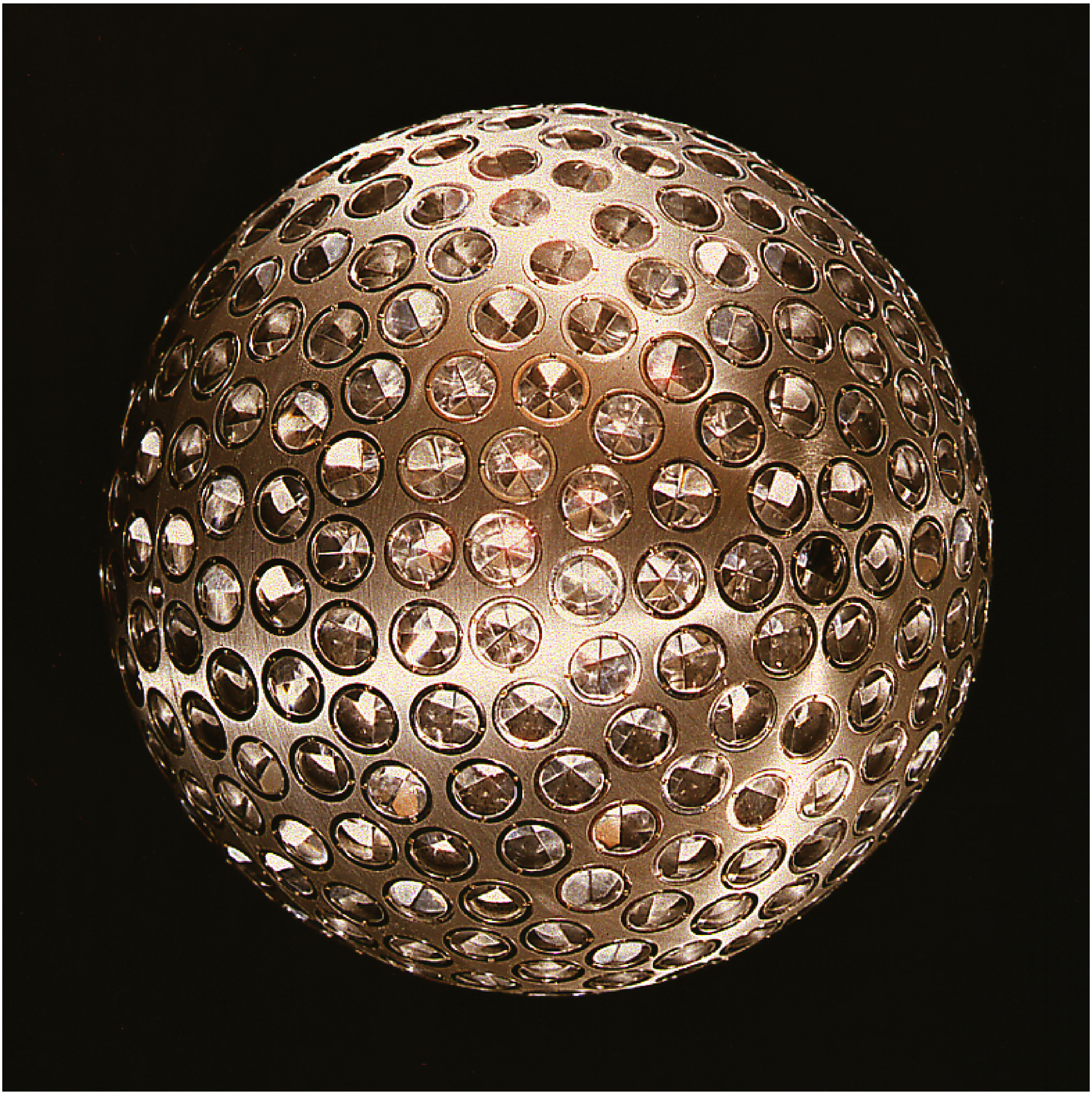
“Isolating such an infinitesimal signal amid the chaos of perturbations in near-Earth space was like searching for the proverbial needle in an orbital haystack”, explains **Massimo Bassan**, formerly Professor at the University of Rome Tor Vergata and an INFN associate researcher. “The LAGEOS satellites are continuously disturbed by the planet’s asymmetric gravitational field, tides, solar radiation pressure – both direct and reflected by the Earth – and thermal thrust effects”.

To overcome this obstacle, the research group applied ultra-selective filtering algorithms.

“We developed – explains **Massimo Visco**, an INAF researcher associated with INFN – an analysis strategy that mathematically combines the orbits of the two satellites while eliminating the main source of systematic error. We used a Phase-Sensitive Detection technique capable of selectively isolating only the signal we were searching for. To ensure the absolute robustness of the result, we carried out the analysis using two completely independent computational software packages. During this delicate validation phase, the role of the international collaboration was crucial, particularly thanks to our Spanish colleague José C. Rodriguez, who conducted the analyses using the British SATAN code, while our INAF colleague Roberto Peron carried them out using GEODYN II, developed by NASA. The two analyses produced fully consistent results”.

Einstein stands firm, but the search continues The final result is clear: no violation of local Lorentz invariance was observed. Once again, general relativity describes the behaviour of gravity in the Solar System with extraordinary precision. This ‘null result’ nevertheless represents an important advance in fundamental physics. By further constraining the possible value of the α_1 parameter, the study places new constraints on several alternative theories of gravity, such as Einstein-aether theory and Hořava-Lifshitz quantum gravity models in their low-energy limit, significantly reducing the region of parameter space compatible with experimental observations.

An investment in gravitational physics The result demonstrates the effectiveness of collaboration between Italian and European institutions. In recent years, INFN has increasingly invested in the study of gravity, from precision tests in the weak-field regime to observations of gravitational waves with Virgo and future experiments such as LISA and the Einstein Telescope. Experimental tests of gravity in weak and strong gravitational fields are in fact complementary: together they make it possible to test general relativity under very different conditions and to search for possible evidence of a more general theory capable of unifying gravity with quantum mechanics. For the time being, however, Einstein's theory continues to pass every test with distinction.



Il satellite LAGEOS ©NASA