High-precision space tests of the equivalence principle coming to reality

The recent detection made by the laser interferometer LIGO of a gravitational wave signal produced by merging black-holes opens the era of gravitational wave astronomy [1]. It will allow General Relativity (GR) to be tested more thoroughly than ever by measuring the details of gravitational phenomena which are not accessible by other means. In addition to the successful tests carried out in the solar system (weak field) and with high-precision radio-telescope observations of binary pulsars (strong field), GR will soon confront itself with a new class of extreme phenomena.

It is expected that this confrontation may lead to new physics beyond the Standard Model and away from the current impasse in understanding most of the mass of the Universe.

These issues are tackled also by testing the foundations of General Relativity. GR is based on the experimental fact that in a gravitational field all bodies fall with the same acceleration regardless of their mass and composition [2]. This is known as the Universality of Free Fall (UFF) or the Weak Equivalence Principle (WEP), though it is not a "Principle" but rather a fact nature. From Galileo till the present time physicists have tested and confirmed UFF with increasing precision, reaching 10^{-13} by means of slowly rotating torsion balances [3] and by laser ranging to retroreflectors on the surface of the Moon [4, 5].

Scientists agree that only an experiment in space could make a leap forward.

On 25 April 2016 the French space agency CNES has launched the Microscope satellite [6] to test to 10^{-15} (100-fold improvement) whether two test cylinders of different composition are equally accelerated from Earth. Evidence of a violation would signal that either GR needs fixing, or a new force of nature has been found. Either way, it would be a scientific revolution.

No matter how rigorously the Microscope experiment will be carried out, such a far reaching result would need confirmation.

Microscope exploits a stronger signal in space and –like torsion balances– relies on rotation in order to up-convert the signal to higher frequency where electronic and thermal noise are lower, allowing it to reach the target precision of 10^{-15} in 1.4 d of integration time.

The design of the Microscope sensor and experiment does not allow the satellite to rotate faster that $\simeq 10^{-3}$ Hz. In the GG ("Galileo Galilei") project [7] the test cylinders and the satellite have beed designed from the start to allow a spin rate 1000 times faster than Microscope (1 s period), made possible by rotation around the symmetry axis rather than perpendicularly to it. At this rate thermal noise is compatible with a 100 times better precision than Microscope (to 10^{-17}) which can be reached in a few hours of integration time [8, 9].

The STE-QUEST space proposal [10] is based on a cold-atom drop test of UFF-WEP which needs about 3 years of integration time to reach the target precision of $2 \cdot 10^{-15}$. A recent paper on Physical Review investigates the effects of initial condition errors, demonstrates that as atom interferometers try to reach 10^{-15} they hit the uncertainty limits of Heisenberg's principle, and concludes that precisions of 10^{-15} and better require macroscopic mass experiments [11].

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