Einstein rules at a precision of 2 × 10^-14

The MICROSCOPE experiment has set the best upper bound to date on the weak equivalence principle, proving Einstein's postulate with an unprecedented precision, as explained by Principal Investigator Pierre Touboul and team members Manuel Rodrigues and Joel Bergé.

Testing gravity has a long history, dating back to Galileo. In particular, the universality of free fall (UFF) has been extensively tested, with modern constraints arising from experiments in the laboratory with torsion pendulums[1] and comparisons of the fall of the Earth and the Moon around the Sun[2]. The modern form of the UFF, the weak equivalence principle (WEP), is the cornerstone of Einstein's general theory of relativity (GR). Testing the WEP allows one to challenge the very foundation of GR, and also to test alternative theories that aim to explain current conundrums such as dark matter, dark energy, or the unification of gravity with the quantum world. Such theories predict a violation of the WEP at a level somewhere below $\eta = 10^{-13}$, where the Eötvös parameter η is directly linked to the difference of acceleration between two test bodies and characterizes the WEP[3–5].

MICROSCOPE is the first test of the WEP performed in space with a drag-free satellite, with the goal to test it at the 10^{-15} level. MICROSCOPE's first results[6] give $|\eta| < 2 \times 10^{-14}$, one order of magnitude better than the best previous experimental constraints[1,2]. They also provide improved constraints on new long-range forces and on the mass and coupling constants of string theory's dilaton particle[7,8].

The MICROSCOPE microsatellite was launched on 25 April 2016. It orbits the Earth in a circular, Sun-synchronous, 710-km-altitude orbit (Fig. 1). The orbit was defined to maximize a potential WEP violation, while minimizing systematic effects (such as atmospheric drag or thermal variations). MICROSCOPE monitors the free fall of two test masses of different compositions; but instead of directly measuring the differences in their motion (as imagined by Galileo), MICROSCOPE forces the masses to follow the same trajectory through the application of electrostatic forces opposed to the Earth's gravity. The difference in the applied forces is directly related to a WEP violation.

The main payload, T-SAGE (Twin-Space Accelerometer for Gravity Experiment), consists of two parallel differential accelerometer instruments: each one provides the difference of outputs of two ultrasensitive accelerometers made of two concentric hollow cylindrical test masses.

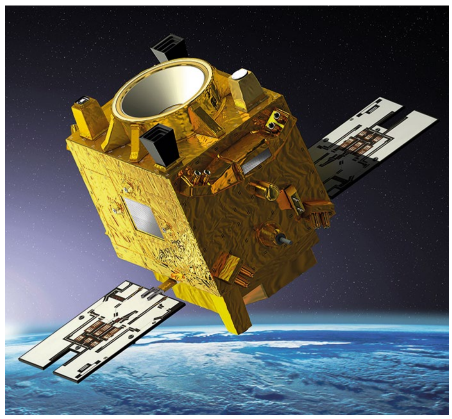

Fig. 1 | An illustration of the MICROSCOPE satellite in Earth orbit. Credit: © CNES/ill./DUCROS David, 2016.

The two instruments are identical, except for the use of different materials for the test masses. In one (reference) instrument, the two test masses have the same composition (a 90/10 platinum/rhodium alloy). In the other instrument, the inner test mass is made of Pt/Rh (90/10) and the outer is a titanium/aluminium/vanadium (90/6/4) alloy. The geometry of the test masses has been designed to reduce the local self-gravity gradients due to gravity multipole moment residues. The test masses' materials have been selected for their good trade-off between macroscopic and microscopic properties. They have significantly different baryonic and leptonic numbers, which maximizes the WEP violation in some phenomenological models[3,4]. Moreover, they have favourable magnetic and the electrical properties, limit disturbing forces like degassing (for radiation and radiometer effects) and are relatively easy to produce.

The MICROSCOPE satellite itself houses the test masses and shields them from the exterior. In particular, its drag-free and propulsion systems use the outputs of the instrument and of star sensors to compensate for the non-gravitational forces and torques applied to the satellite. The propulsion system relies on cold gas thrusters, which provide an impulse resolution as small as 0.1 μN over a full range of 100 μN. The 300 kg microsatellite has a maximum load of gaseous fuel of 30 kg, which allows for a one-year mission. It has furthermore been designed to optimize the thermal stability at the heart of the instrument (to <15 μK), with a thermal radiator on the satellite wall opposite the Sun, to compensate for its heat.

Finally, the Earth's gravity field can be modulated in the instrument frame by rotating the satellite about the normal to the orbital plane, thereby changing the frequency of a potential WEP violation signal. This is done to take advantage of the decreasing frequency noise between 2–50 × 10^{-4} Hz, where the damping noise is predominant: the noise spectral density has been measured and confirms the instrument behaviour[6,9].

These first results are based on the analysis of only 10% of the total data and the remaining data should allow us to reduce the statistical uncertainties. The main science mission is now coming to its end and will be followed by secondary experiments (geodesy, technology tests) until the autumn of 2018.

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