As a consequence, space missions can potentially test the Equivalence Principle to a considerable higher accuracy than ground tests, deeply probing a so far totally unknown field of physics where a violation is likely to occur. On these grounds space missions on the Equivalence Principle have been proposed since the early 1970s, and they have attracted more and more attention from space agencies around the world in the last 10 years.

Just as an additional example on the relevance of an Equivalence Principle test to a very high accuracy, let us consider the case of antiparticles. A peculiarity of gravity, strictly related to the Equivalence Principle, is that there is so far no evidence for antigravity, namely for the possibility that matter is gravitationally repelled by antimatter. A negative ratio of inertial to gravitational mass would obviously violate the Equivalence Principle and forbid any metric theory of gravity. Yet, there are theoretical formulations which would naturally lead to antigravity. Unfortunately, while experiments concerning the inertial mass of antiparticles have been highly successful, and these are very accurately known, gravitational experiments (i.e. involving the gravitational mass of antiparticles) are extremely difficult because of the far larger electric effects, such as those due to stray electric fields in the drift tube. In absence of such direct tests, an improvement by several orders of magnitude of current tests of the Equivalence Principle with ordinary matter would also be an important constraint as far as the relation between gravity and antimatter is concerned.

Yet, one should not undermine the difficulties of a space experiment. It must be operated from remote, with no direct access to the apparatus after launch. Experiment parts must be tested at 1–g, while they have been designed and optimized for weightlessness. Space is not as empty and quiet as one might think at first glance. Although there is no seismic noise of the kind we are used to on Earth, the spacecraft is subject to air resistance along its orbit, as well as to pressure from solar photons, both of them giving rise to disturbances on the test bodies. There are electric charges inside the spacecraft, whose interactions could completely mask gravitational effects. The spacecraft is exposed to heat sources (from the Sun and the Earth itself), which might produce relevant disturbances on the test bodies. All these are matters of concerns for any space experiment aiming to test the Equivalence Principle.

Data from a space experiment can be analyzed for checking any deviation from the Universality of Free Fall not only toward the Earth but also toward the Sun, or the center of our galaxy. However, except in the case of the Earth, the corresponding driving signal would be no bigger than it is in ground based experiments. Short range tests, which require an artificial source mass nearby (possibly a big one), are also not suitable candidates for a space experiment, and are much better carried out on the ground [23]

7 Proposed space experiments to test the Equivalence Principle

Ground tests of the Equivalence Principle based on the torsion balance have so far achieved the best accuracy. However, is the torsion balance the best instrument to fly? Test bodies on a torsion balance are sensitive to differential forces in the plane perpendicular to the suspension wire of the balance, which on the surface of the Earth aligns itself along the direction of the local vertical. Indeed, any deviation of the suspension wire from the verticality (e.g. due to terrain tilts related to microseismicity and Earth tides) is a disturbance and a serious matter of concern in these experiments. In an almost 0-g environment inside a spacecraft orbiting around the Earth there is no natural “vertical”, and the wire of the balance must be aligned by an active system of sensors and actuators. A good active alignment is possible; however, the *passive nature* of the instrument as it has been used so far in ground experiments, which proved vital in the detection of extremely small gravitational forces, would no longer be there.

Test bodies orbiting around the Earth at a non zero separation distance would be subject to varying tidal forces that are differential by nature. In addition, if the bodies have non zero (and different) multipole moments, they are also subject to a differential gravitational attraction from nearby mass anomalies and from the Earth itself. It is mandatory to make these classical effects as small as possible, and this suggests that the test bodies should be concentric –in order to reduce tidal effects–, spherical and homogenous –in order to reduce the effects of differential coupling to multipole moments. The closest practical solution, also taking into account that there must be a read–out system in between the test bodies to monitor their differential motions, is to have concentric, coaxial, hollow cylinders with appropriate dimensions to reduce their multipole moments while maintaining the cylindrical symmetry. Indeed, in all experiments proposed so far to test the Equivalence Principle in space the test bodies are concentric cylinders, differing only in the way they are arranged and suspended.

The first experiment to test the Equivalence principle in low Earth orbit was proposed in the USA in 1970 [24]. The authors suggested to place the test cylinders on a rotating aluminum wheel with their symmetry/sensitive axes in the radial direction and the rotation axis perpendicular to the plane of the wheel. The rotation speed was to be quite high: 100 *rpm* (1.7 *Hz*), the purpose being to modulate a putative signal of Equivalence Principle violation at high frequency. After the success of the Princeton and Moscow experiments [12, 13], which improved by a few orders of magnitude over the Eötvös result mostly thanks to a 24–*hr* modulation, the importance to modulate the signal at higher frequency had became apparent and motivated the experiment design proposed by [24]. The idea was abandoned, probably because of the disturbances that fast rotation would cause on the test bodies in this design. The authors did not seem to be aware that, with only one dimension available for the motion of the test cylinders, such a system is indeed known to be unstable [25]. If this limitation is removed, fast rotation can in fact be exploited to reduce perturbations related to the rotation itself, but this became known only many years later (see Sec. 7.2).

Shortly after [24] another American proposal was put forward for a space experiment to test the Equivalence Principle, named STEP (Satellite Test of the Equivalence Principle) [26]. Although the idea of a rapid rotation of the test masses, and consequent high frequency modulation of the expected signal was abandoned, the STEP experiment could still offer a modulation of the signal at a frequency more than a factor of 10 higher than the modulation frequency of the Princeton and Moscow experiments (see Sec. 7.1). STEP has dominated the field of space experiments on the Equivalence Principle for over 25 years by now [26–31]. A simplified version of it, based on the same concepts (named μSCOPE), has been proposed in France [32]. A different experiment and mission design, based on fast rotation and high frequency modulation (at 2 *Hz*, close to the original proposal of [24]) has come from Italy in the 1990s [33–37], named “GALILEO GALILEI” (GG). STEP, μSCOPE and GG are all under investigation by national space agencies. The goals are: 10^{-15} for the French μSCOPE, 10^{-17} for the Italian “GALILEO GALILEI” (GG), 10^{-18} for the American STEP. Their main features and the expected sensitivity are discussed in the next two sub Sections. Ground testing of a prototype of the GG apparatus proposed for flight is described in Sec. 8.