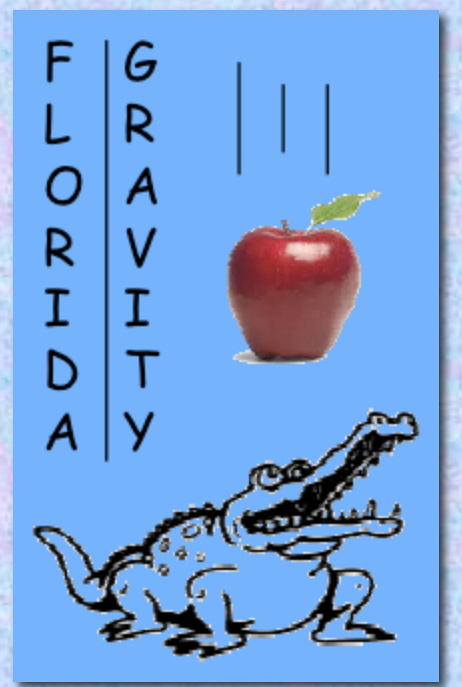
The Eötvös Experiment



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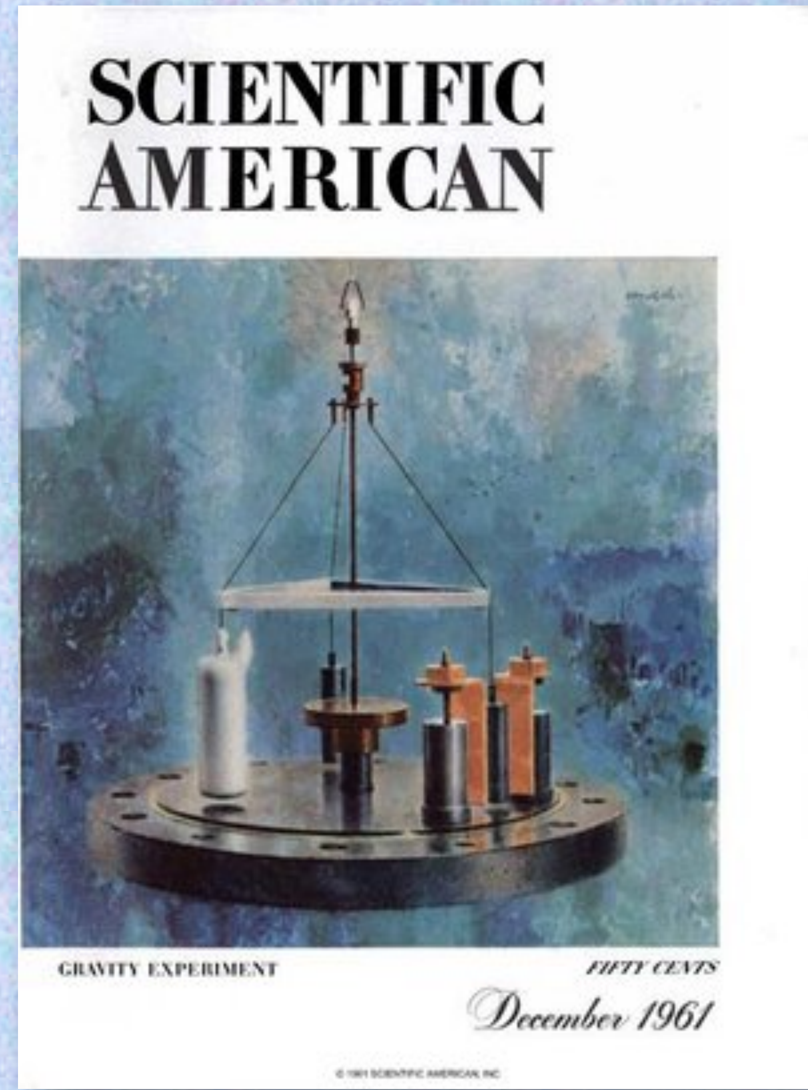
EPS Historic Site Ceremony, L. Eötvös University, 12 Oct. 2018

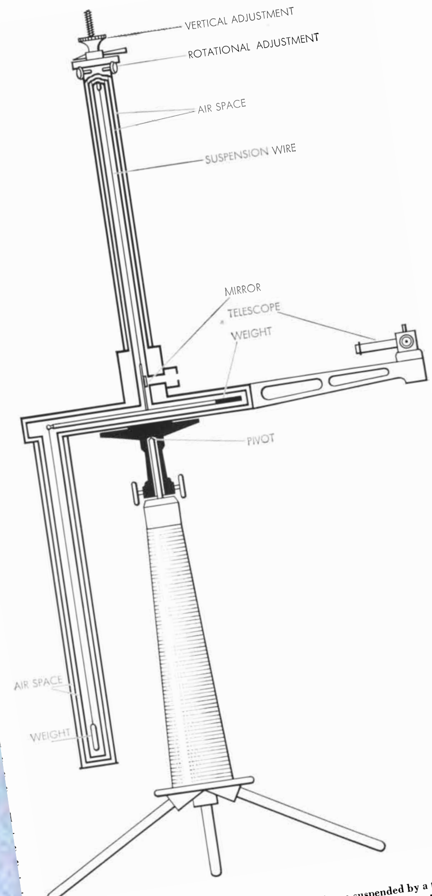
A 15th birthday present

The Eötvös experiment may have had an effect on my career as a scientist. For my 15th birthday, my parents gave me a subscription to "Scientific American". The very first issue I received had a cover story about the Eötvös experiment being carried out by Robert Dicke at Princeton. I didn't understand the article, but somehow I was fascinated by it, and remembered it many years later.



A 15th birthday present

Eötvös' apparatus



EÖTVÖS APPARATUS consisted of a light horizontal beam suspended by a thin platinum-iridium wire. Attached to the beam were two weights, one suspended 20 centimeters below the other—an arrangement that only increased the difficulty of the experiment. Any small rotation of the beam could be observed by viewing a calibrated scale through a telescope.

THE EÖTVÖS EXPERIMENT

Around 1900 a Hungarian baron conducted exquisite meas[...] to demonstrate that all bodies fall at precisely the same rate. [...] crucial to the general theory of relativity, has now been [...]

by R. H. Dicke

Some 350 years ago Galileo Galilei performed one of the most famous experiments in the history of sci[...]ce. From a "high tower" in Pisa (not [...]cessarily the famous Leaning Tower) [...] dropped weights of wood and lead [...]determine their rate of fall. He con[...]ded from this and other experiments, [...]vell as from logical reasoning, that [...]for air resistance all bodies fall with [...]ame acceleration. The constancy of [...]tational acceleration was tested [...] times thereafter, culminating in [...]traordinarily precise experiments [...]between 1889 and 1908 by Baron [...] von Eötvös of Hungary. [...] date of these experiments has led [...]hysicists to believe that Eötvös' [...]d a decisive influence on Albert [...] as he was formulating his gen[...]ory of relativity between 1908 [...]. The fact is, as Einstein wrote [...]he "had no serious doubts about [...]ancy of gravitational accelera[...] without knowing the results [...]irable experiments of Eötvös, [...]ny memory is right—I only [...]ow later." Nevertheless, it is [...]urate to say that if the re[...]Eötvös experiments had been [...]t negative, every physicist [...]heard the astonishing news [...]nd the whole foundation on [...]eneral theory of relativity [...]have vanished before the [...]en conceived. [...]at any experiment capa[...]he constancy of gravita[...]ion with higher accuracy [...]eved by Eötvös would [...]mental test of Einstein's [...]aratus used by Eötvös [...]cy with an accuracy of [...]five parts in a billion). [...] new experiment, still [...]aboratory at Princeton University, in which the accuracy of the experiment has been improved substantially, with further improvement still possible. I shall also discuss the significance of the experiment for contemporary physics.

As the old Galilean experiment is commonly described, it is not always made clear that two fundamental questions are involved. First, do objects of different mass fall at the same rate? Second, do objects of different composition fall at the same rate? It is primarily the second question that concerns us here. One could make a crude Galilean test of this question by dropping a wooden ball and a hollow lead ball of the same weight and external dimensions. (The object of making the two balls the same size is to equalize air friction and thus obviate the need for a vacuum chamber for the test.) From the experiment one would learn if carbon and oxygen (the chief constituents of wood) respond to gravity in the same fashion as lead, even though the nuclei of carbon and oxygen atoms contain equal numbers of neutrons and protons and the nucleus of the lead atom contains 50 per cent more neutrons than protons.

At least four important conclusions could be drawn from an experiment showing that objects accelerate equally regardless of composition. First, that single neutrons and hydrogen atoms (or electron-proton pairs) would be expected to fall with the same acceleration. Second, that the strong nuclear forces that bind the nucleus of the atom together, although quantitatively different in light elements and in heavy elements, have no effect on acceleration. Third, that the greater electrostatic energy associated with the nuclei of heavy elements has no effect. Fo[...]ties of electrons [...]shells of heavy el[...]er than those in [...]effect on gravitat[...]

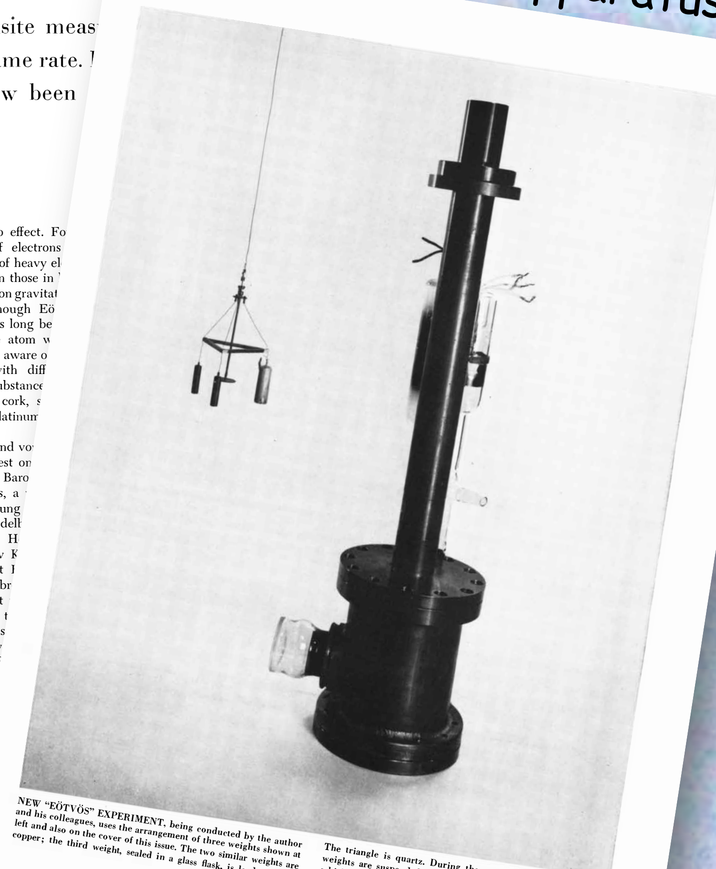
Although Eö[...]gations long be[...]of the atom w[...]dently aware o[...]ing with diff[...]the substance[...]glass, cork, s[...]and platinum[...]

Roland vo[...]pest on[...]son of Baro[...]Eötvös, a [...]the young[...]of Heidelb[...]under H[...]Gustav K[...]Robert [...]dealt br[...]ena; it [...]of 41, [...]famous[...]only w[...]so diff[...]worke[...]

Aft[...]used[...]para[...]of [...]wor[...]Th[...]ha[...]ies[...]ex[...]sc[...]r[...]c[...]

[...]193[...] [...]Eötvös experiment using [...]

Dicke's apparatus



NEW "EÖTVÖS" EXPERIMENT, being conducted by the author and his colleagues, uses the arrangement of three weights shown at left and also on the cover of this issue. The two similar weights are copper; the third weight, sealed in a glass flask, is lead chloride. The triangle is quartz. During the experiment the triangle and weights are suspended inside the high-vacuum chamber at right, which is sealed belowground (see illustration on page 94). The principle of the experiment is diagrammed on pages 88 and 89.

The Weak Equivalence Principle (WEP)

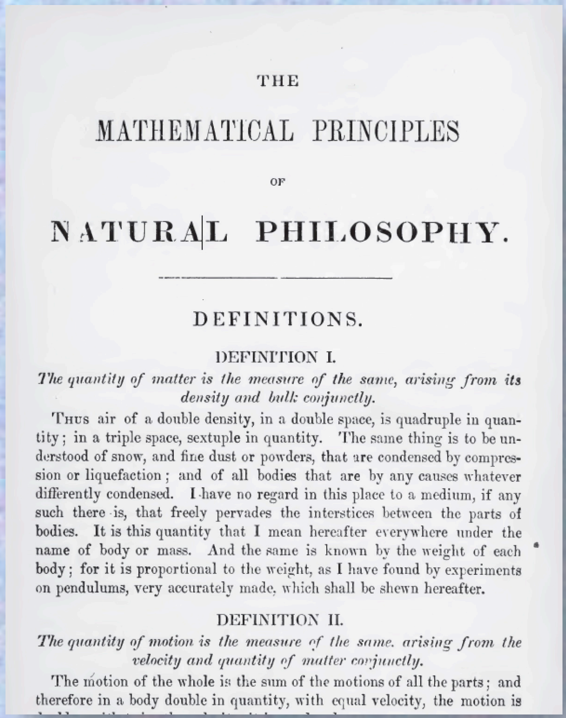
400 CE Ioannes Philiponus:
"…let fall from the same height two weights of which one is many times as heavy as the other …. the difference in time is a very small one"

1553 Giambattista Benedetti
proposed equality

1586 Simon Stevin
experiments

1589-92 Galileo Galilei
Leaning Tower of Pisa?

1670-87 Newton
pendulum experiments



THE

MATHEMATICAL PRINCIPLES

OF

NATURAL PHILOSOPHY.

DEFINITIONS.

DEFINITION I.

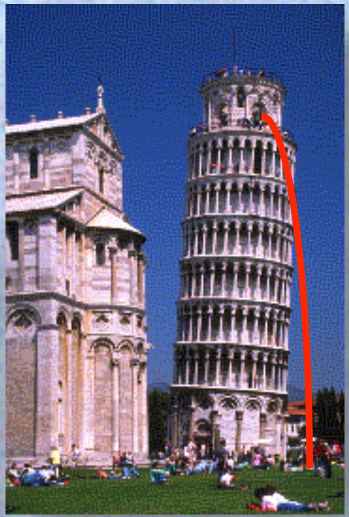
The quantity of matter is the measure of the same, arising from its density and bulk conjunctly.

Thus air of a double density, in a double space, is quadruple in quantity; in a triple space, sextuple in quantity. The same thing is to be understood of snow, and fine dust or powders, that are condensed by compression or liquefaction; and of all bodies that are by any causes whatever differently condensed. I have no regard in this place to a medium, if any such there is, that freely pervades the interstices between the parts of bodies. It is this quantity that I mean hereafter everywhere under the name of body or mass. And the same is known by the weight of each body; for it is proportional to the weight, as I have found by experiments on pendulums, very accurately made, which shall be shewn hereafter.

DEFINITION II.

The quantity of motion is the measure of the same, arising from the velocity and quantity of matter conjunctly.

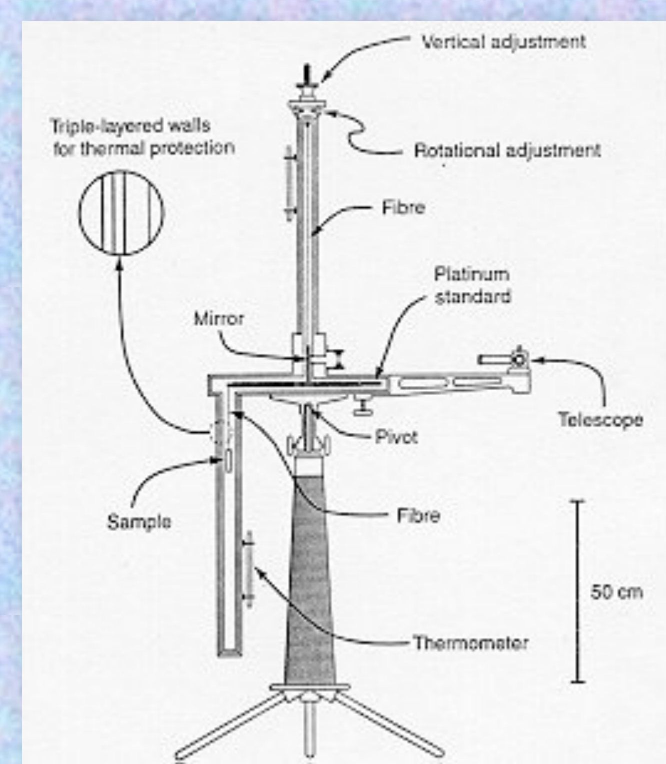
The motion of the whole is the sum of the motions of all the parts; and therefore in a body double in quantity, with equal velocity, the motion is

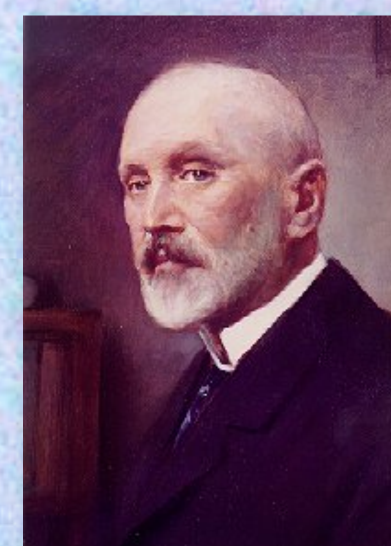


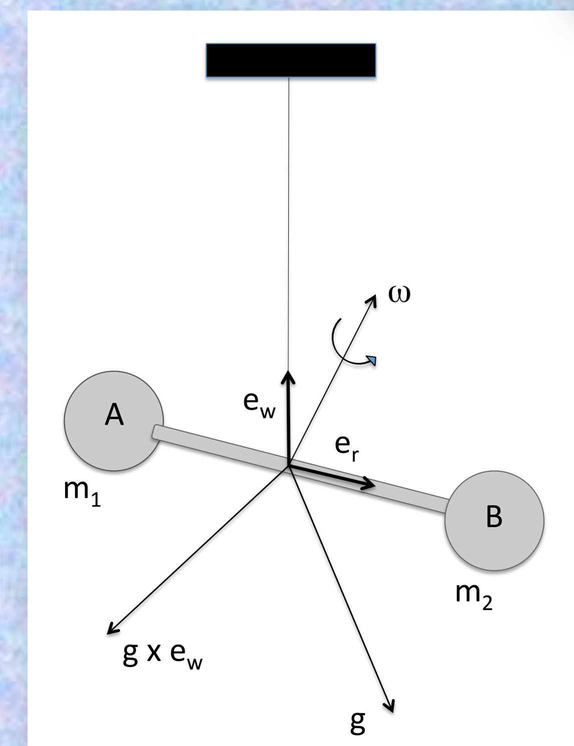
Bodies fall in a gravitational field with an acceleration that is independent of mass, composition or internal structure

The Eötvös Experiment

- Experiments 1885, 1889, 1906 – 09
- Comprehensive paper with Pekár & Fekete, 1922

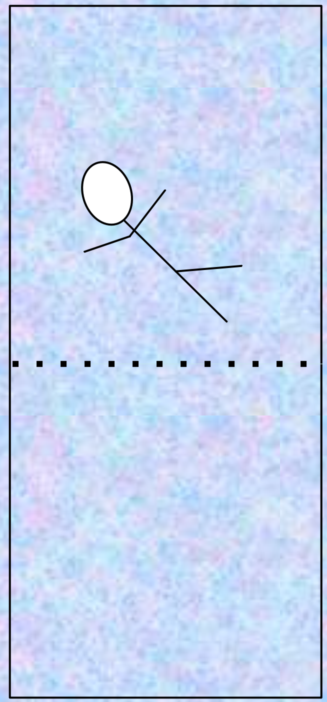




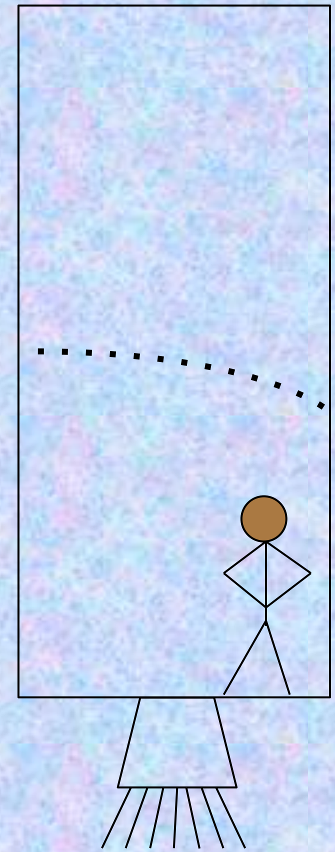


WEP and curved spacetime

Einstein used the equality of acceleration to argue that a gravitational field and an accelerating laboratory were "equivalent". This principle of equivalence became a foundation for his conception that gravity was the result of spacetime curvature



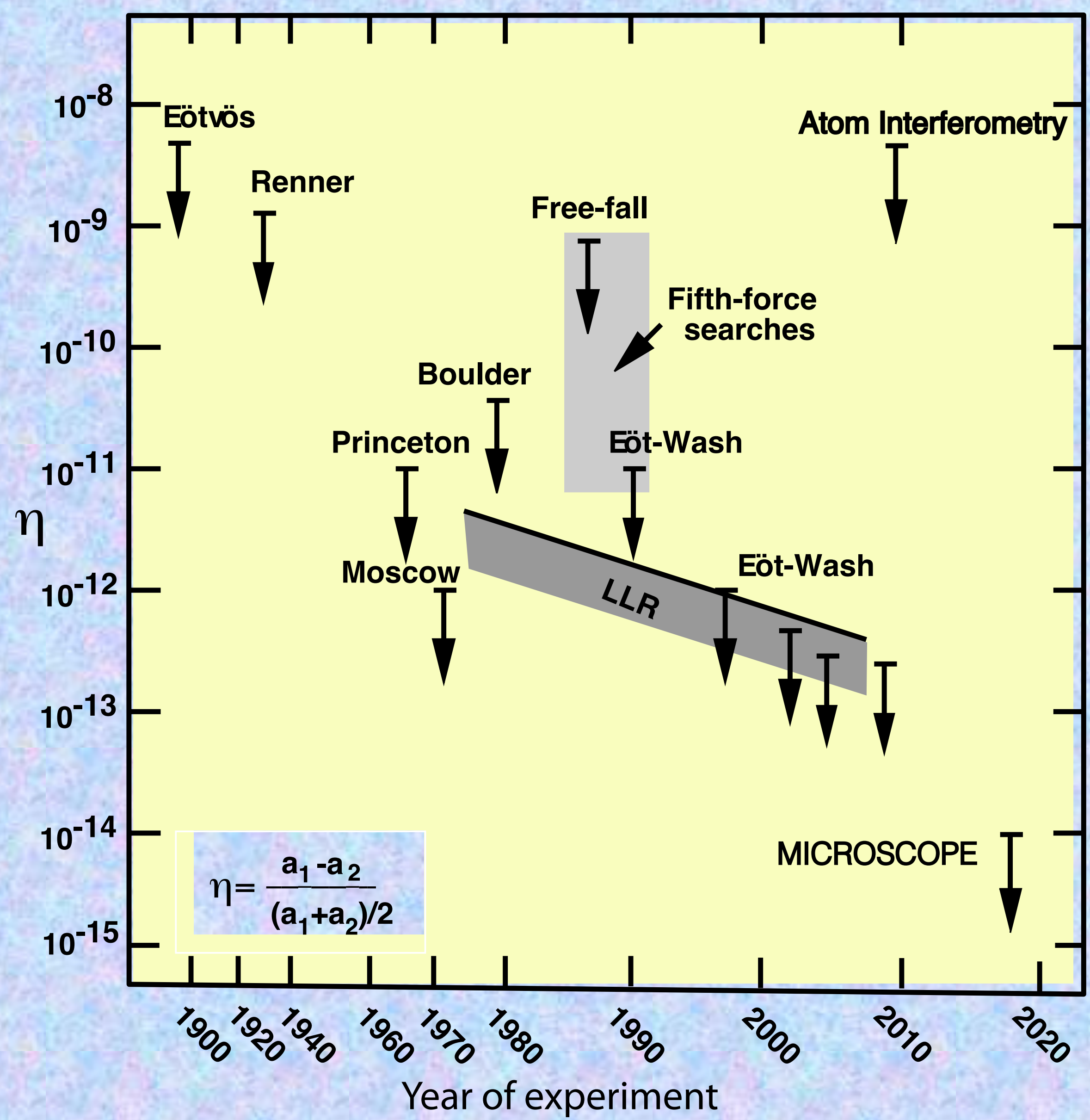
freely falling frame
= no gravity



accelerating frame
= frame in gravity

To Einstein, gravity = geometry

Tests of the Weak Equivalence Principle

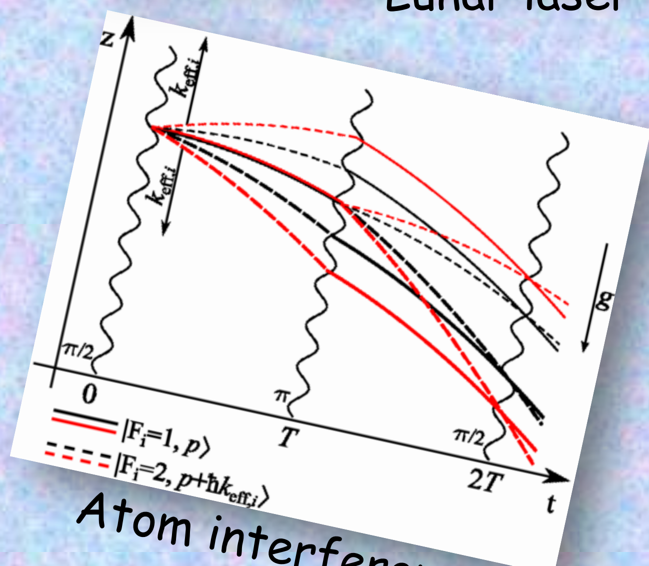


The parameter η, expressing the difference in acceleration between different materials divided by the average acceleration is now called the "Eötvös ratio".

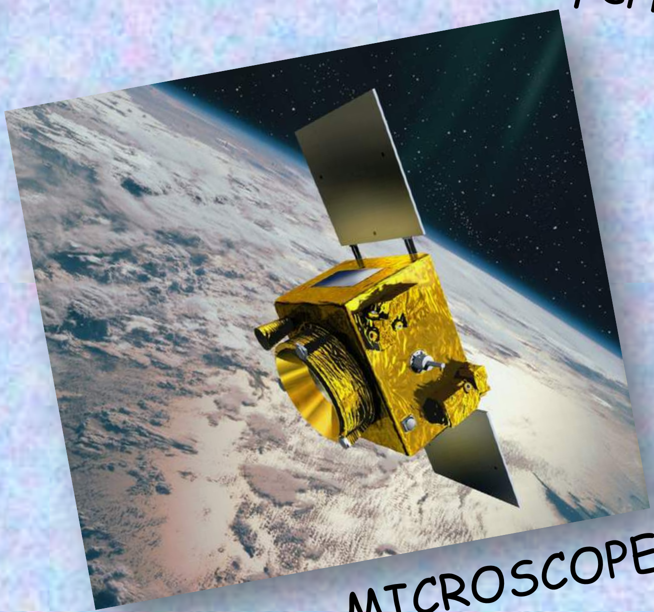
Tests of the Weak Equivalence Principle

Lunar laser ranging

The Eöt-Wash experiment



Atom interferometry

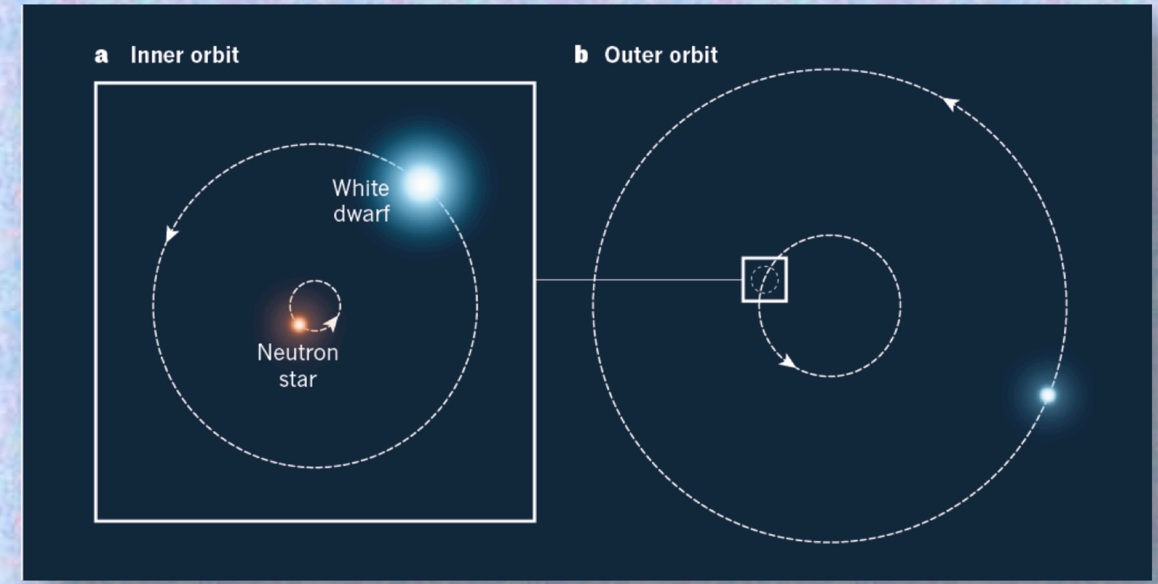


MICROSCOPE

The ultimate Eötvös experiment

A pulsar in a triple system J0337+1715 (2014)

	Inner binary	Outer binary
$M_1(M_\odot)$	1.4378	1.6353
$M_2(M_\odot)$	0.1975	0.4103
P_b(days)	1.629	327.26
$e(10^{-2})$	0.0692	3.5356



The neutron star and white dwarf in the inner orbit fall toward the distant white dwarf to 2.6 parts per million.

$$\eta < 2.6 \times 10^{-6}$$

Archibald et al *Nature* **559**, 73 (2018)
CMW, Commentary, *Nature* **559**, 40 (2018)

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