Testing Einstein's General Theory of Relativity

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Albert Einstein (1879–1955) had already proposed three possibilities for testing his General Theory of Relativity:

- An additional perihel motion of Mercury (43″/century), which could not be explained by Newton's theory of gravity; this was already known since 1850.
- Deflection of light from the Sun (1.75″): The angular position of the stars are more distant from the Sun during a total solar eclipse than half a year later during the night.
- Gravitational redshift of the Sun (2×10^{-6} of the wave length or 0.01 Å): The spectral lines of the Sun are shifted to the red by one millionth of the wave length of the light; this corresponds to a Doppler shift of 0.6 km/s.

Many astronomers were sceptical against the new theory (ART), but Erwin Finlay-Freundlich (1885–1964) became interested in the ART since 1913 and tried to verify the theory empirically. He started an solar eclipse expedition in 1914 with the help of the Academy of Sciences which was not successful due to the outbreak of World War II. Karl Schwarzschild (1873–1916) tried to measure the redshift in the solar spectrum in 1913–1914 in the Astrophysical Observatory Potsdam. From these experiments it was clear that results could only be reached with much larger instruments.

Arthur S. Eddington (1882–1944) had observed the light from stars passing close to the Sun was slightly bent, so that stars appeared slightly out of position. This spectacular success of the English solar eclipse expedition (1.98″) was announced in November 6, 1919. This caused activities to errect a solar tower observatory in Potsdam; the Einstein tower was finished in 1921, but the hope for successfully testing the theory failed. Since that time scientists have thought of new experiments to test Einstein's theory of gravity.

Currently the deflection of "light" is best measured using radio astronomy, since radio waves can be measured during the day without waiting for an eclipse of the Sun. In 1969 the deflection in the gravitational field of quasars was measured by Seielstad, Sramek et al.

Instead of using the bending of light by the Sun, in 1964 Irwin Shapiro (MIT) measured the running time delay of radar signals sent between Earth and Mars. As the beams pass closer and closer to the Sun, a radar-echo time delay is measured. This delay is caused by the gravitational force of the Sun. Later a far more accurate test was made with the Mariner 6 and 7 spacecrafts as they orbited the planet Mars. The first test, using the MIT Haystack radar, was successful, matching the predicted amount of time delay. The experiments have been repeated many times since, with increasing accuracy.

A gravitational lens is formed when the light from a very distant, bright source (such as a quasar) is "bent" around a massive object (such as a massive galaxy) between the source object and the observer. This effect is called gravitational lensing (e.g. Einstein ring), predicted already by Einstein in 1936, first observed in 1979, using the Kitt Peak National Observatory 2.1 meter telescope.

In addition, orbiting clocks should be mentioned. Nearby to massive bodies and in larger height clocks slow down (Joseph Hafele and Richard Keating 1971). But also on the Earth one can measure the effect by using the muon live time: In comparison to the calculation the measured number of muons is much larger because for the fast moving muons the time slows down. In 1959 this could be confirmed with the particle accelerator of CERN.

Einstein showed that an object accelerated due to gravitational forces emits gravitational waves, thereby loosing energy. Recent experiments on a binary pulsar system by Russell A. Hulse and Joseph H. Taylor Jr. (Princeton University) have verified Einstein's predictions to within one percent (Nobel prize 1993).

The gravitational redshift was measured for white dwarfs, first in the case of Sirius B in 1925. The effect is well confirmed in the Earth's gravitational field (Robert V. Pound and Glen A. Rebka 1959) by means of the Mößbauer effect (1957): the change of frequency (gravitational shift) of gamma quantums at Earth's surface over a drop of 22.6 m.

Modern experiments: The radio waves transmitted past the Sun and towards the Earth by the Cassini spacecraft (NASA 2002) flying between Jupiter and Saturn are delayed by their passage through the curved space-time near the Sun. Bruno Bertotti (University of Pavia) et al. have analysed these waves, and their value for the Shapiro time delay agrees with the predictions of general relativity to 1 part in 10^5. Another recent experiment is the gravity probe B satellite (Stanford university, launch 2004) with four miniature gyroscopes.

According to all these experiments Einstein's General Theory of Relativity seems to be in the moment the best theory of gravity. But the testing in strong gravitational fields is still missing.