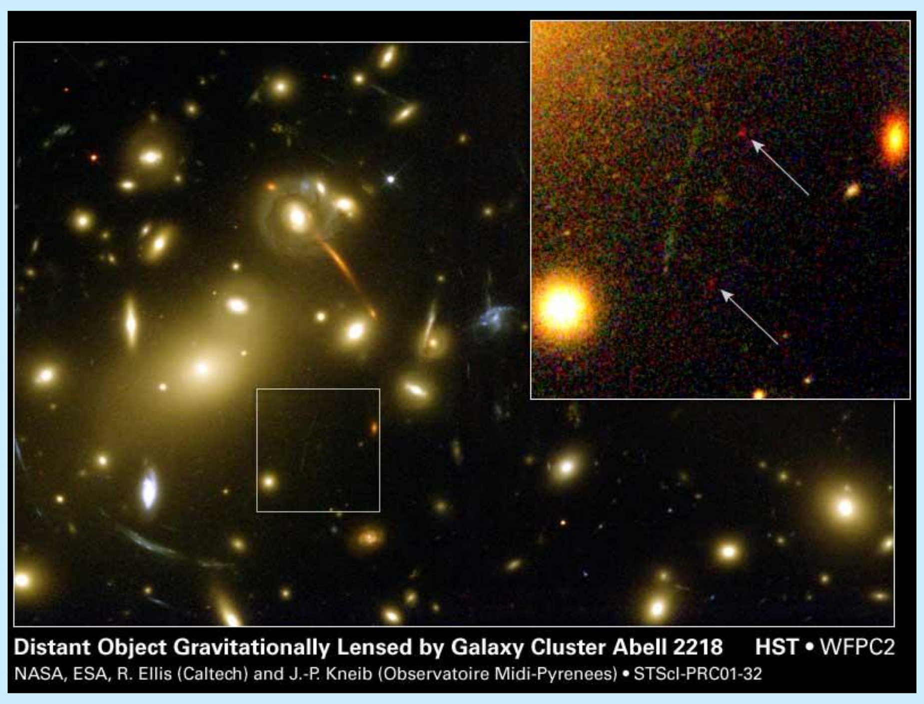
On the Track of Modern Physics

E pur si muove!

Abell 2218: A Galaxy Cluster Lens
The shapes of distant galaxies are distorted by presence of great masses (some of them invisible) along the light path; and distant, faint galaxies are magnified.



http://www.noao.edu/image_gallery/images/d5/q2237.jpg

This epoch sentence is attributed to Gallileo, and was referred to Copernicus' vision of the Earth rotating around Sun.
Einstein's general relativity predicts the SPACE rotating around EARTH, but the effect is small.
So small, that even Einstein did not believe in observing it.

ANNALEN DER PHYSIK.
VIERTE FOLGE. BAND 49.

1. *Die Grundlage der allgemeinen Relativitätstheorie;* *von A. Einstein.*

$$B = \int^{+\infty} \frac{\partial \gamma}{\partial x_1} dx_2 ,$$

während (73) und (70) ergeben

$$\gamma = \sqrt{-\frac{g_{44}}{g_{22}}} = 1 + \frac{\alpha}{2r}\left(1 + \frac{x_2^2}{r^2}\right) .$$

Die Ausrechnung ergibt

$$B = \frac{2\alpha}{\Delta} = \frac{\varkappa M}{4\pi\Delta} . \quad (74)$$

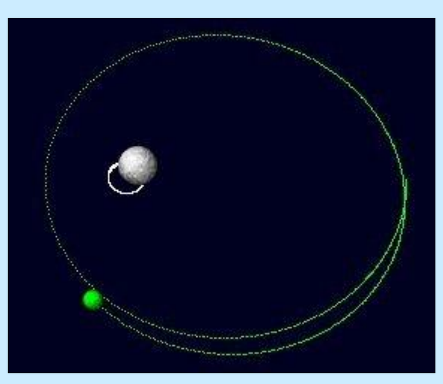
Ein an der Sonne vorbeigehender Lichtstrahl erfährt demnach eine Biegung von 1,7″, ein am Planeten Jupiter vorbeigehender eine solche von etwa 0,02″.

The deviation of light from General Relativity is double compares to that resulting from Newton's theory.

Die Rechnung ergibt für den Planeten Merkur eine Drehung der Bahn um 43″ pro Jahrhundert, genau entsprechend der Konstatierung der Astronomen (Leverrier); diese fanden nämlich einen durch Störungen der übrigen Planeten nicht erklärbaren Rest der Perihelbewegung dieses Planeten von der angegebenen Größe.

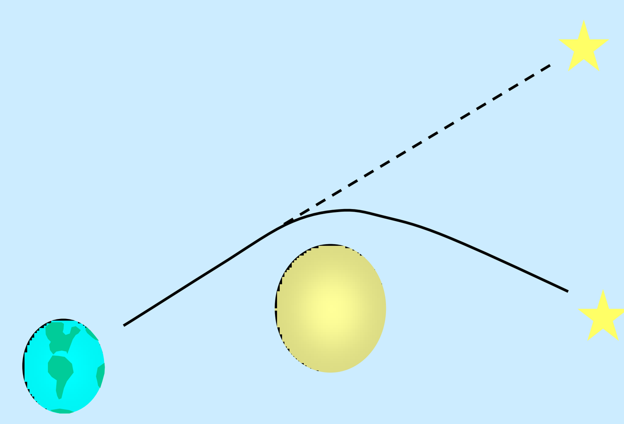
1) Bezüglich der Rechnung verweise ich auf die Originalabhandlungen A. Einstein, Sitzungsber. d. Preuß. Akad. d. Wiss. 47. p. 831. 1915. — K. Schwarzschild, Sitzungsber. d. Preuß. Akad. d. Wiss. 7. p. 189. 1916.

(Eingegangen 20. März 1916.)

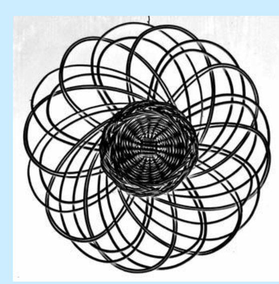


In 1916, Albert Einstein, professor in Berlin, submits another important paper, written with the help of his friend from studies, mathematician M. Grossmann.

As always, at the end of complex formula A. Eintein gives some **practical predictions**.
Here he calculates the **deviation of light** by the gravitational field of Sun and of Jupiter



and the **precession** of the Mercury orbit.



Only the Newton's, 1/r gravitational field assures closed orbits of planets. If the field is non-Newtonian, or The space "curved", non-Euclidean, then the orbits are open.

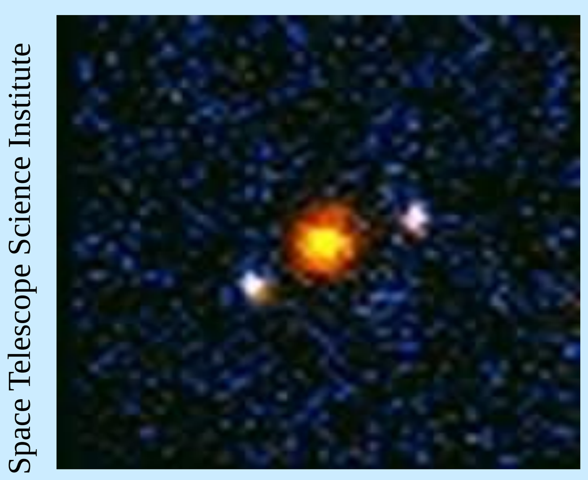
Mercury, close to the Sun, probes the time-space curvature.

Gravitational lenses act like this, multi-facets lens: from a single object they produce multiple images.

National Optical Astronomy Observatory, Tucson
www.noao.edu/image_gallery/html/im0553.htm

Q2237+0305 quasar

Space Telescope Science Institute



HST 01247+0352

Gravitational lenses produce multiple images, like that of Q2237+0305 quasar. Many gravitational lenses were found by the Hubble telescope: HST 01247+0352 is a pair of images around the red spherical elliptical lensing galaxy.

"Extending the GPS Paradigm to Space Exploration" (*)

Around the world atomic clock experiment

(Flying clock – Reference clock)

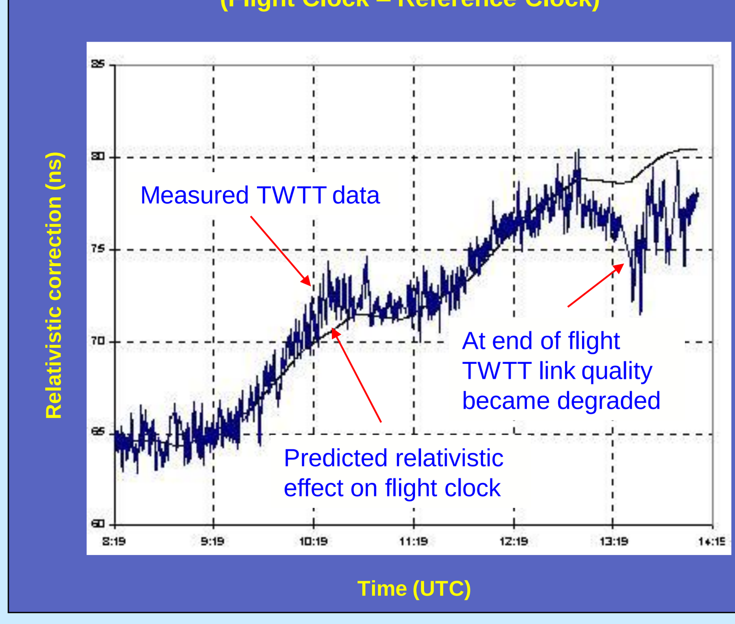
$$v_2 = v' + \omega R \qquad v_1 = \omega R$$

$$\Delta\tau_2 - \Delta\tau_1 \approx \left[-\frac{1}{2c^2}(v_2^{\,2} - v_1^{\,2}) + \frac{g\,h}{c^2}\right]\Delta\tau_1 = \left[-\frac{1}{2c^2}\left(v'^2 + 2\,v'\,\omega\,R\right) + \frac{g\,h}{c^2}\right]\Delta\tau_1 = -\frac{2\pi R}{c^2}\left(\frac{1}{2}|v'| \pm \omega\,R\right) + \frac{g\,h}{c^2}\Delta\tau_1$$

predicted effect	*direction* East	West
Velocity (time dilation)	– 51 ns	– 47 ns
Sagnac effect	– 133 ns	+ 143 ns
Gravitational potential (redshift)	+ 144 ns	+ 179 ns
Total	– 40 ± 23 ns	+ 275 ± 21 ns
Measured	– 59 ± 10 ns	+ 273 ± 7 ns

Prediction of Relativistic Effects

Comparison of Measured Data with Prediction (Flight Clock – Reference Clock)



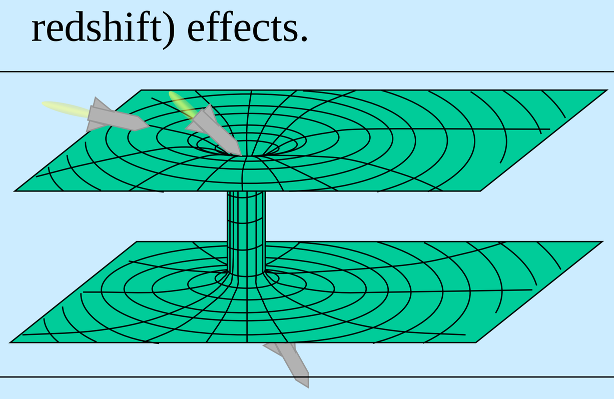
Relativistic Corrections

Velocity (time dilation) $\Delta\tau = -\frac{1}{2\,c^2}\sum_{i=1}^{N} v_i^{\,2}\,\Delta t_i$

Gravitation (redshift) $\Delta\tau = \frac{g}{c^2}\sum_{i=1}^{N}(h_i - h_0)\,\Delta t_i$

Sagnac effect (rotation) $\Delta\tau = -\frac{\omega}{c^2}\sum_{i=1}^{N} R_i^{\,2}\cos^2\phi\;\Delta\lambda_i$

Flights with an atomic clock around the world show both the special relativity (time dilatation and Sagnac rotational) and the general relativity (gravitational redshift) effects.



Some bizarre theories say that the space can be wrapped by a huge mass, like black hole, to another dimension. For the moment, we have no experimental indications for such phenomena.

In 1918 J. Lense and H. Thirring, noted from the general relativity theory, that a rotating mass creates time-space deformation (besides "ordinary" deformation caused by mass in itself) - like pulling it in the direction of rotation. Unfortunately such an effect in the case of Earth is insignificantly small - it causes change of Moon's orbit just by a few millimetres per year.

Einstein, commenting Lens-Thirring's equation noted, that the effect would be greater if Moon was closer to Earth.
He did not predict satellites!

Equation of motion to post-Newtonian order

$$\ddot{\mathbf{r}} = -\frac{GM}{r^3}\mathbf{r} - \frac{1}{c^2}\frac{GM}{r^3}\left[\left(4\frac{GM}{r} - \dot{\mathbf{r}}\nabla^2\dot{\mathbf{r}}\right)\mathbf{r} + 4\left(\mathbf{r}\nabla^2\dot{\mathbf{r}}\right)\dot{\mathbf{r}}\right]$$

Newtonian acceleration — Precession of periapsis (like for Mercury)

$$+\,2\frac{1}{c^2}\frac{GM}{r^3}\left[\frac{3}{r^2}\left(\mathbf{r}\nabla^2\mathbf{J}\right)\mathbf{r} - \mathbf{J}\right]\times\dot{\mathbf{r}} + 3\frac{1}{c^2}\frac{GM}{r^3}\left(\mathbf{r}\times\dot{\mathbf{r}}\right)\times\dot{\mathbf{r}}$$

Lens-Thirring precession (frame dragging) — Geodetic (de Sitter) precession of the spin axis

The equation of motion for satellites contain several corrections, all due to the General Relativity

In 1996, small changes in the orbit of "Lageos" satellite, were measured with the 1 cm precision, using laser impulses from Earth. A shift of the orbit of about 1 degree per 120 years was noticed. This confirms the Lens-Thirring effect.

Taking into account that changes of the orbit caused by non spherical shape of the Earth are 10 million times bigger in the magnitude, Einstein would say for sure:
"**E pur si muove (the time-space)!**"

Credits: Abel 1689 cluster is by Andrew Fruchter (STScI) et al., WFPC2, HST, NASA
http://oposite.stsci.edu/pubinfo/PR/2001/32/content/0132w.jpg
Quasar Q2237+0305 is by J.Rhoads, S.Malhotra, I.Dell'Antonio (NOAO)/WIYN/NOAO/NSF
HST 01247+0352 Kavan Ratnatunga (Carnegie Mellon Univ.) and NASA
http://hubblesite.org/newscenter/newsdesk/archive/releases/1999/18/image/c

(*) Dr. Robert A. Nelson
Satellite Engineering Research Corporation
Bethesda, Maryland USA
Civil GPS Service Interface Committee (CGSIC) Meeting
Long Beach, California USA, September 21, 2004

• The gravitational redshift in vertical direction was observed in 1960 by Pound and Rebka by the Mössbaer effect, with γ-rays of 0.86 Å.
• In 1993, the Nobel Prize in Physics was awarded to R.Hulse and J.Taylor for their 1974 discovery of the binary pulsar PSR 1913+16 and their analysis of its emission of gravitational waves, indicating a loss of energy, in agreement with the General Relativity.