# Physics is Fun:
# Why do objects fall?
# Part II

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# Physics is Fun!

## But physics is also discovery:

Albert Einstein:

How can we recognize real absence of gravity from free falling?

→ General theory of relativity (1915)

# Copernicus: does it Earth that moves?

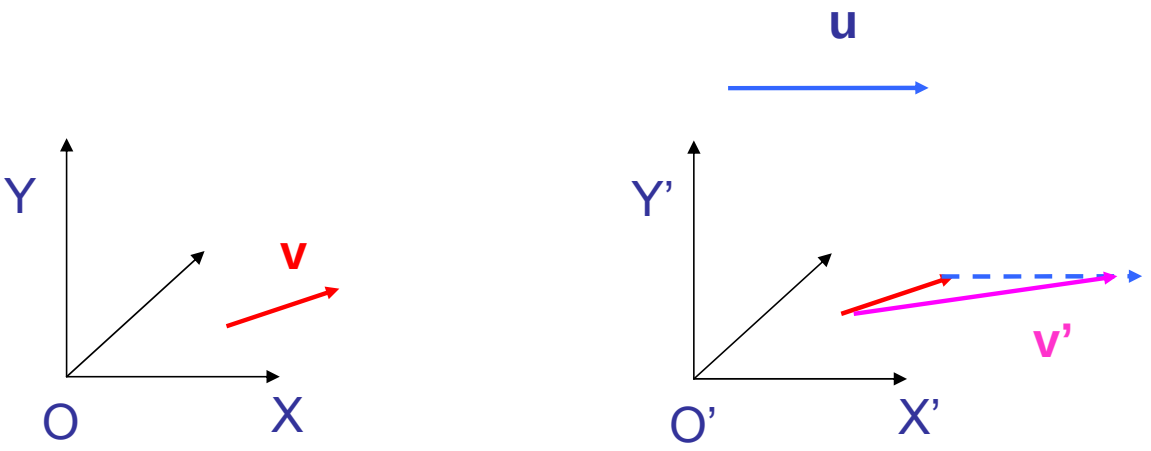
Incoming
metorite
(up to 70 m/s)

Sky rotation in 2 hours

# Can we recognize an absolute motion?

# Galileo's transformations

$\mathbf{v'} = \mathbf{v} + \mathbf{u}$




All (?) observers moving with constant velocity are equivalent

# Maxwell's equations (~1865)


God said:

$$\nabla \cdot \mathbf{E} = \rho/\varepsilon_0$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 I + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

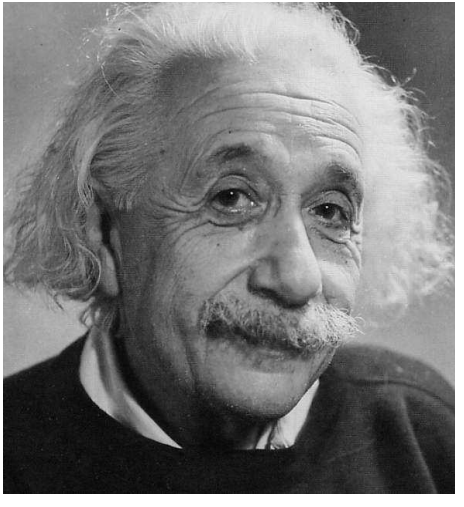
and there was light!

# On electrodynamics of moving bodies (Albert Einstein, June 1905)

3. ***Zur Elektrodynamik bewegter Körper;***
***von A. Einstein.***

Daß die Elektrodynamik Maxwells — wie dieselbe gegenwärtig aufgefaßt zu werden pflegt — in ihrer Anwendung auf bewegte Körper zu Asymmetrien führt, welche den Phänomenen nicht anzuhaften scheinen, ist bekannt. Man denke z. B. an die elektrodynamische Wechselwirkung zwischen einem Magneten und einem Leiter. Das beobachtbare Phänomen hängt hier nur ab von der Relativbewegung von Leiter und Magnet, während nach der üblichen Auffassung die beiden Fälle, daß der eine oder der andere dieser Körper der bewegte sei, streng voneinander zu trennen sind. Bewegt sich nämlich der Magnet und ruht der Leiter, so entsteht in der Umgebung des Magneten ein elektrisches Feld von gewissem Energiewerte, welches an den Orten, wo sich Teile des Leiters befinden, einen Strom erzeugt. Ruht aber der Magnet und bewegt sich der Leiter, so entsteht in der Umgebung des Magneten kein elektrisches Feld, dagegen im Leiter eine elektromotorische Kraft, welcher an sich keine Energie entspricht, die aber — Gleichheit der Relativbewegung bei den beiden ins Auge gefaßten Fällen vorausgesetzt — zu elektrischen Strömen von derselben Größe und demselben Verlaufe Veranlassung gibt, wie im ersten Falle die elektrischen Kräfte.

Beispiele ähnlicher Art, sowie die mißlungenen Versuche, eine Bewegung der Erde relativ zum „Lichtmedium“



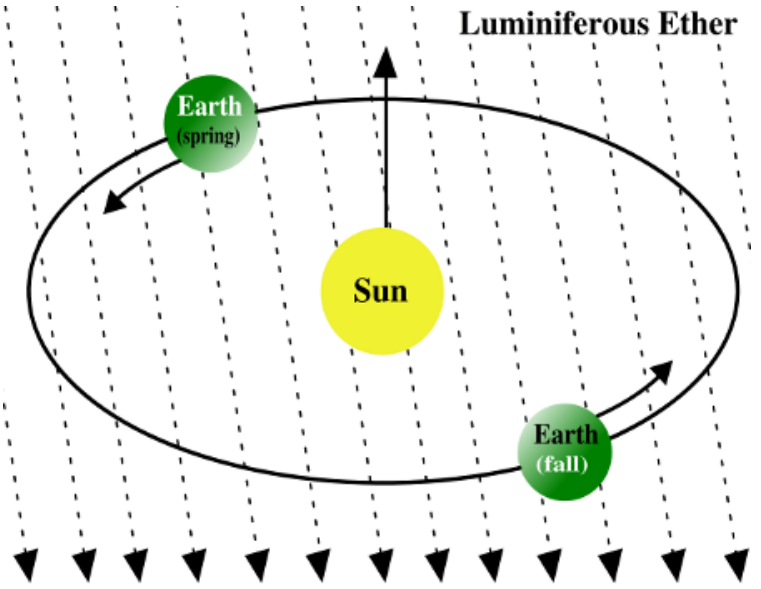
How Maxwell’s law transform in a moving reference frame?

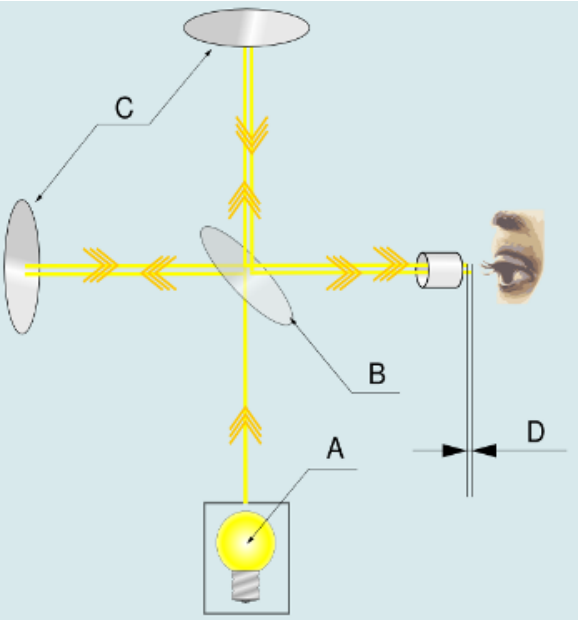
# Abraham Michelson – experiment on motion of Earth (Potsdam, 1881)

Born in Strzelno (50 km from Toruń) in 1852,
moved with parents to USA when he was 3 yrs old.

First American Nobel Prize (1907)

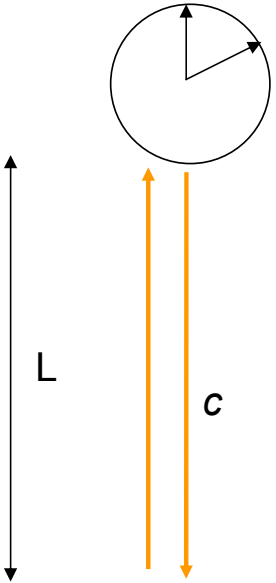
# Abraham Michelson – how velocity of Earth changes in one year ?

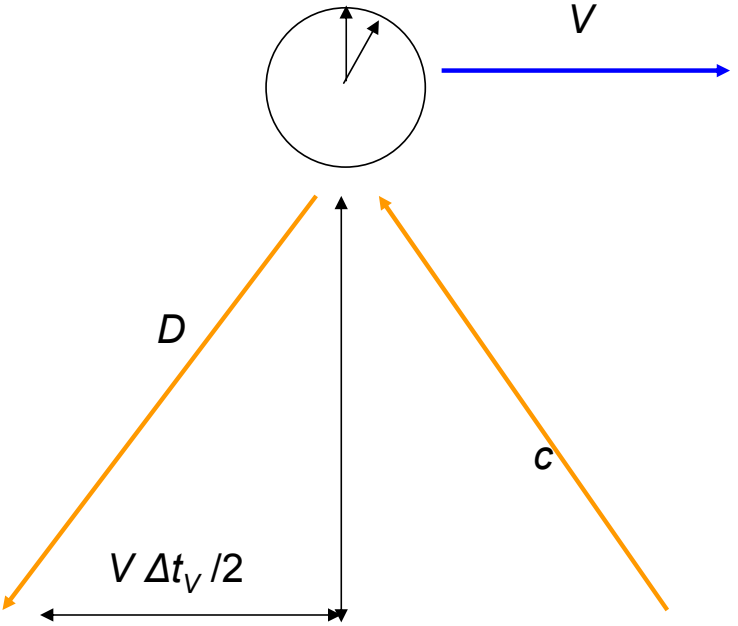



Earth's velocity on orbit is 30 km/s. Velocity of light is 300 000 km/s. We can measure this by *ligth interference*.

# Idea: the path is different in perpendicular direction



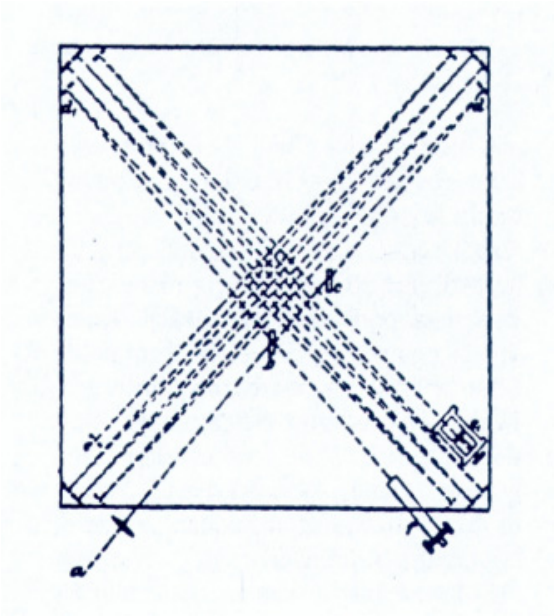



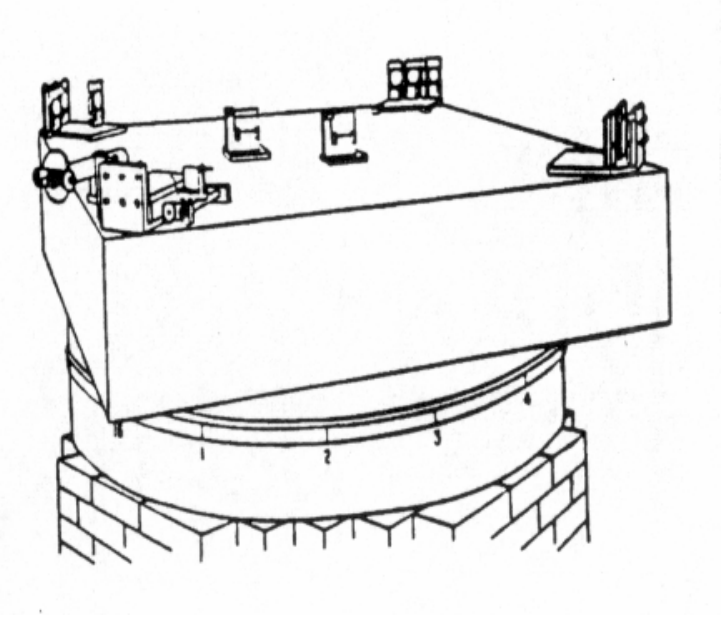

$\Delta t_0 = 2L/c$

$\Delta t_V = 2D/c$

$D^2 = L^2 + (V\,\Delta\, t_V/2)^2$ ....

# Abraham Michelson – experiment on motion of „ether”, i.e. velocity of light

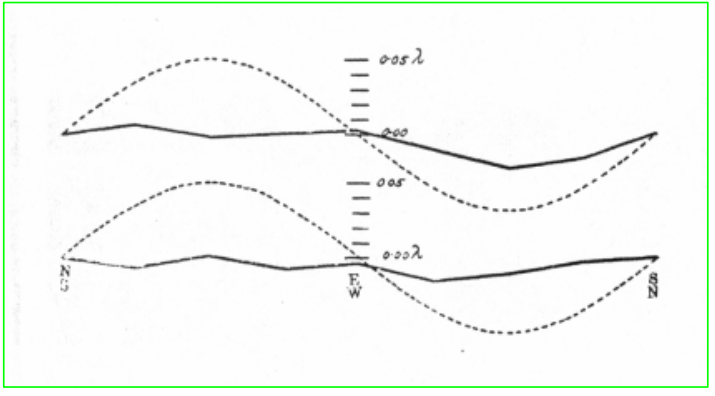




Wynik: Ziemia w stosunku do „eteru” spoczywa
Einstein (1905): prędkość światła (w próżni) mierzona przez każdego obserwatora, niezależnie od jego prędkości, jest taka sama

# Abraham Michelson & Morley (1898 Cleveland):

## Earth is not moving!




Result:

**No orbit velocity, within 0.1 of expected values is measured**

? Earth is not moving

? There is no ether

? There is something wrong with the velocity of ligth

# Einstein: (Special) Relativity Theory

- Velocity of ligth is constant, independently from rest or motion

- Laws of Physics are the same for all obvservers that move with a constant velocity

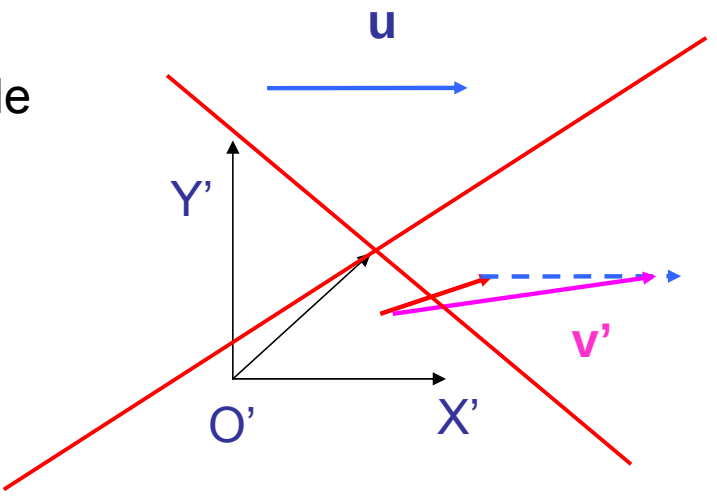
-Velocity of ligth is the limiting velocity that can transport Information

# Relativity theory (special):

→ Galileo transformations are not valid (for v→*c*)
(i.e. *1c+1c=1c*)

→ light velocity is highest possible
(that bring information)

**v’ < v + u**




https://en.wikipedia.org/wiki/Annus_Mirabilis_papers#Special_relativity

# Einstein: shortening in X direction

wenn eine senkrecht zur Geschwindigkeit des Elektrons wirkende magnetische Kraft $N$ (als einzige ablenkende Kraft) vorhanden ist. Aus der zweiten der Gleichungen (A) erhalten wir:

$$-\frac{d^2y}{dt^2} = \frac{v^2}{R} = \frac{\varepsilon}{\mu}\frac{r}{V}N\cdot\sqrt{1-\left(\frac{v}{V}\right)^2}$$

oder

$$R = V^2\frac{\mu}{\varepsilon}\cdot\frac{\frac{v}{V}}{\sqrt{1-\left(\frac{v}{V}\right)^2}}\cdot\frac{1}{N}\cdot$$

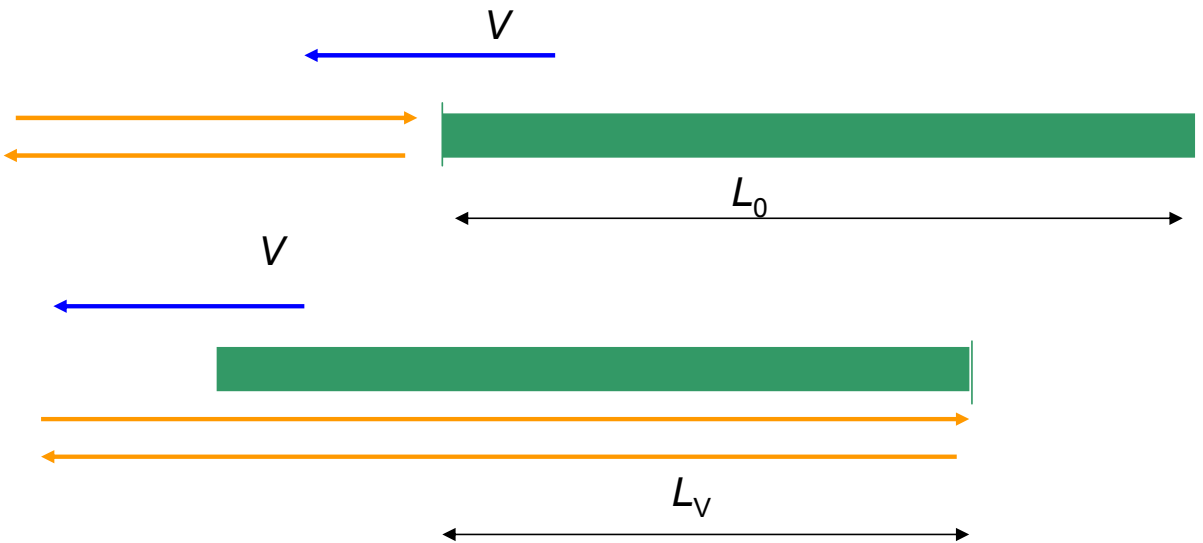
Diese drei Beziehungen sind ein vollständiger Ausdruck für die Gesetze, nach denen sich gemäß vorliegender Theorie das Elektron bewegen muß.

Zum Schlusse bemerke ich, daß mir beim Arbeiten an dem hier behandelten Probleme mein Freund und Kollege M. Besso treu zur Seite stand und daß ich demselben manche wertvolle Anregung verdanke.

Bern, Juni 1905.

(Eingegangen 30. Juni 1905.)

# SRT: – „have a look” on a moving bar



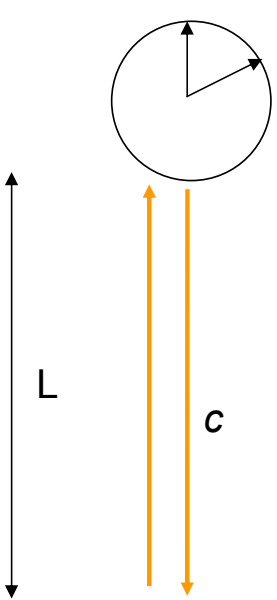

$$L_V = L_0\sqrt{(1- V^2/c^2)}$$

= shortening of a bar that moves

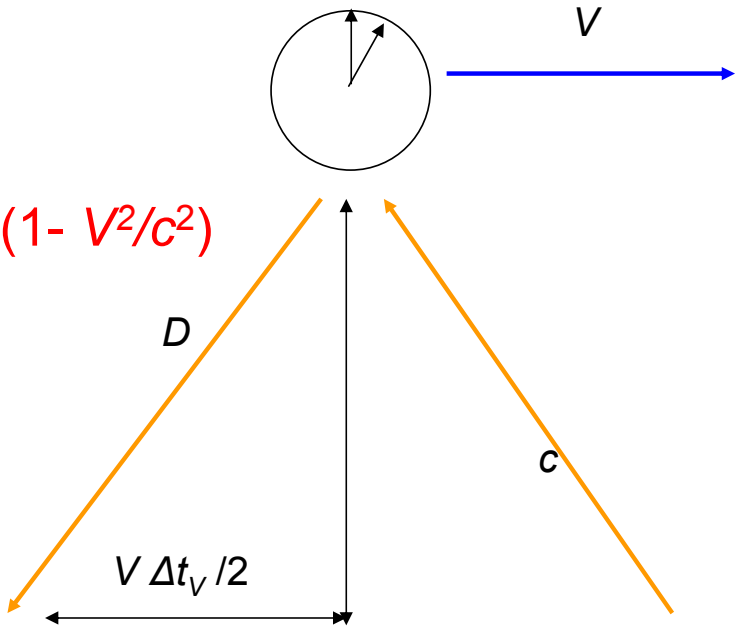
Lawrence Lerner, *Modern Physics*

# SRT: „have a look” on a moving clock

**Dilatation** of time unit, i.e. clock that move in respect to us go *slower* than the clock in our reference frame




$$\Delta t_V = \Delta t_0 / \sqrt{(1- V^2/c^2)}$$




$\Delta t_0 = 2L / c$

$\Delta t_V = 2D / c$

$D^2 = L^2 + (V \Delta t_V/2)^2$ ....

# Universe ends at distance 13.8 bln light yrs

Flammarion,
~ 1880

Copernicus: Earth, even if being a huge sphere, is nothing as compared to the sice of the Universe, that dimensions we do not know, or probably, even ***can not*** know.

# Einstein, September 1905: „Does the mass of a body depend on its energy?

13. ***Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?***
***von A. Einstein.***

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Die Resultate einer jüngst in diesen Annalen von mir publizierten elektrodynamischen Untersuchung[1]) führen zu einer sehr interessanten Folgerung, die hier abgeleitet werden soll.

Unter Vernachlässigung von Größen vierter und höherer Ordnung können wir setzen:

$$K_0 - K_1 = \frac{L}{V^2}\frac{v^2}{2}.$$

$E=mc^2$

Aus dieser Gleichung folgt unmittelbar:

Gibt ein Körper die Energie $L$ in Form von Strahlung ab, so verkleinert sich seine Masse um $L/V^2$. Hierbei ist es

(Eingegangen 27. September 1905.)

# $E=mc^2$: nuclear energy, etc.

Nuclear plant 3 GW = 1 milion of houses

1 glass of antimatter=10 yrs of energy for 1mln houses

# Evolution of stars: thermonuclear reactions

- Aristotle: „It seems to us that stars are immobile,but in reality they live their own, rich life” *De coeli*

Death of a star

270px-Crab_Nebula.jpg

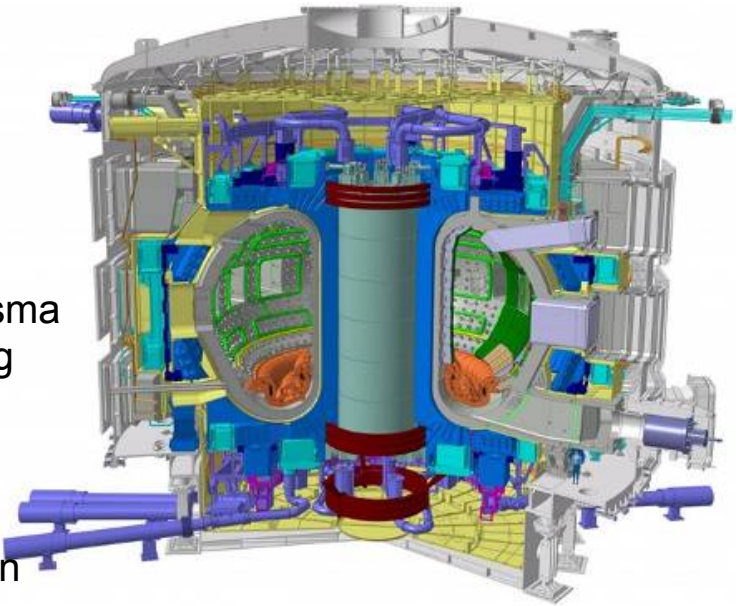
Birth of a star

600px-RhoOph.jpg

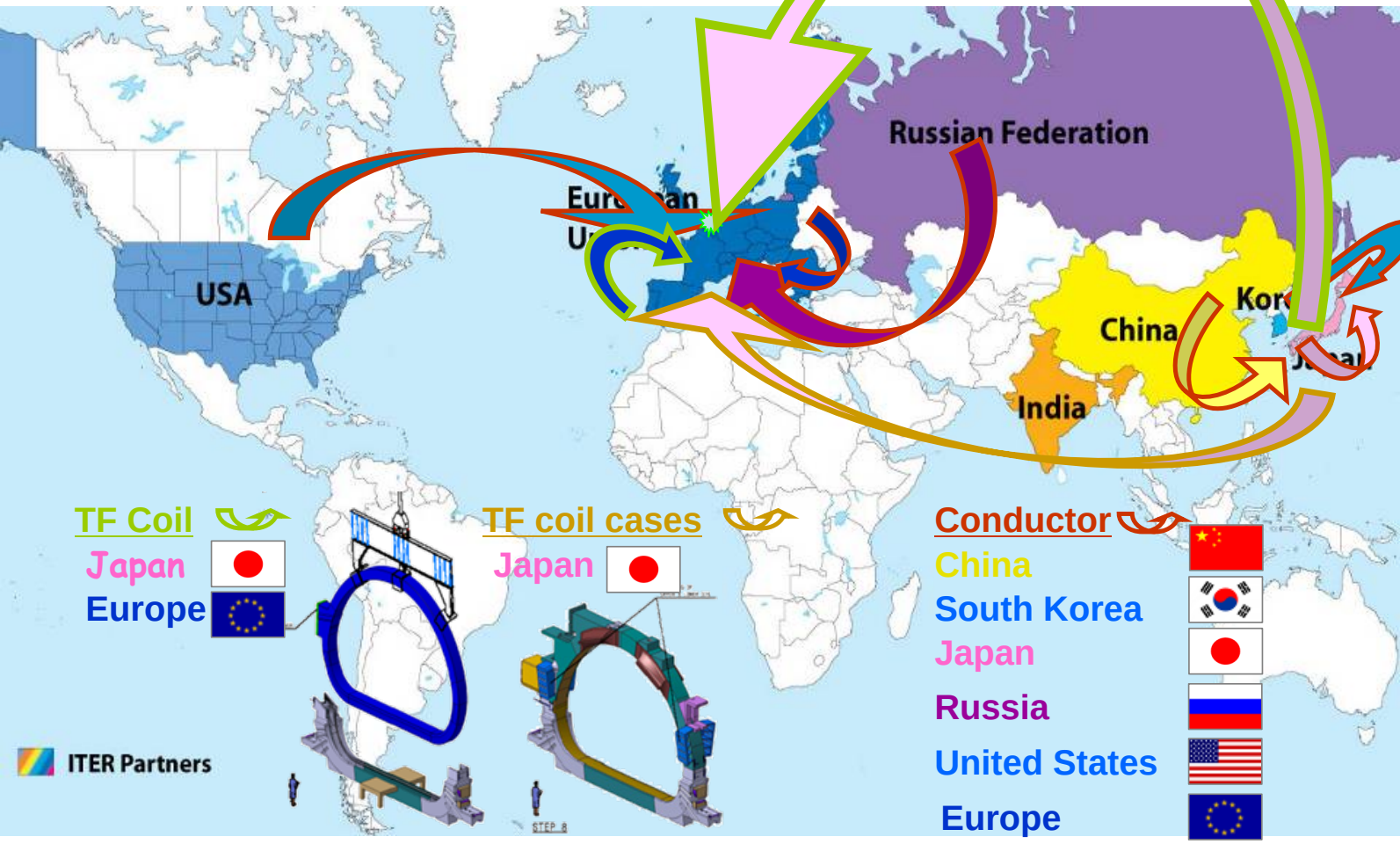
# Thermonuclear plant: ITER

- **ITER Program Objective:**
  - to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes

- **Key Technical Goals:**
  - achieve extended burn of a DT plasma with dominant alpha-particle heating (Q ≥ 10, ~500 s)
  - develop steady-state fusion power production as ultimate goal
  - integrate and test all essential fusion power reactor technologies and components
  - demonstrate safety and environmental acceptability of fusion
  - 50 MW input → 500 MW output



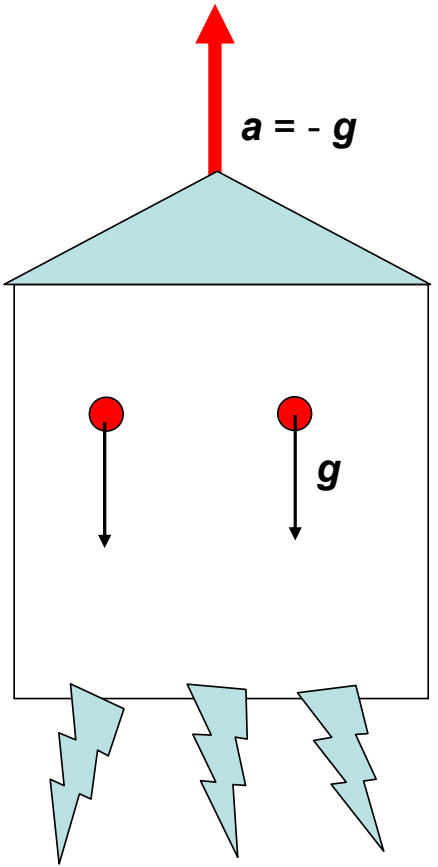
# TF Coils – A Global Collaboration



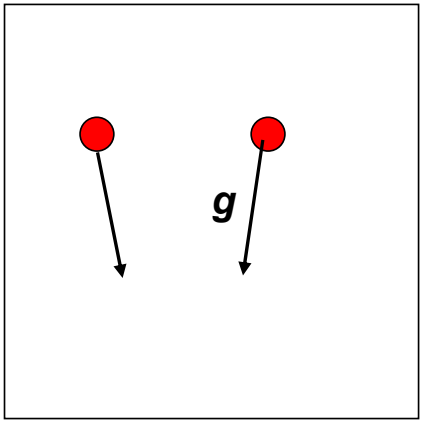
# Einstein: gravitation ↔ acceleration

- Galileo (1589): all objects fall with the sam ~~velocity~~ acceleration $g$=9.81 (m/s)/s
- Einstein (Prague, 1911): Why?
- $\boldsymbol{F} = m\boldsymbol{a} \quad \leftrightarrow \quad \boldsymbol{F}=m\boldsymbol{g}$
- Why inertial mass and gravitional mass are the same?
- Can we distinguish between a lift accelerating up or the gravitation of a planet below?

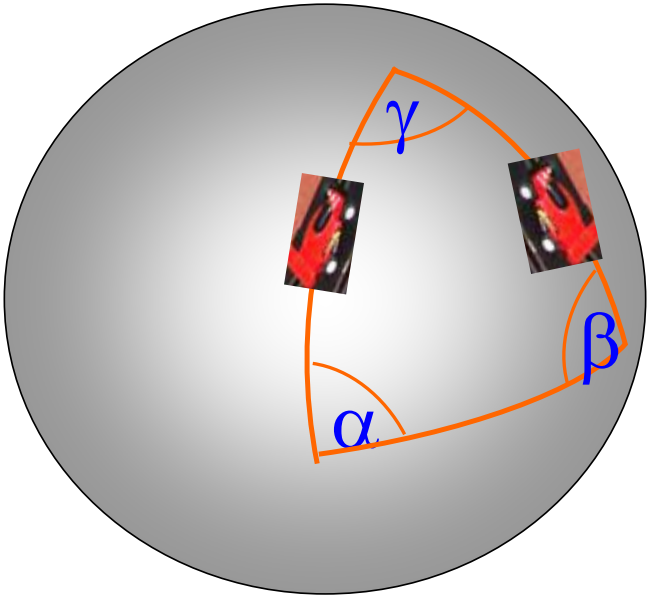
# General theory of relativity (1915)




The difference is in the
***curvature***
of trajectories




# Curvature of space




„geodic lines”
= straigth-on

? Gravitation or curved surface?

Curvature of Gauss $k = \pm 1/(R_{min} R_{max})$ Radius $R = 1/k$

# Einstein: General relativity theory

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

Die spezielle Relativitätstheorie weicht also von der klassischen Mechanik nicht durch das Relativitätspostulat ab, sondern allein durch das Postulat von der Konstanz der Vakuum-Lichtgeschwindigkeit, aus welchem im Verein mit dem speziellen Relativitätsprinzip die Relativität der Gleichzeitigkeit sowie die Lorentztransformation und die mit dieser verknüpften Gesetze über das Verhalten bewegter starrer Körper und Uhren in bekannter Weise folgen.

Die Modifikation, welche die Theorie von Raum und Zeit durch die spezielle Relativitätstheorie erfahren hat, ist zwar eine tiefgehende; aber *ein* wichtiger Punkt blieb unangetastet. Auch gemäß der speziellen Relativitätstheorie sind nämlich die Sätze der Geometrie unmittelbar als die Gesetze über die möglichen relativen Lagen (ruhender) fester Körper zu deuten, allgemeiner die Sätze der Kinematik als Sätze, welche das Verhalten von Meßkörpern und Uhren beschreiben. Zwei

# Tensor of space-time

Deshalb liegt es nahe, für das materiefreie Gravitationsfeld das Verschwinden des aus dem Tensor $B^{\varrho}_{\mu\sigma\tau}$ abgeleiteten symmetrischen Tensors $B_{\mu\nu}$ zu verlangen. Man erhält so 10 Gleichungen für die 10 Größen $g_{\mu\nu}$, welche im speziellen erfüllt sind, wenn sämtliche $B^{\varrho}_{\mu\sigma\tau}$ verschwinden. Diese Gleichungen lauten mit Rücksicht auf (44) bei der von uns getroffenen Wahl für das Koordinatensystem für das materiefreie Feld

$$\left\{\begin{array}{c} \dfrac{\partial \Gamma^{\alpha}_{\mu\nu}}{\partial x_{\alpha}} + \Gamma^{\alpha}_{\mu\beta}\,\Gamma^{\beta}_{\nu\alpha} = 0 \\ \sqrt{-g} = 1\,. \end{array}\right. \tag{47}$$

Es muß darauf hingewiesen werden, daß der Wahl dieser Gleichungen ein Minimum von Willkür anhaftet. Denn es gibt außer $B_{\mu\nu}$ keinen Tensor zweiten Ranges, der aus den

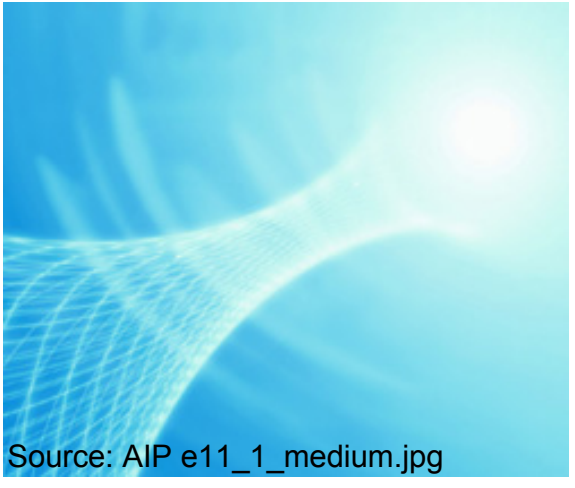
(Eingegangen 20. März 1916.)

# Geometry of space-time

$$\frac{\partial \Gamma^{\alpha}_{\mu\nu}}{\partial x_{\alpha}} + \Gamma^{\alpha}_{\mu\beta}\,\Gamma^{\beta}_{\nu\alpha} = -\varkappa\left(T_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} T\right),$$

$$\sqrt{-g} = 1 .$$

$$\mathbf{G} = \frac{8\pi G}{c^4}\mathbf{E}$$



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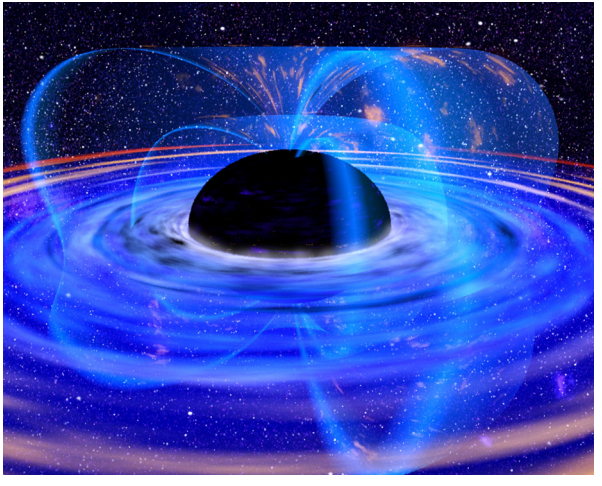


Space-time tunnels?

https://en.wikipedia.org/wiki/List_of_most_massive_black_holes

# GRT: implications

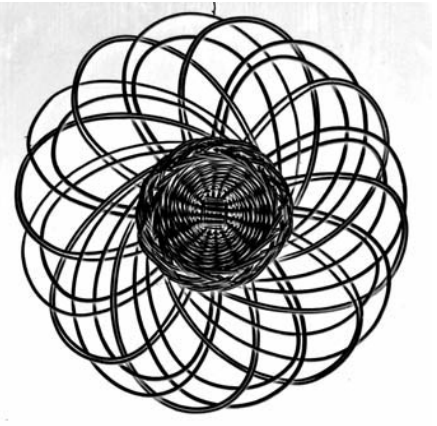
ANNALEN DER PHYSIK.
VIERTE FOLGE. BAND 49.

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

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.)



# GRT: non-euclidean space

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.

# GTR: curvature of light by gravitational masses

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

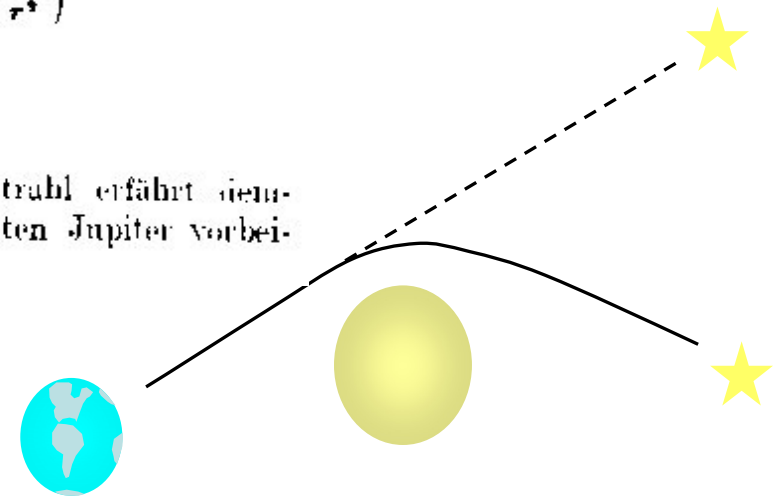
während (73) und (70) ergeben

$$\gamma = \sqrt{-\frac{g_{44}}{g_{11}}} = 1 + \frac{\alpha}{2r}\left(1 + \frac{x_2^2}{r^2}\right) .$$

Die Ausrechnung ergibt

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

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



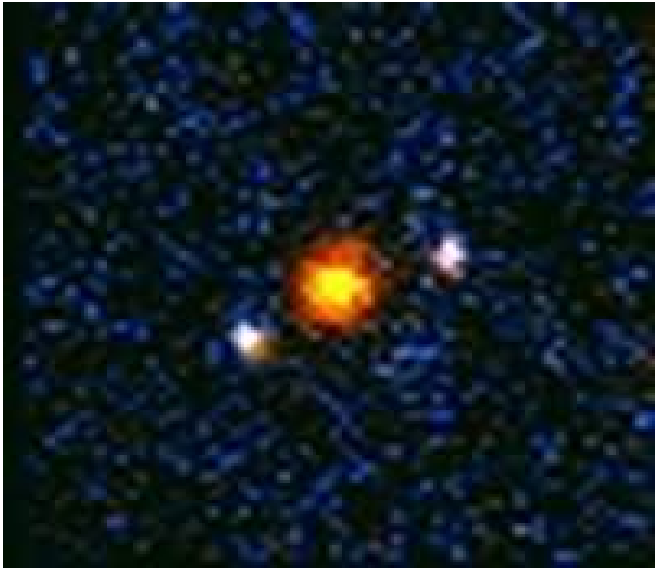
The deviation of light from General Relativity is double as compared to that resulting from Newton's theory.

# GRT: light of distant galaxies

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

Q2237+0305 quasar

Space Telescope Science Institute



HST 01247+0352

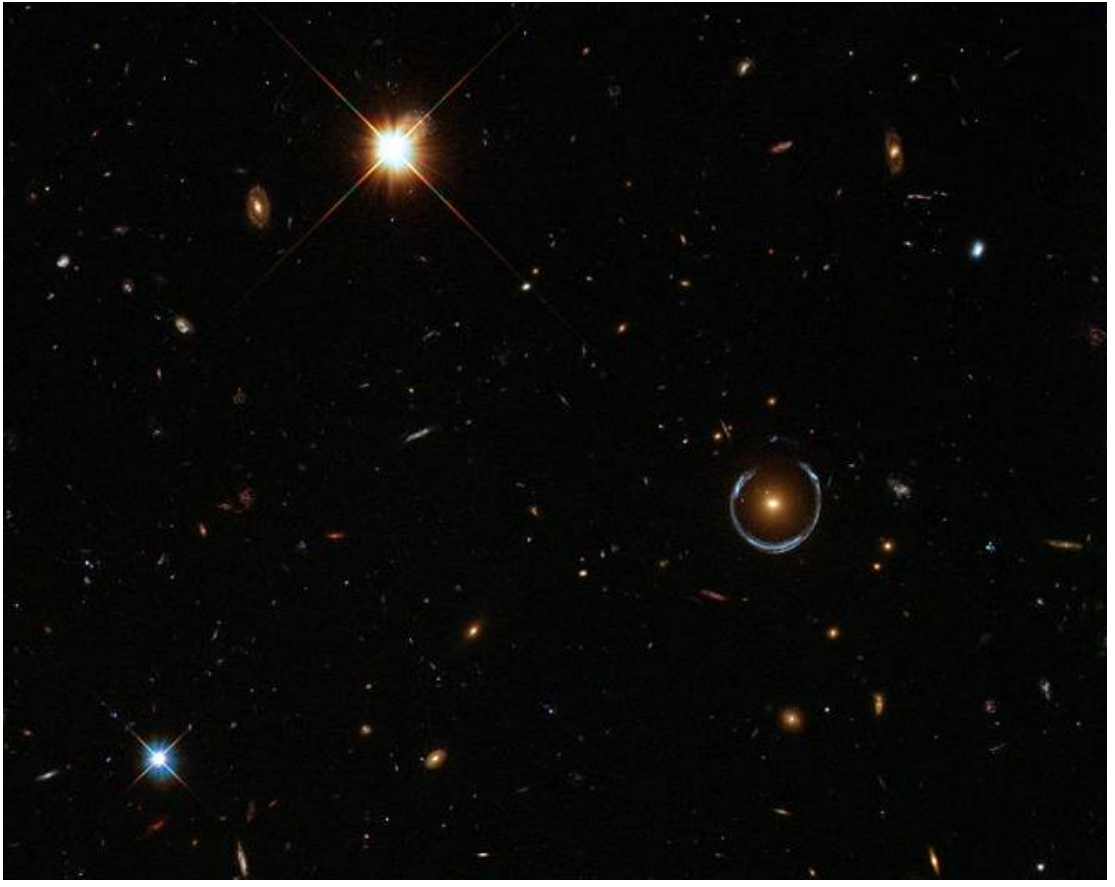
Gravitational lenses produce multiple images, like that of Q2237+0305 quasar.
Many gravitational lenses were found by the Hubble telescope:

HST 01247+0352 is a pair of images  around the redspherical elliptical lensing galaxy.

# „Multiplied” pictures

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

# Even more distant galaxies



*800px-Lensshoe_hubble.jpg*

# Gravitational time dilatation

$$t_0 = t_f \sqrt{1 - \frac{2GM}{rc^2}}$$

for spherical field, $t_f$ – far, $t_0$ local

This effect was measured by first running the clocks at a vertical difference of 17 cm and then jacking one of the clocks up by 33 cm and running them again. This revealed a shift of about $4 \times 10^{-17}$ in the frequencies of the clocks – in agreement with general relativity. In human terms, this time difference adds up to about 90 billionths of a second over an 80-year life span.

Earth's core, of 4.567 bln age, is by 2.5 yr younger than Earth's surface.

http://physicsworld.com/cws/article/news/2010/sep/24/relativity-with-a-human-touch

# Global positioning system

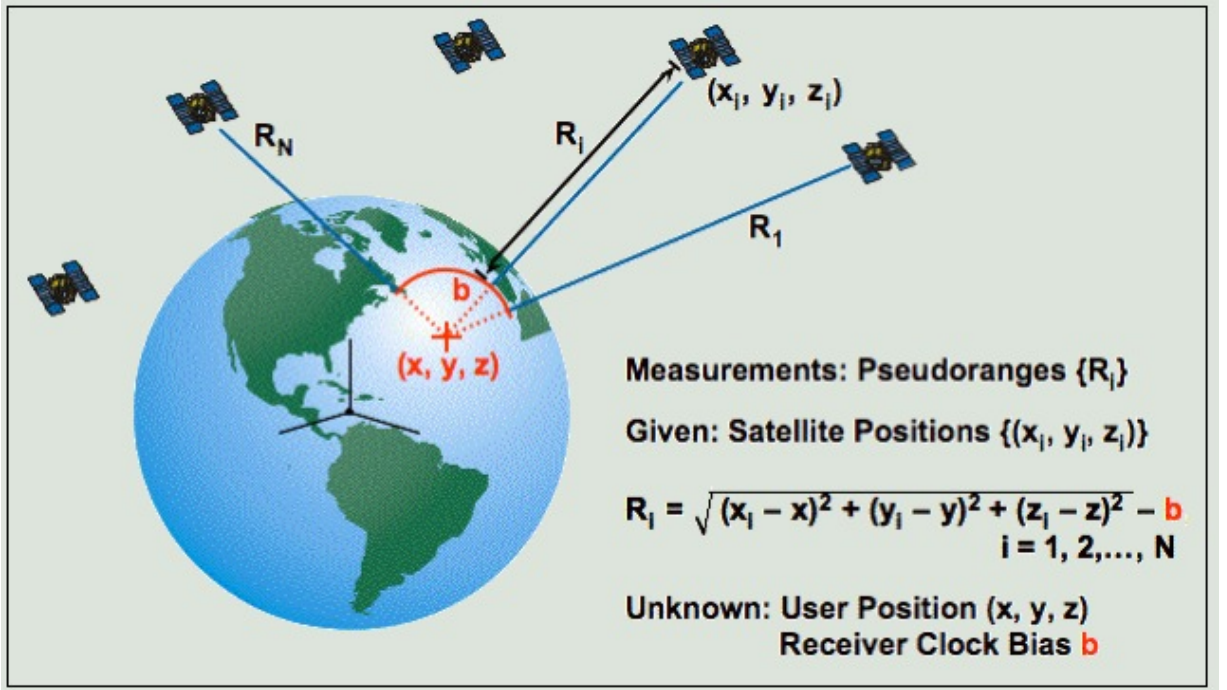
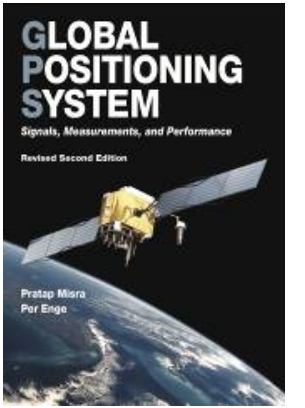



**Figure 1.9** The principle of satellite navigation. The user-satellite range measurements based on the times of transmission and receipt of signals are biased by a common amount and are called pseudoranges. Pseudorange measurements are needed from at least four four satellites to estimate the user position and receiver clock bias.




*http://www.gpstextbook.com/*

# GPS: Relativistic corrections

Around the world atomic clock experiment

**(Flying clock – Reference clock)**

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

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

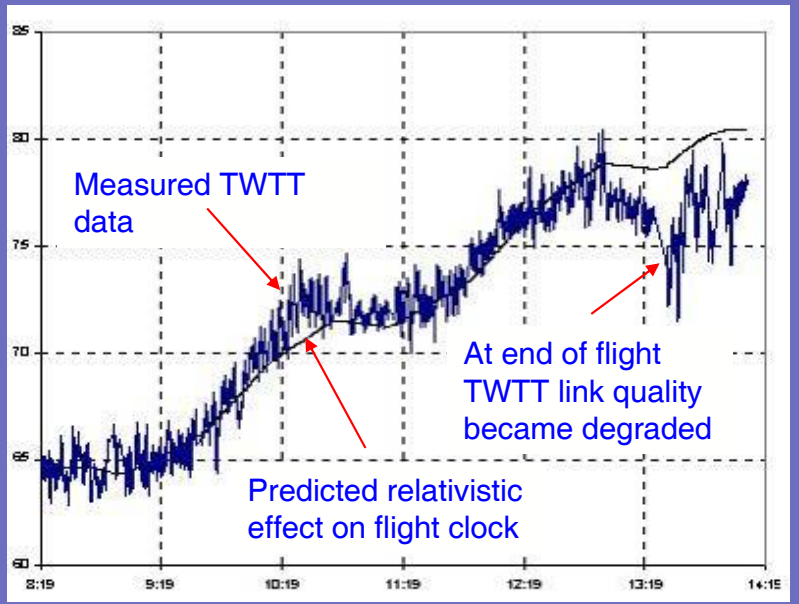
| *predicted effect* | *direction* East | West |
|---|---|---|
| Velocity (time dilation) | – 51 ns | – 47 ns |
| Sagnac effect | – 133 ns | + 143 ns |
| Gravitational potential (redshift) | + 144 ns | + 179 ns |
| Total | – 40 ± 23 ns | + 275 ± 21 ns |
| Measured | – 59 ± 10 ns | + 273 ± 7 ns |

(*) 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

# Global Positioning System

## Prediction of Relativistic Effects

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




**Relativistic Corrections**

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

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

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

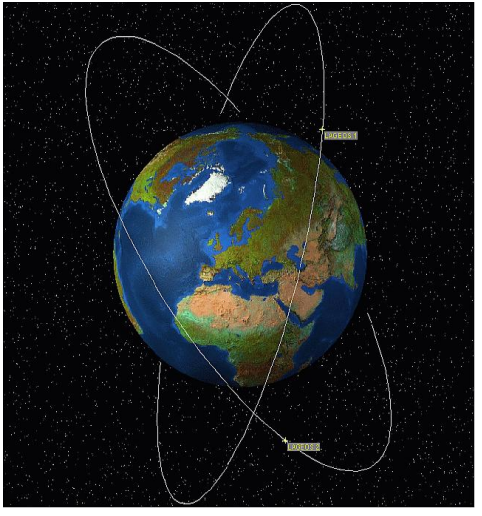
(*) Dr. Robert A. Nelson
Satellite Engineering Research Corporation, Bethesda, Maryland USA
Civil GPS Service Interface Committee (CGSIC) Meeting, Long Beach, California USA, September 21, 2004

# „E pur si muove”

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!



Lageos satellite

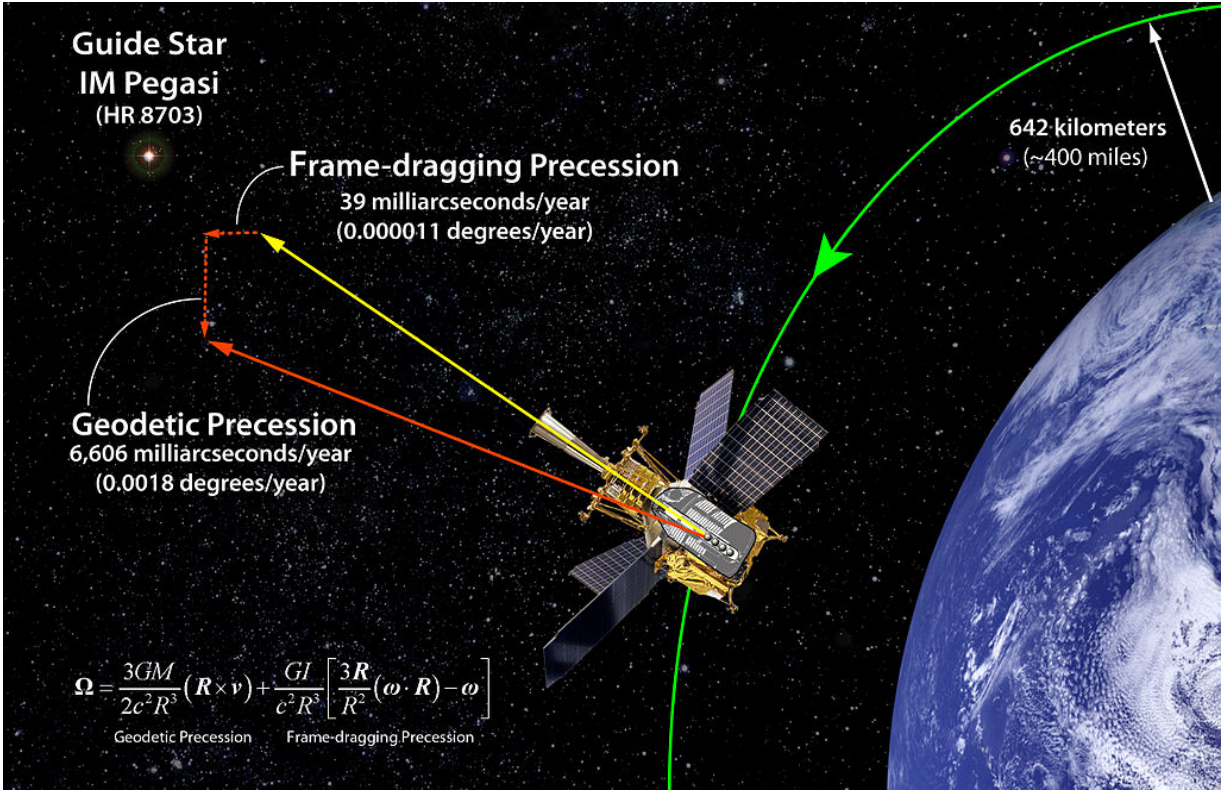
# Frame-dragging

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.

https://mylittlekitchen.files.wordpress.com/2012/12/chocolate-mix-liquor-and-pudding-smooth.jpg

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)!"**

# Geodetic precession




Gravity probe-B

# First four terms...

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

out of, probably, 10 000 terms

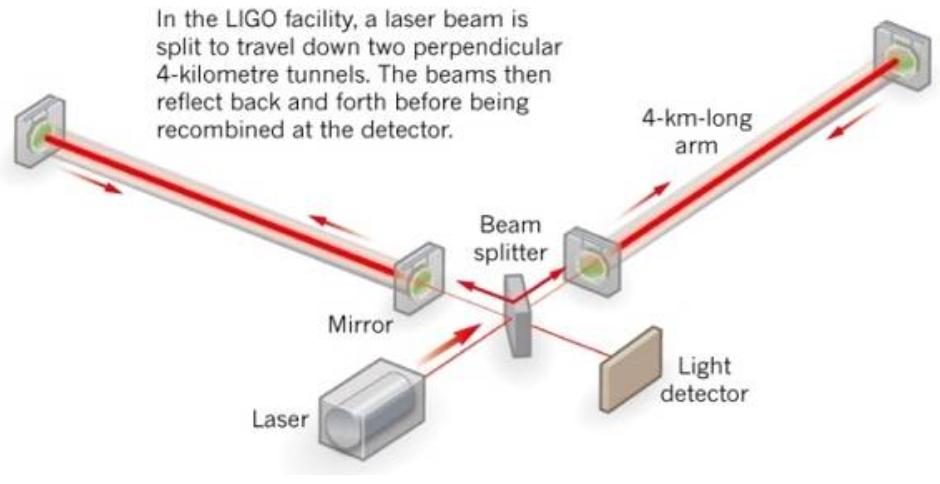
# Ligth Interference Gravitational-wave Observatory (LIGO)


**LIGO and the Detection of Gravitational Waves**

Barry C. Barish and Rainer Weiss

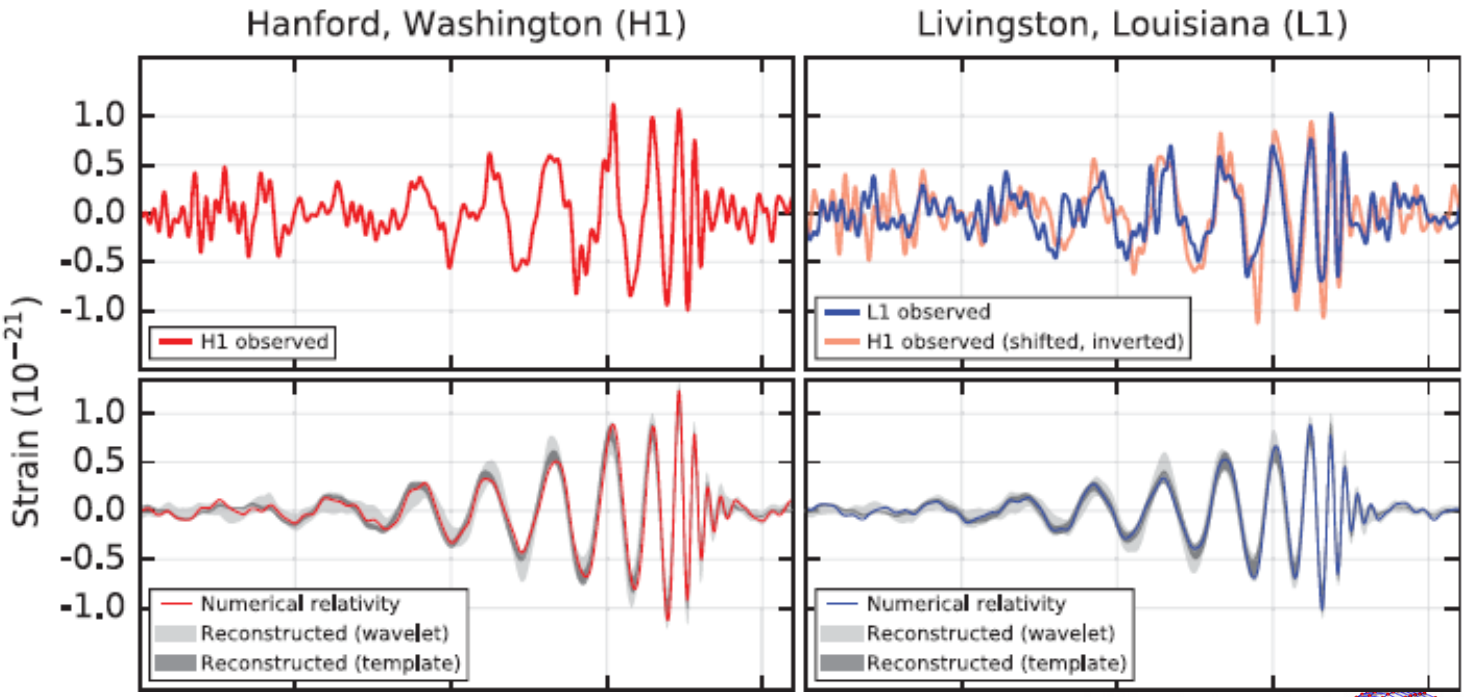
Physics Today **52**(10), 44 (1999); doi: 10.1063/1.882861

# Hanford (WA), Livingstone (LO)

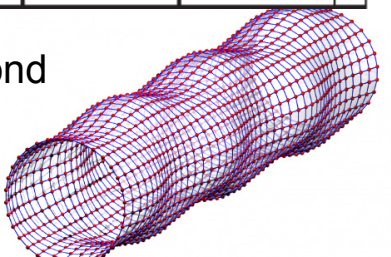



Michelson's laser interferometer

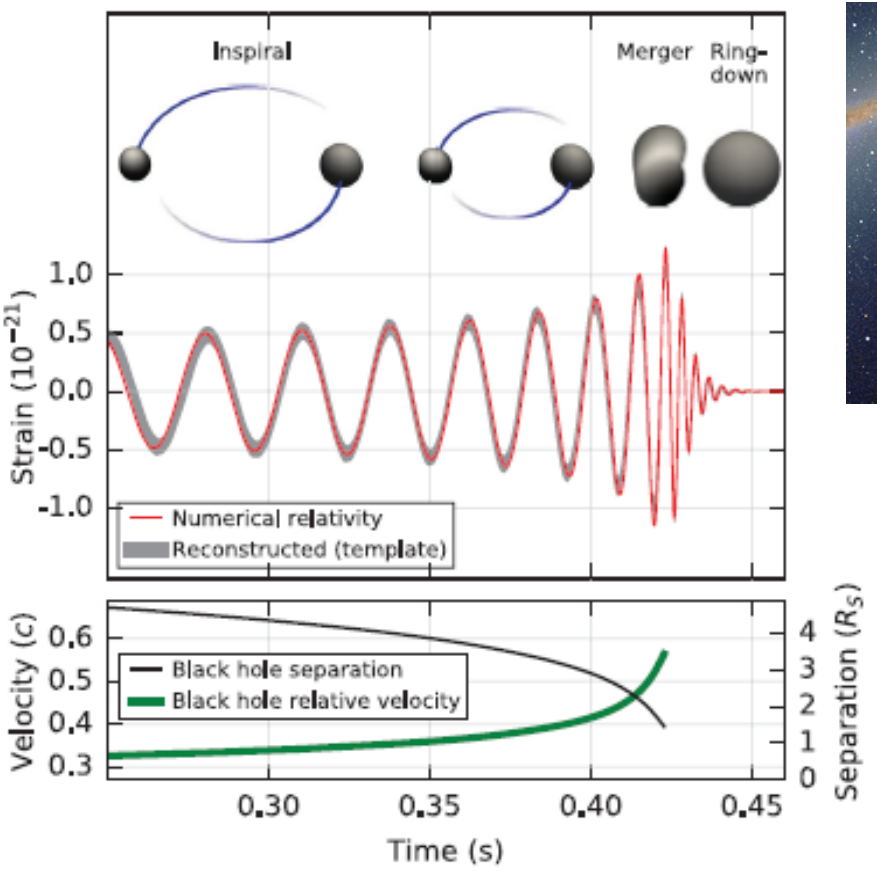
# 14.09.2015, 11:50:45 CET

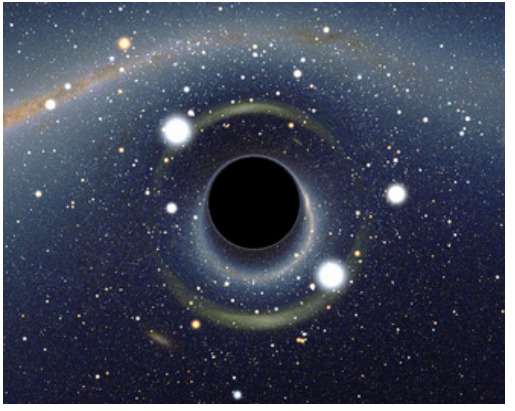



Radius of our Galaxy changed by 1 meter, for 10 microsecond



# 1,3 bln years ago: two black holes collided



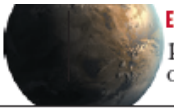
36±4 $M_o$

29±4 $M_o$

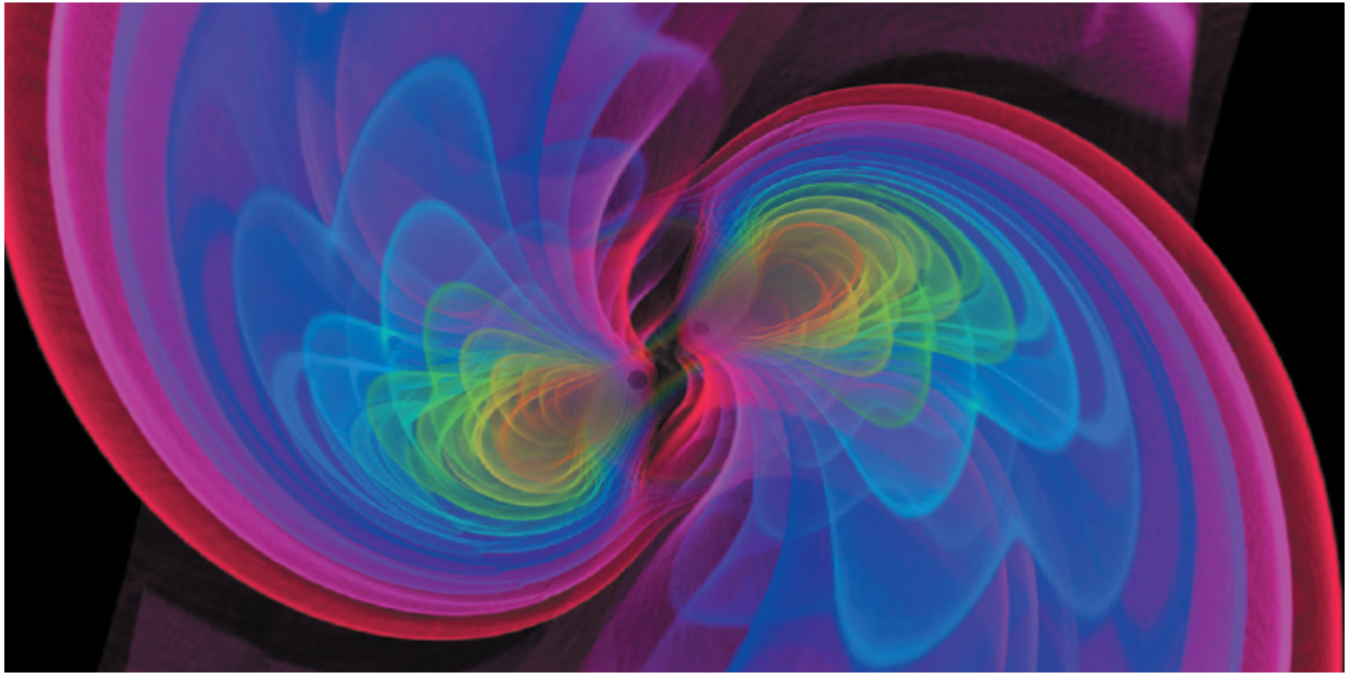
**LAB LIFE** The environmental factors that ruin mouse experiments **p.264**

**PUBLISHING** Biologists urged to hug a preprint — and accelerate research **p.265**

**POLLUTION** Delhi driving ban yields trove of data **p.266**



**EXOPLANETS** The race to probe atmospheres of other worlds **p.272**



S. OSSOKINE, A. BUONANNO (MAX PLANCK INST. GRAVITATIONAL PHYS.); SCIENTIFIC VISUALIZATION: W. BENGER (AIRBORNE HYDRO MAPPING)

**The pair of merging black holes that LIGO detected using gravitational waves — as produced by a computer simulation.**

GRAVITATIONAL WAVES

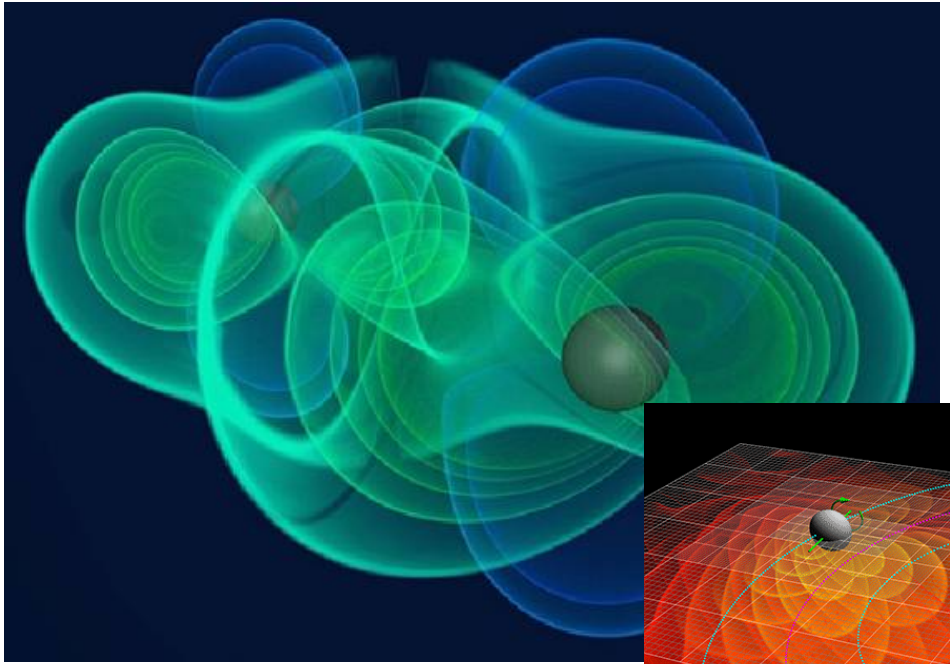
# LIGO's path to victory

*Historic discovery of ripples in space–time meant ruling out the possibility of a fake signal.*

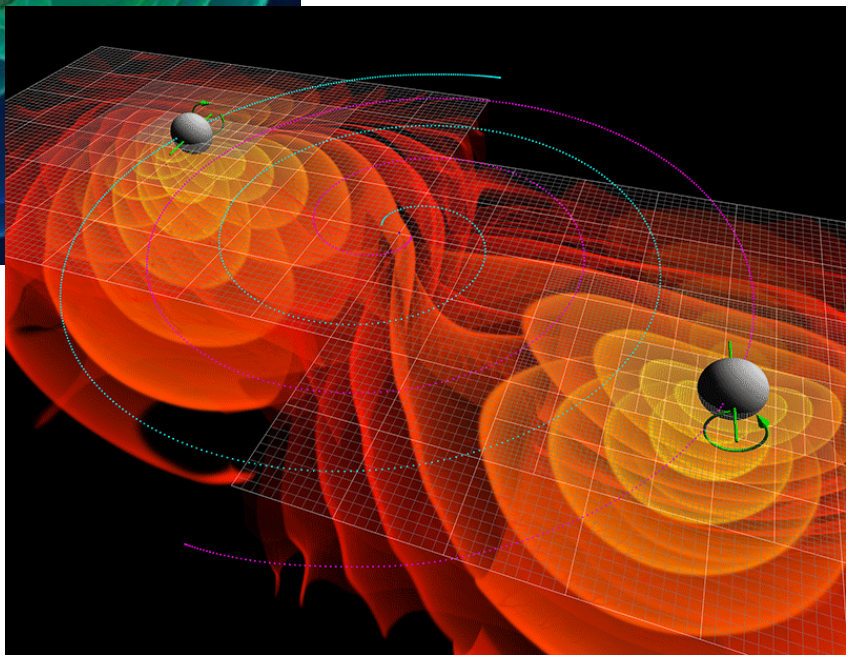
**BY DAVIDE CASTELVECCHI**

LIGO's twin detectors in Washington state and

about the Universe (see page 263).



Source: „Nature”



Source: AIP, 16.02.2016

# GTR: cosmology (1917)

- The Universe can not esist: the density fo matter is such, that it should have collapsed immediately
- (we know it from ever – he number of stars is great (like $r^3$), so their sumed brilliance should be infite (as single star brilliance falls like $1/r^2$)
- →"Albert, we have a problem..."

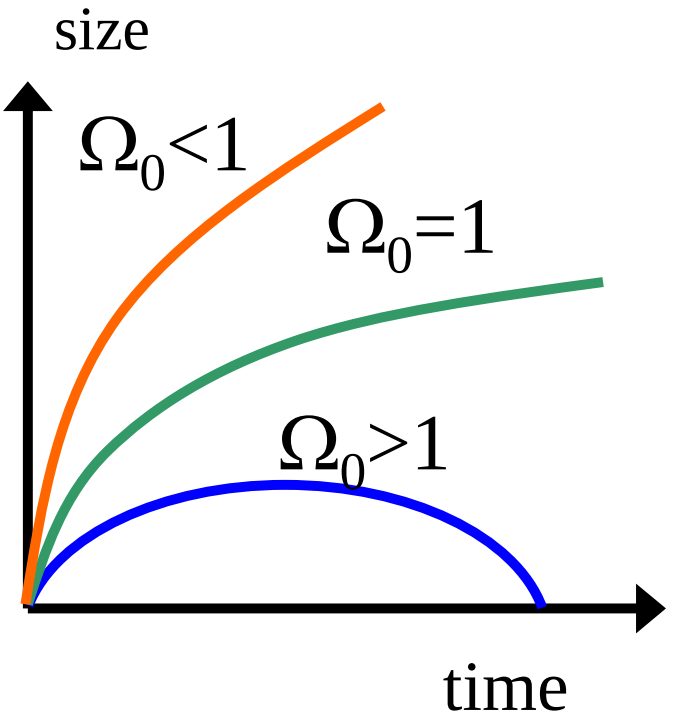
$$\mathbf{G} + \Lambda = \frac{8\pi G}{c^4}\mathbf{E}$$

- An additional, *ad hoc* „cosmological" term was introduced by Einstein
- Still, a stable Universe can not exists: it mus expands in continuation

[Friedman, meteorologist, physicists from Leningrad, Soviet Union, 1922]

# „Big Bang” 13,8 bln years ago

**What is the geometry of the Universe?**
The density of matter inside the Universe determines its geometry: for a high density we will obtain a closed universe with a positive curvature, but with a density lower than the critical density, we will obtain an open universe.




Time evolution of the Universe for different mass density parameter $\Omega_0$ which measures the ratio between the density $\rho$ of the studied universe and a particular density, called the critical critical density $\rho_c$. (about $6 \cdot 10^{-27}$ kg/m$^3$ ).

# Invisible (gravitational) mass

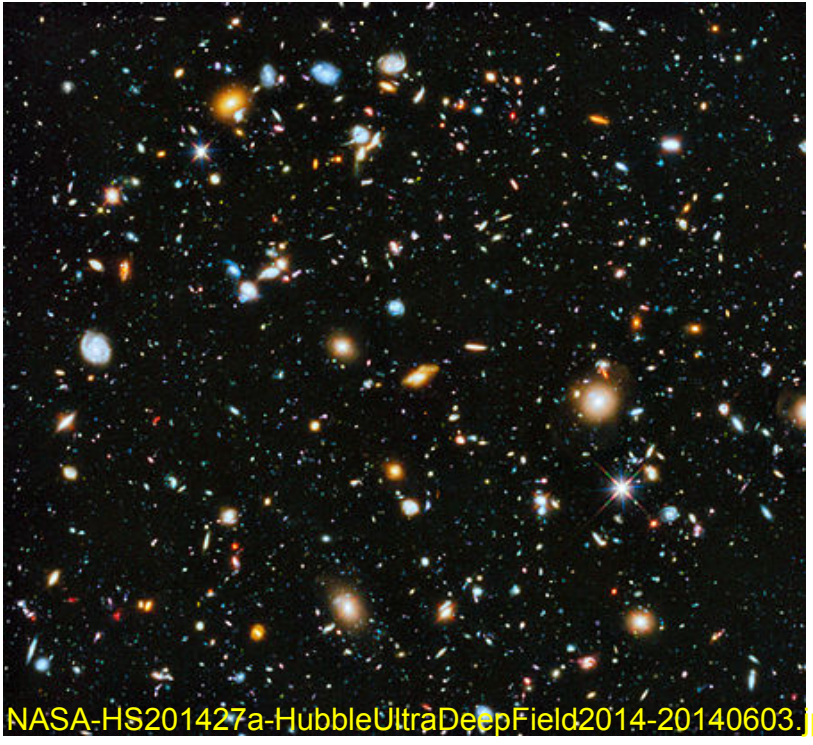
Galaxy Andromeda (2 mln light yrs from us)

Kepler law:

$$G\frac{M}{4\pi^2} = \frac{R^3}{T^2}$$

**We lack 75% of mass!**

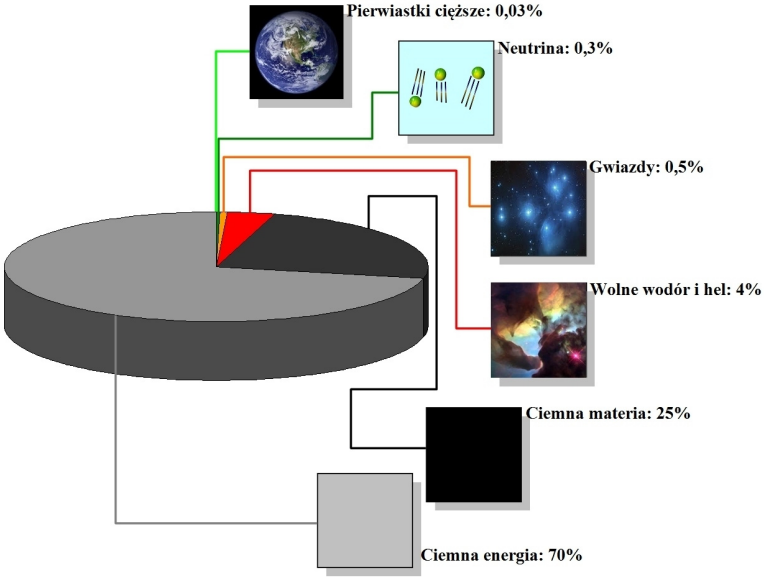
# How many galaxies in the Universe?

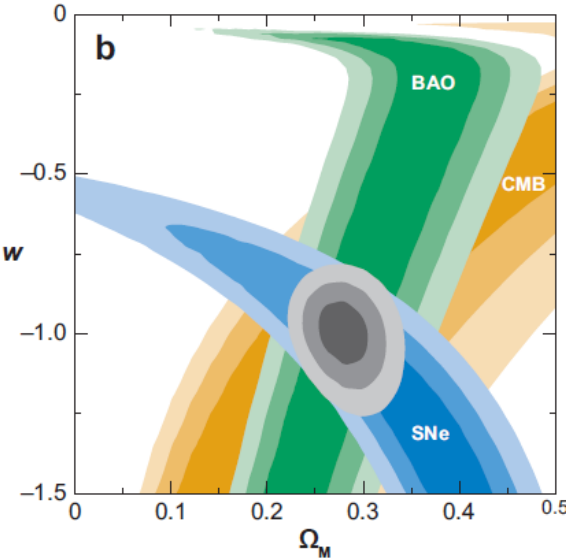


NASA-HS201427a-HubbleUltraDeepField2014-20140603.jpg

There are some 10 bln galaxies in the Universe that we can see
Galaxies escape from us: more red (apparently) are further
Most red on his photo are some 13 bln yrs from us!
We do not know, what accelerates this expansion...

# Mechanism for accelerating expansion: some „dark” energy




The visible universe (optical, IR, UV, X-Ray, gamma, radio) is only 4% of the existing (gravitationally and as energy) Universe.
What is the remaining 96% we do not have **any** idea!

# Fingers of God

Fingers of God - Wikipedia, the free encyclopedia - Mozilla

Plik Edycja Widok Przejdź Zakładki Narzędzia Okno Pomoc

http://en.wikipedia.org/wiki/Fingers_of_God

Szukaj

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"You've revolutionized research. Thank you." — Lieselot Whitbeck

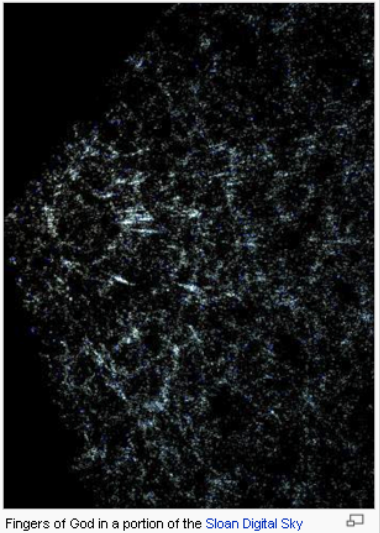
## Fingers of God

From Wikipedia, the free encyclopedia

**Fingers of God** is an effect in observational cosmology that causes clusters of galaxies to be elongated in redshift space, with an axis of elongation pointed toward the observer.[2] It is caused by a Doppler shift associated with the peculiar velocities of galaxies in a cluster. The large velocities that lead to this effect are associated with the gravity of the cluster by means of the virial theorem; they change the observed redshifts of the galaxies in the cluster. The deviation from the Hubble's law relationship between distance and redshift is altered, and this leads to inaccurate distance measurements.

The effect can be seen in the image to the right. The Earth is at the apex of the survey, on the left edge of the image; the individual "fingers", each one actually a cluster of galaxies all at the same distance, point towards it. At greater distances the fractional effect decreases as the peculiar velocities remain roughly constant, and the actual redshift increases. In a plot of "true" distance, instead of the displayed distance in the figure calculated from naïve application of Hubble's law, these fingers would be collapsed back to small spheres at the true cluster sites.

A closely related effect is the **Kaiser effect**.[3] It is caused, again, by peculiar velocities lending an additional Doppler shift to the cosmological redshift, and it leads also to a kind of line-of-sight distortion. It is not caused, however, by the random internal motions of the cluster predicted by the virial theorem; rather, it arises from coherent motions as the galaxies fall inwards towards the cluster center as the cluster assembles. Depending on the particular dynamics of the situation, the Kaiser effect usually leads not to an elongation, but an apparent flattening ("pancakes of God"), of the structure. It is a much smaller effect than the fingers of God, and can be distinguished by the fact that it occurs on larger scales.[4]



Fingers of God in a portion of the Sloan Digital Sky Survey; image from the Cosmus Open Source Science Outreach project.[1]

### References [edit]

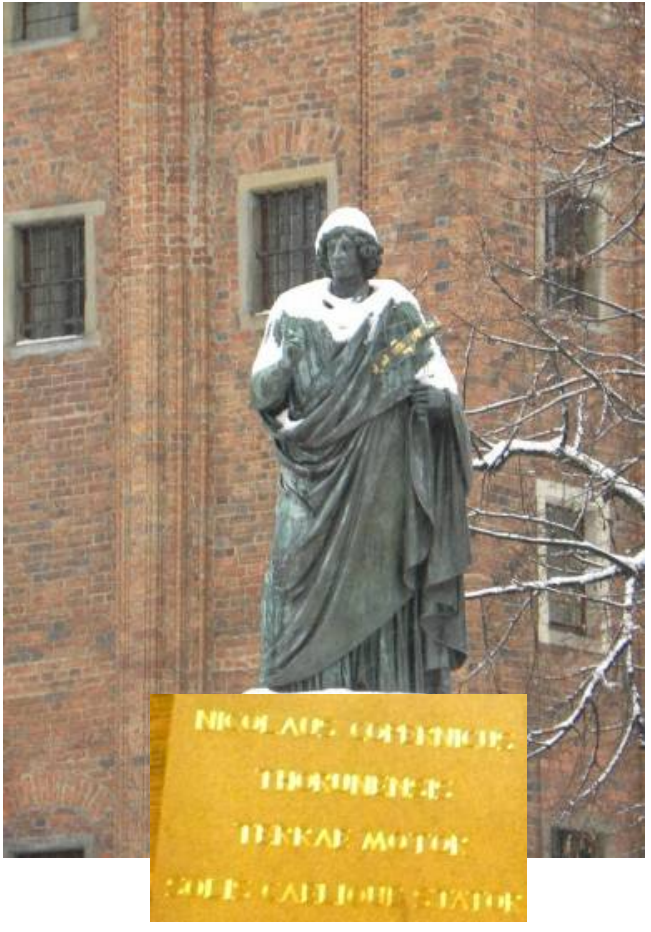
1. ^ http://astro.uchicago.edu/cosmus/
2. ^ Jackson, J.C. (1972). "A critique of Rees's theory of primordial gravitational radiation". *Monthly Notices of the Royal Astronomical Society*, 156, 1P-6P.
3. ^ Kaiser, N. (1987). "Clustering in real space and in redshift space". *Monthly Notices of the Royal Astronomical Society*, 227, 1-21.
4. ^ http://astron.berkeley.edu/~louis/astro228/redshift.html

Categories: Observational astronomy | Physical cosmology

Start spotkanie - Wysłane ... Menedżer pobierania ... Fingers of God - Wiki... Microsoft PowerPoint ... PL 19:06

Hogan, Jenny, Nature:Volume 448(7151), 19 July 2007, pp 240-245, “Unseen Universe”

# „He stopped the Sun and...”



**Physics is Fun!**

**Thank you for attention!**

감사