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?

$\rightarrow$ 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

v' = v + u
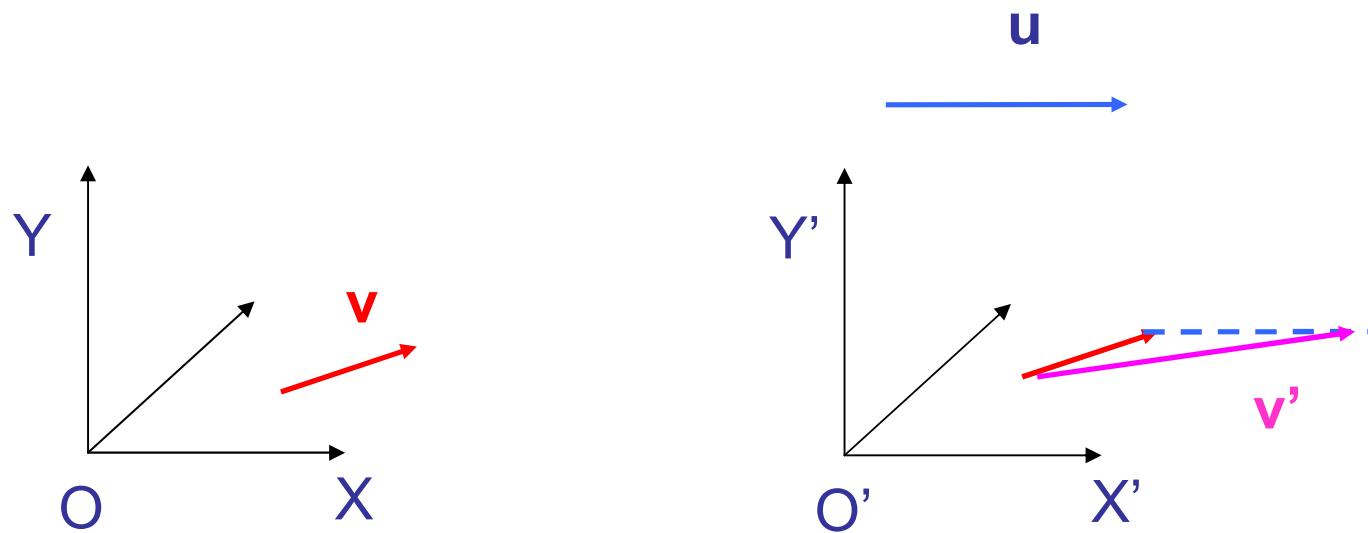
All (?) observers moving with constant velocity are equivalent

Maxwell's equations (~1865)

James Clerk Maxwell.

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" zu
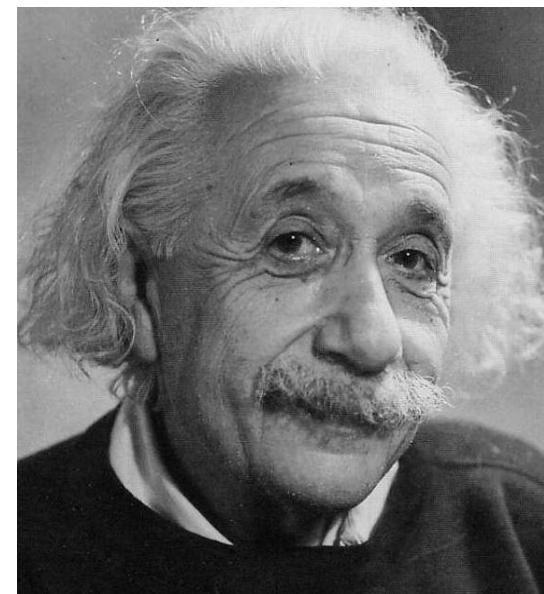
How Maxwell's law transform in a moving reference frame?

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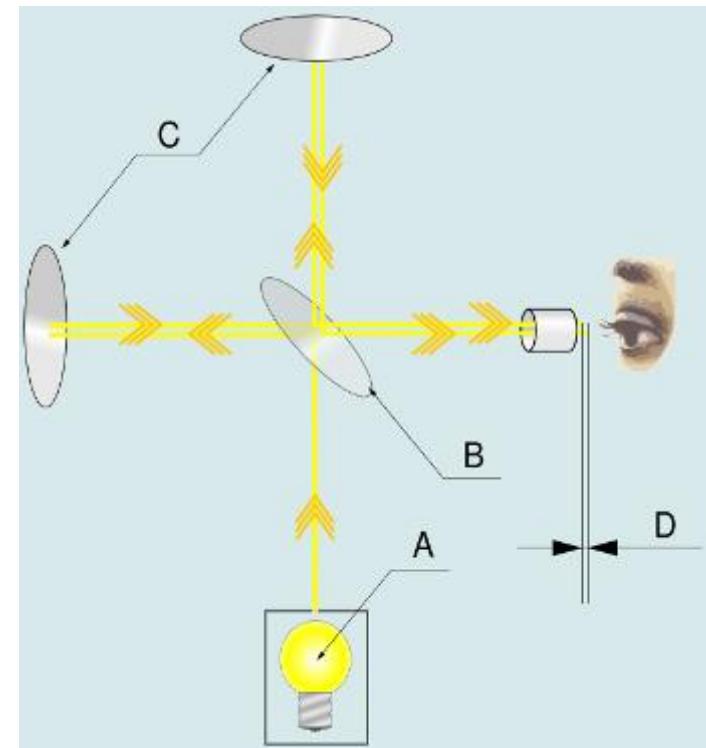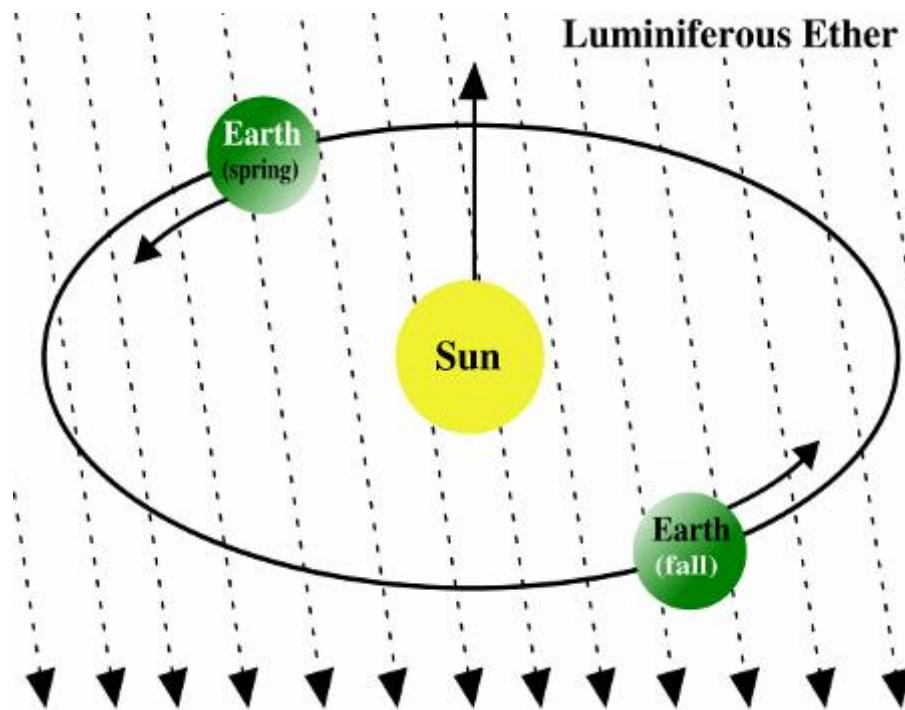
Earth's velocity on orbit is 30 km/s. Velocity of light is 300 000 km/s. We can measure this by *ligth interference*.

Idea: the path is different in perpendicular direction

L

c

V

D

$V \Delta t_V / 2$

c

$\Delta t_0 = 2L / c$

$\Delta t_V = 2D / c$

$D^2 = L^2 + (V \Delta t_V / 2)^2$ ....
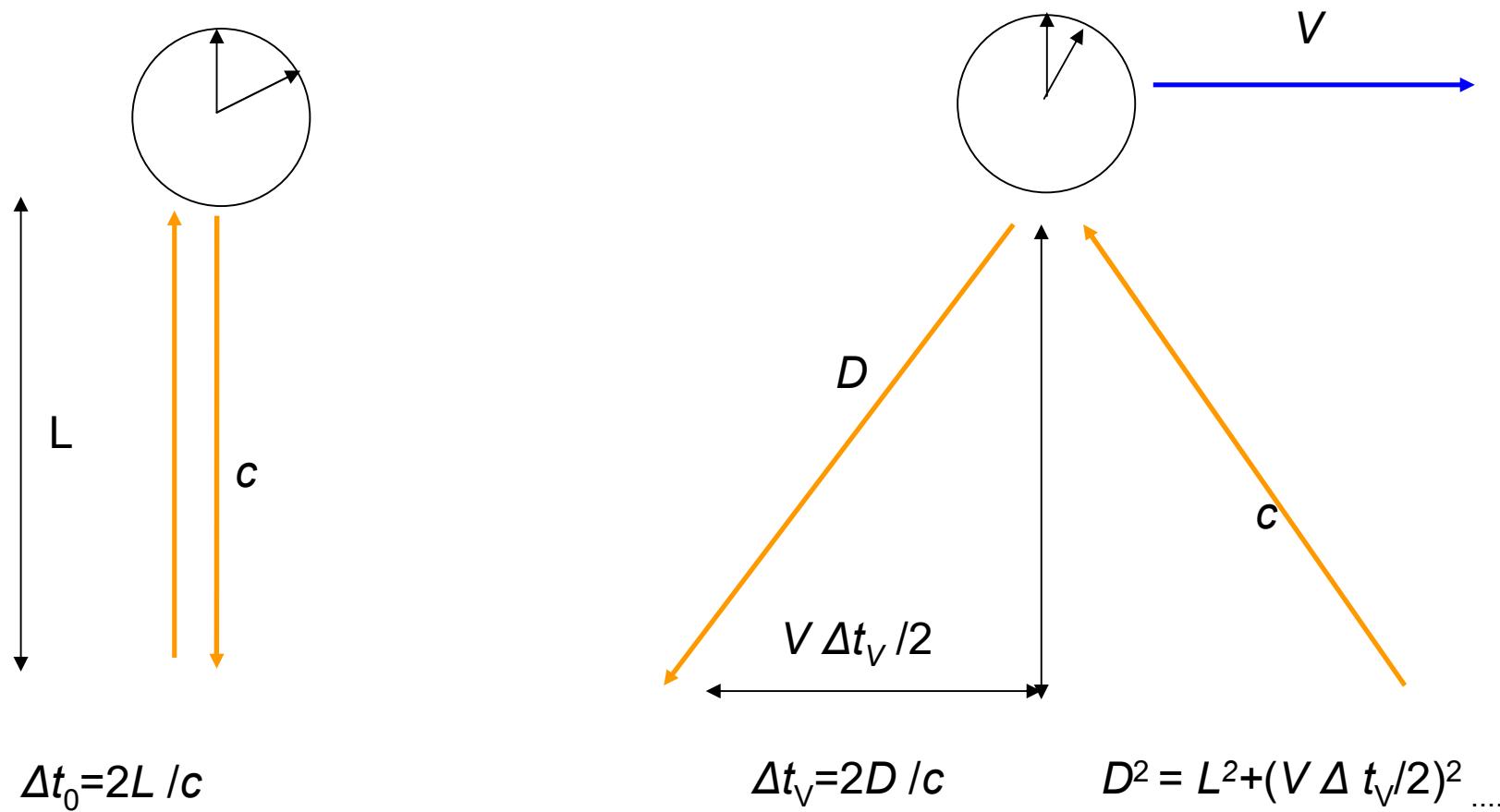
Abraham Michelson – experiment on motion of „ether", i.e. velocity of light
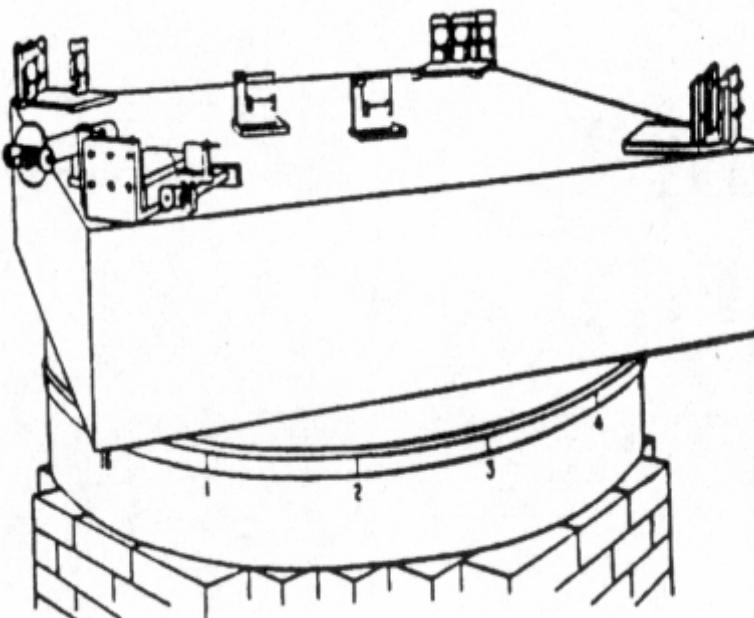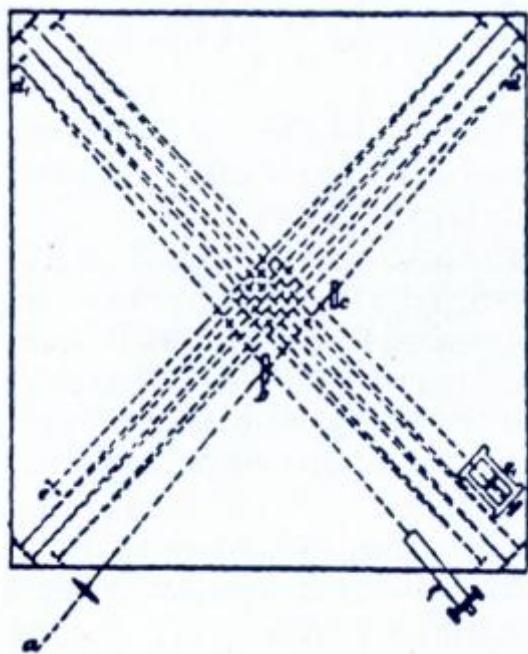
Wynik: Ziemia w stosunku do „eteru" spoczywa
Einstein (1905): prędkość światła (w próżni) mierzona przez każdego obserwatora, niezależnie od jego prędkości, jest taka sama

Abraham Michelson & Morley (1898 Cleveland):

Earth is not moving!
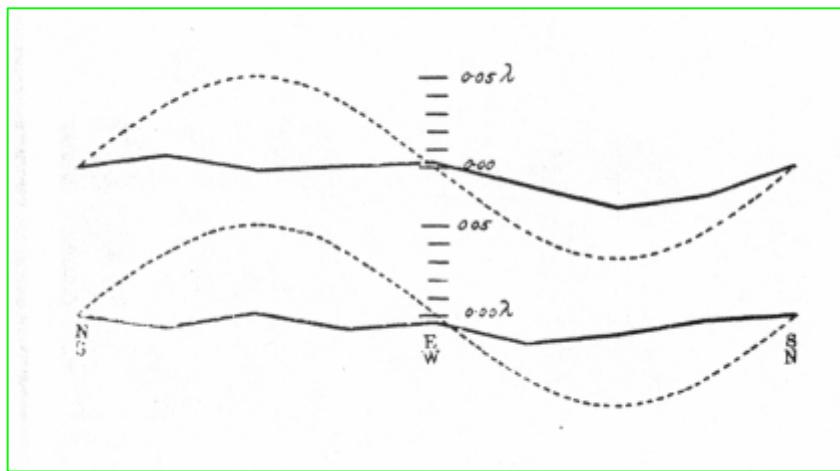
Result:

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

u

Y'

O' X'

v'
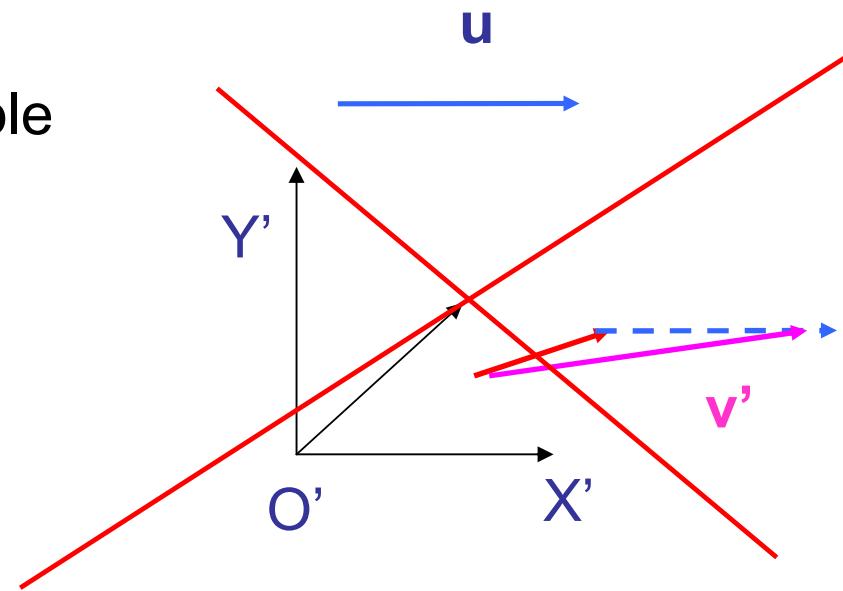
Einstein: shortening in X direction

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:

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

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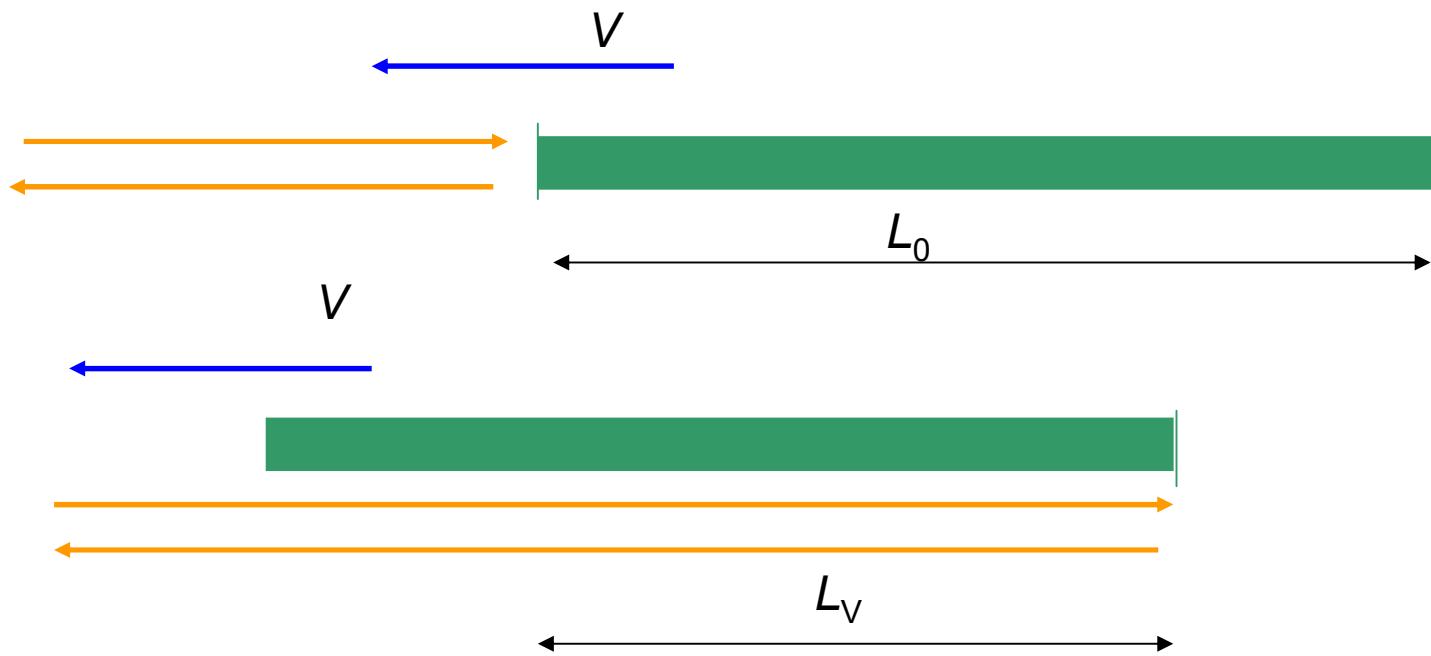
$$L_V = L_0\sqrt{(1 - V^2/c^2)}$$

= 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

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

L

c

D

$V \Delta t_V /2$

c

V

$\Delta t_0 = 2L /c$

$\Delta t_V = 2D /c$

$D^2 = L^2 + (V \Delta t_V /2)^2$ ....
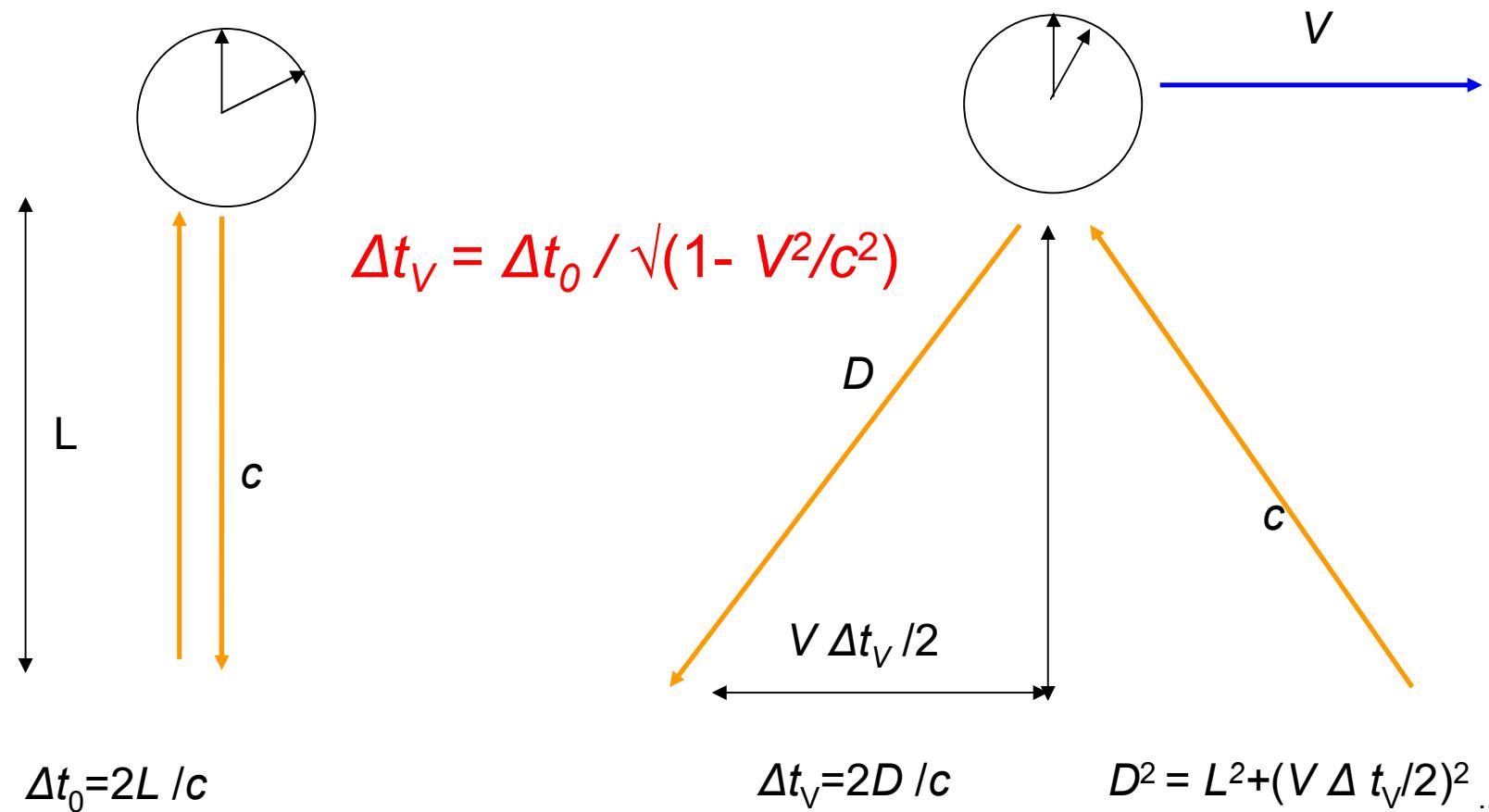
SRT: space-time
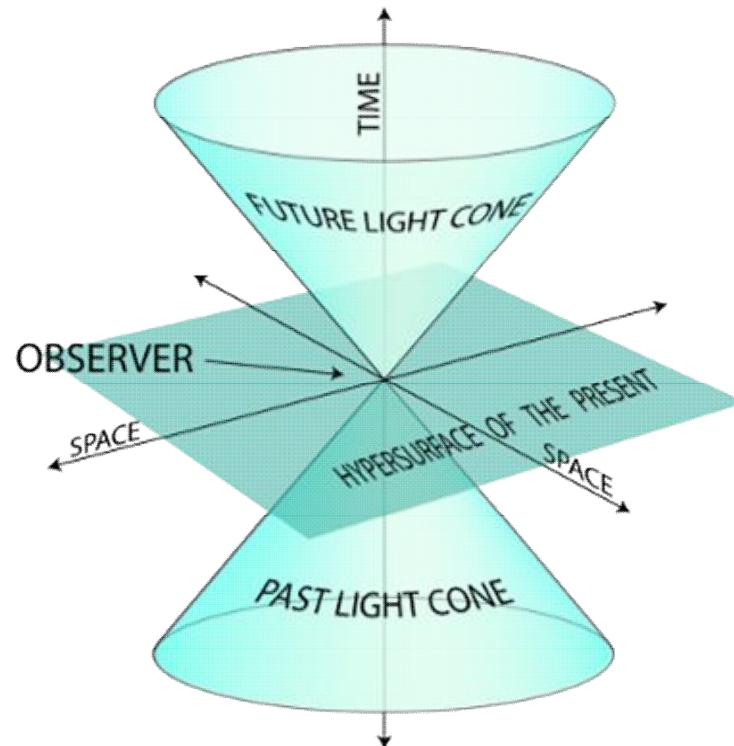
Events at distance bigger that $x>ct$ are not accessible to us

The concept of „the same-time events" does not have any sense – the coincidence depends on the observer

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.

———

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*
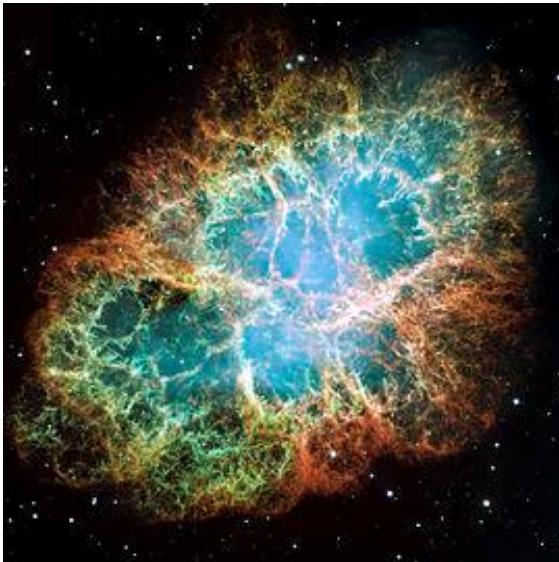
Death of a star


Birth of a star

270px-Crab_Nebula.jpg
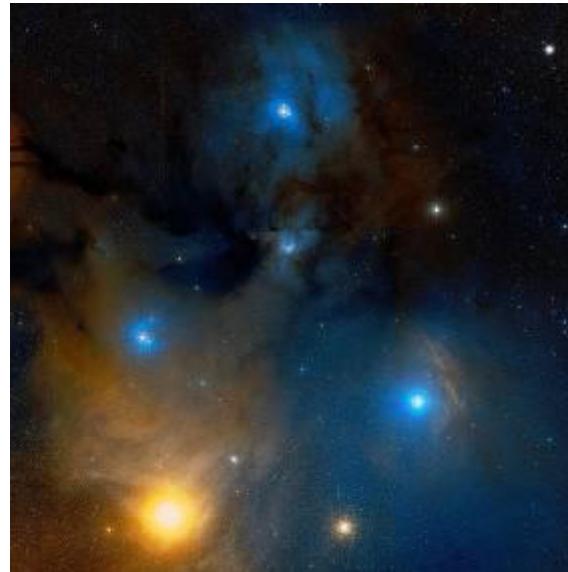
600px-RhoOph.jpg

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

(C) D.J. Campbell, ITER
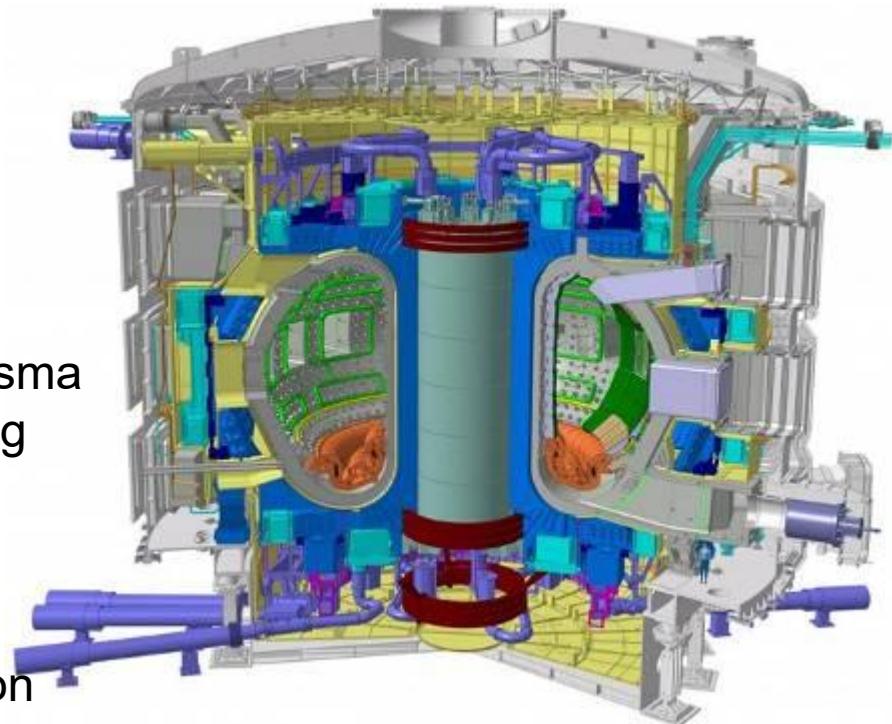
TF Coils – A Global Collaboration
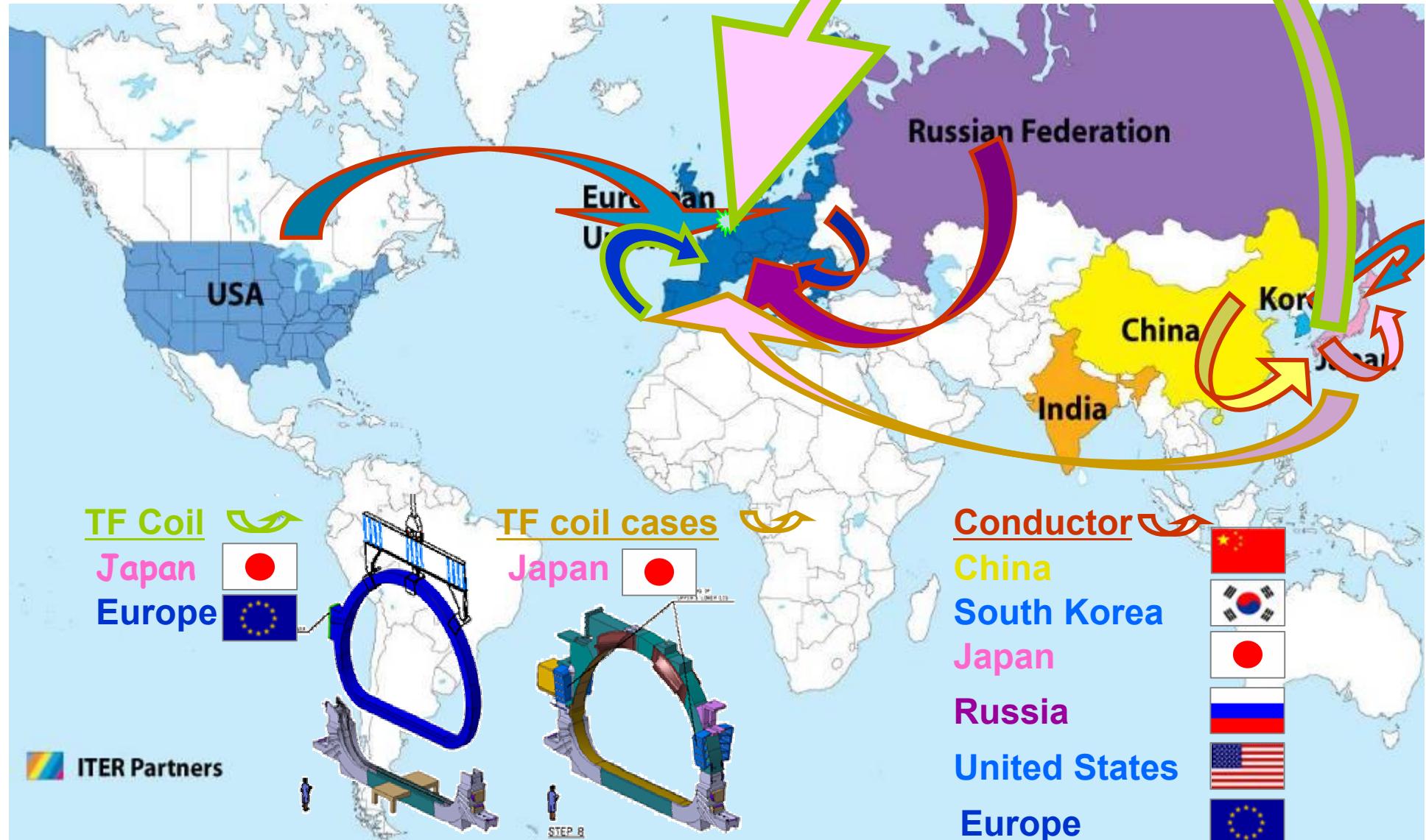
Einstein: gravitation ↔ acceleration

- Galileo (1589): all objects fall with the sam ~~velocity~~ acceleration g=9.81 (m/s)/s

- Einstein (Prague, 1911): Why?

- $F = ma$ ↔ $F=mg$

- 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)

$a = -g$
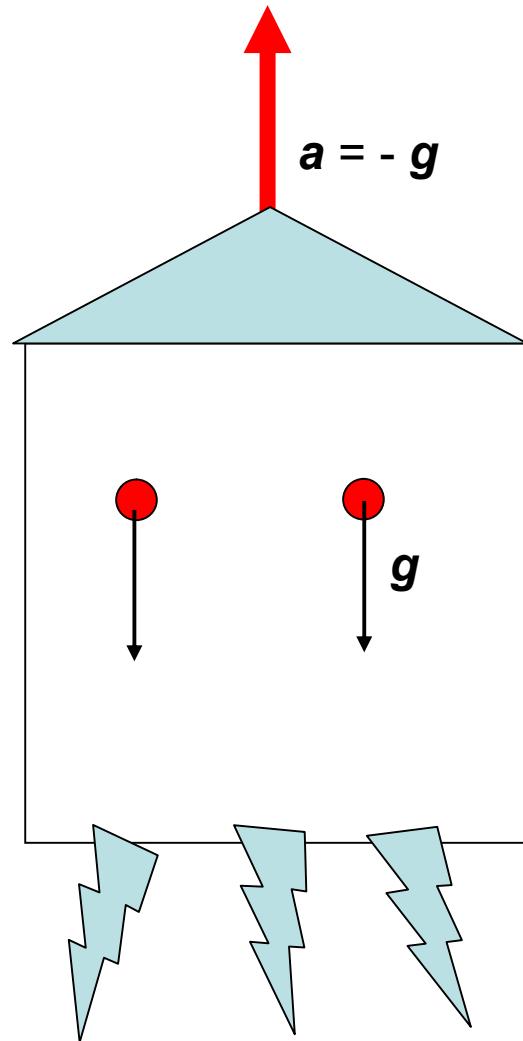
The difference is in the
curvature
of trajectories

g

g
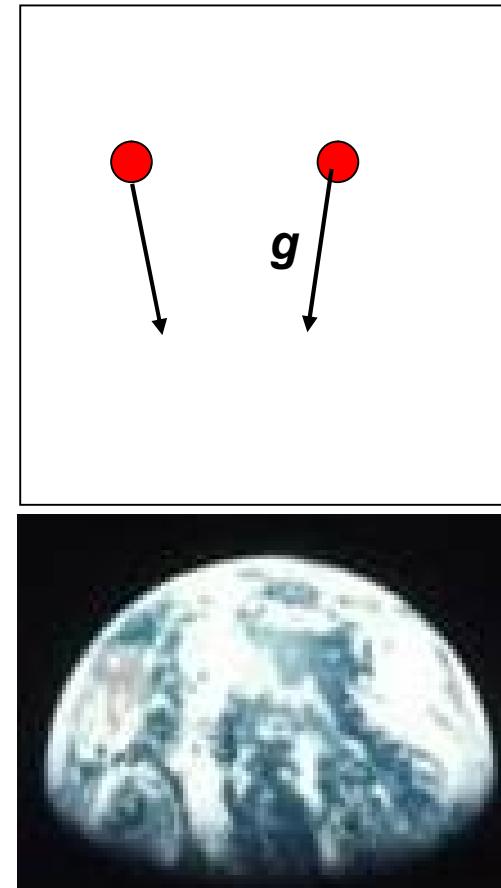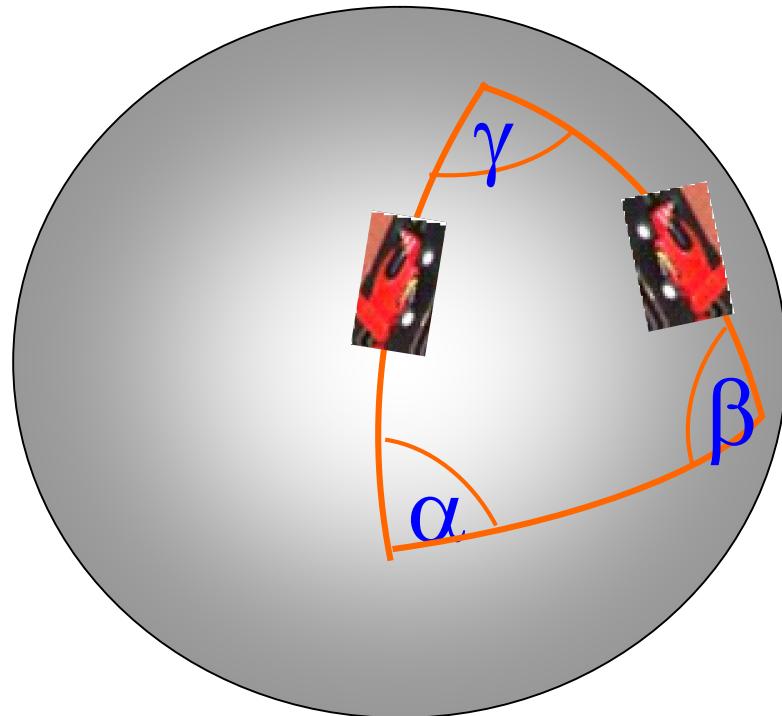
Curvature of space

"geodic lines"
= straigth-on

? Gravitation or curved surface?

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

Curvature of space

$\alpha + \beta + \gamma > 180°$

$\alpha + \beta + \gamma < 180°$

$\alpha + \beta + \gamma = 180°$
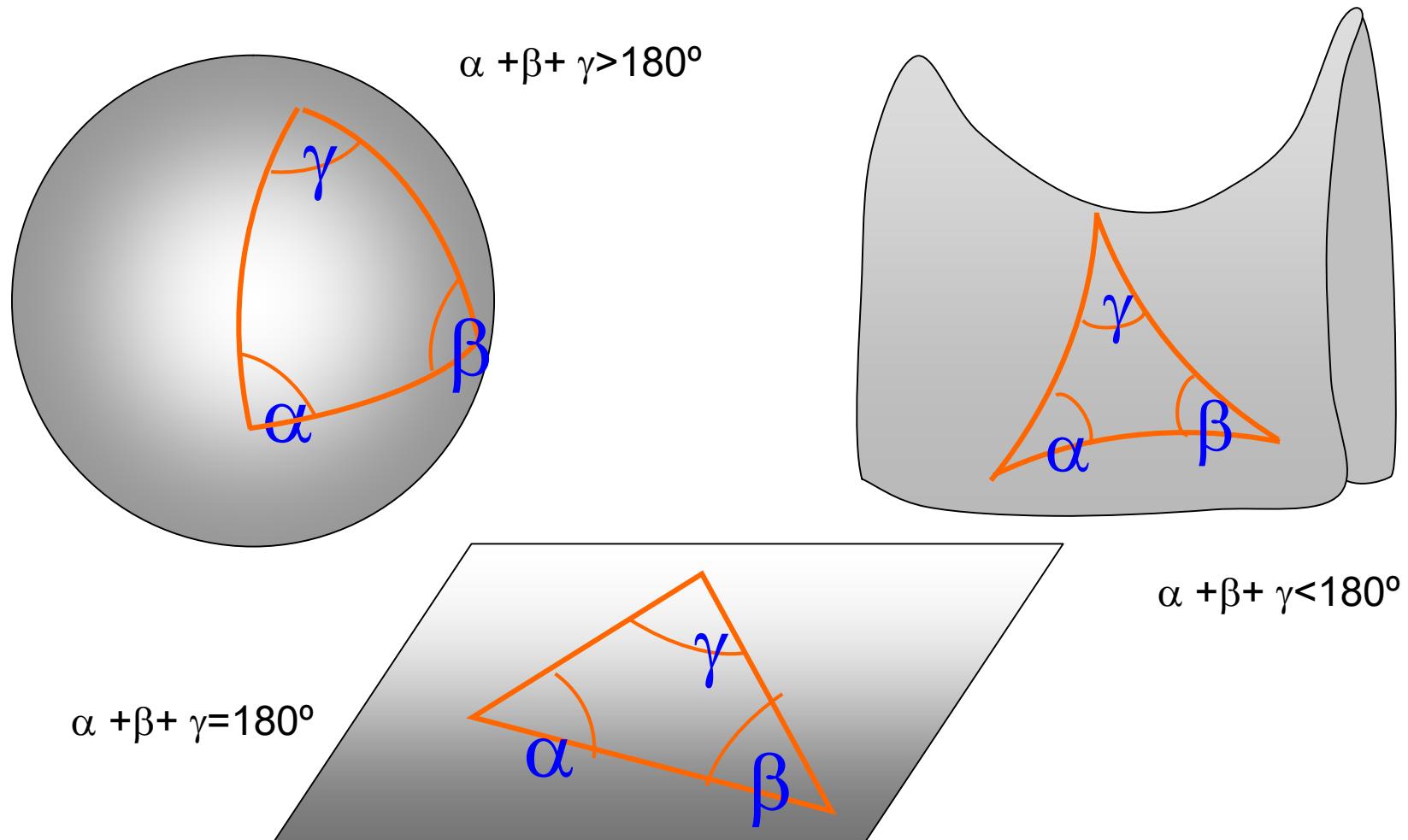
Curvature of Gauss $k = \pm 1/(R_{min}R_{max})$

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 Gravitations-feld 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 Glei-chungen lauten mit Rücksicht auf (44) bei der von uns ge-troffenen Wahl für das Koordinatensystem für das materie-freie Feld

$$(47) \quad \begin{cases} \dfrac{\partial \Gamma^{a}_{\mu\nu}}{\partial x_{\alpha}} + \Gamma^{a}_{\mu\beta}\, \Gamma^{\beta}_{\nu\alpha} = 0 \\[2mm] \sqrt{-g} = 1. \end{cases}$$

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

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

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

$$\mathbf{G} = \frac{8\pi G}{c^{4}}\mathbf{E}$$
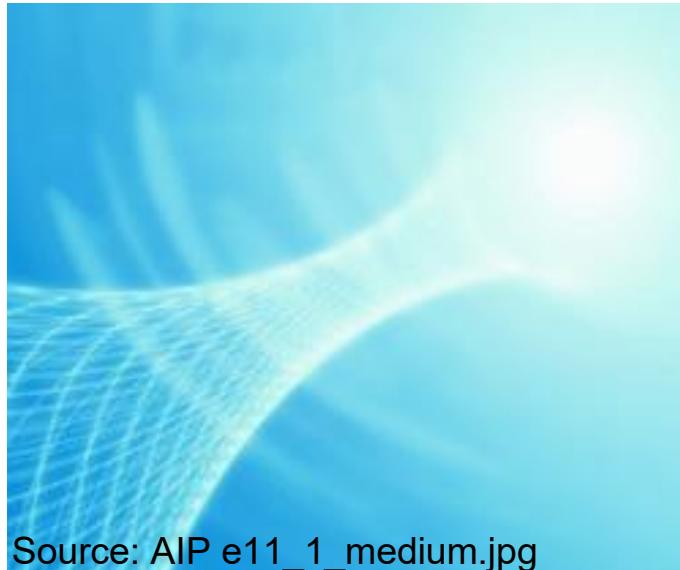
Source: AIP e11_1_medium.jpg
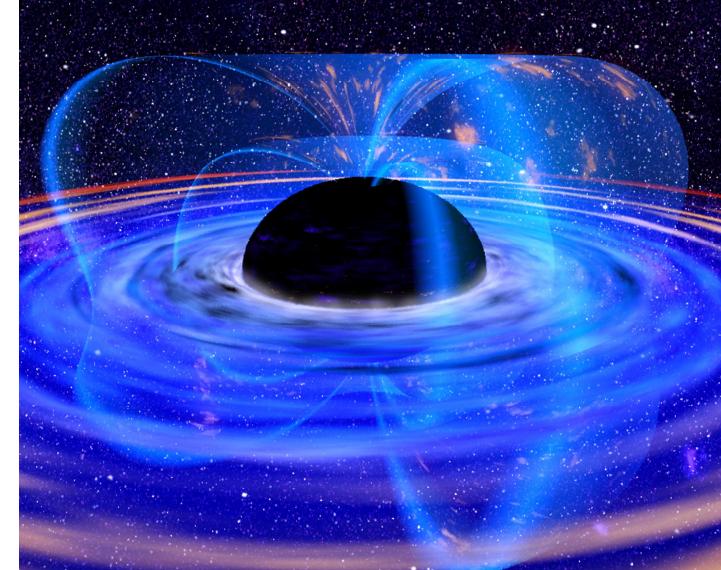
Space-time tunnels?

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.)
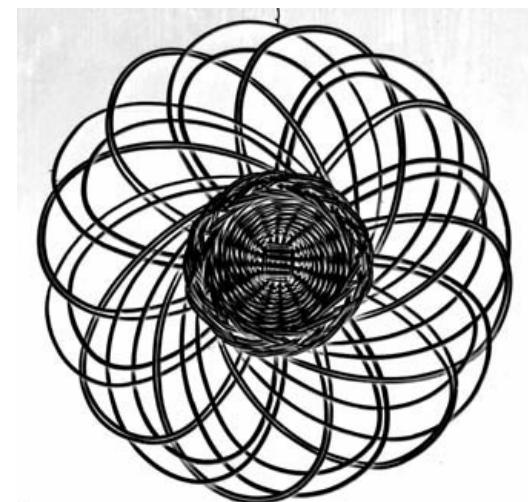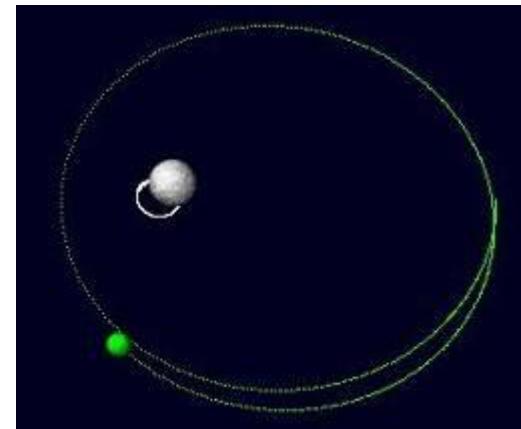
GRT: non-euclidean space

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

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

während (73) und (70) ergeben

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

Die Ausrechnung ergibt

(74)
$$B = \frac{2a}{\varDelta} = \frac{\varkappa M}{4\pi\varDelta} \cdot$$

Ein an der Sonne vorbeigehender Lichtstrahl erfährt demnach eine Biegung von 1,7", ein am Planeten Jupiter vorbeigehender eine solche von etwa 0,02".
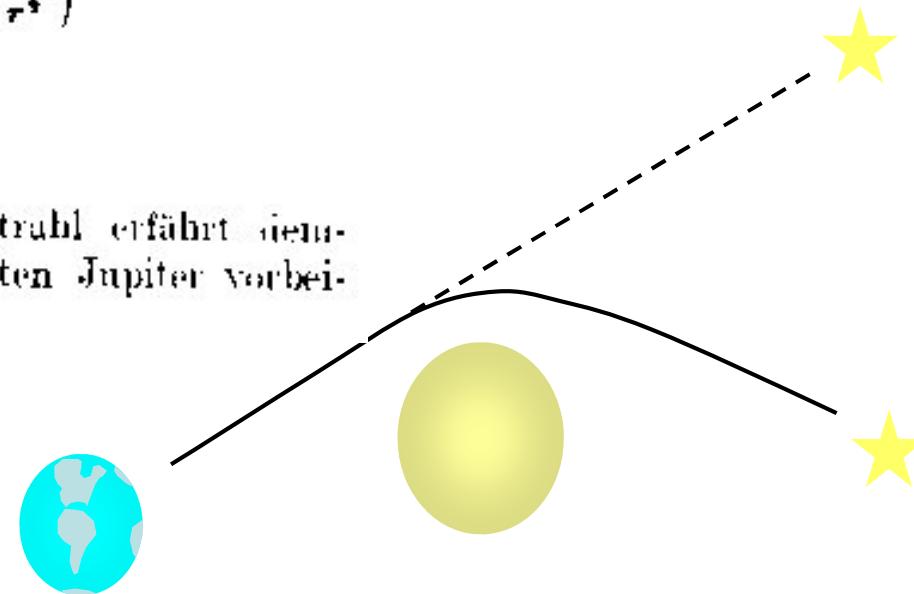
The deviation of light from General Relativity is double
as compared to that resulting from Newton's theory.

GRT: light of distant galaxies

Q2237+0305 quasar
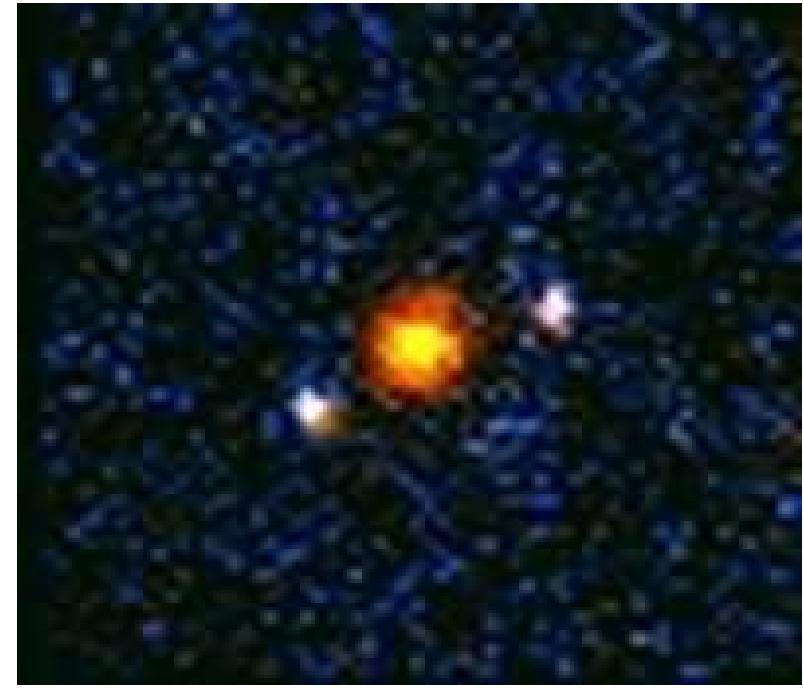
HST 01247+0352

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 4×10^{-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.
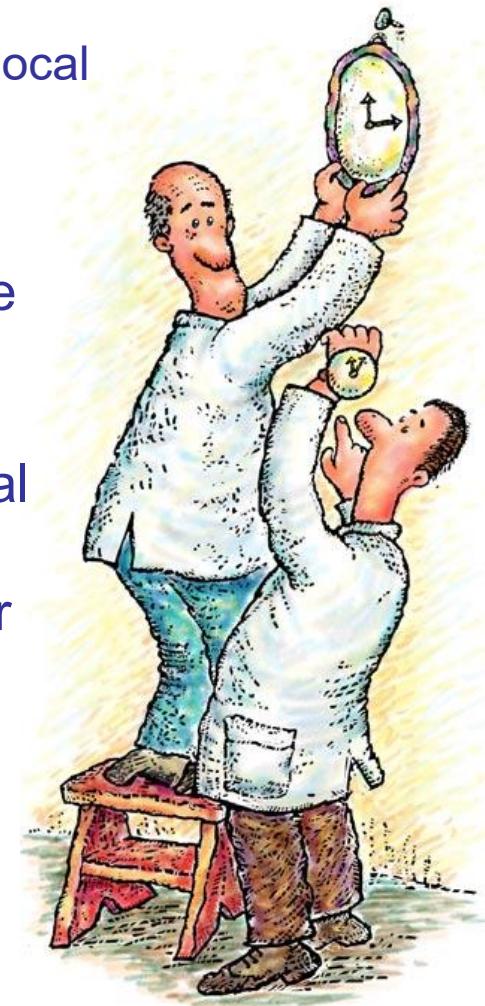
Global positioning system
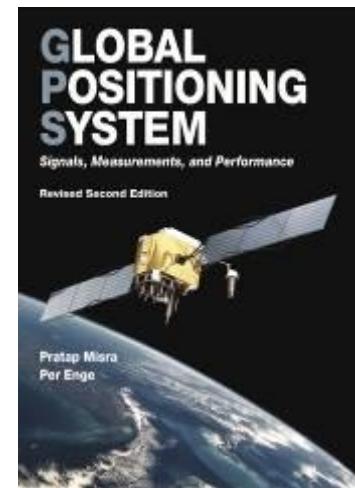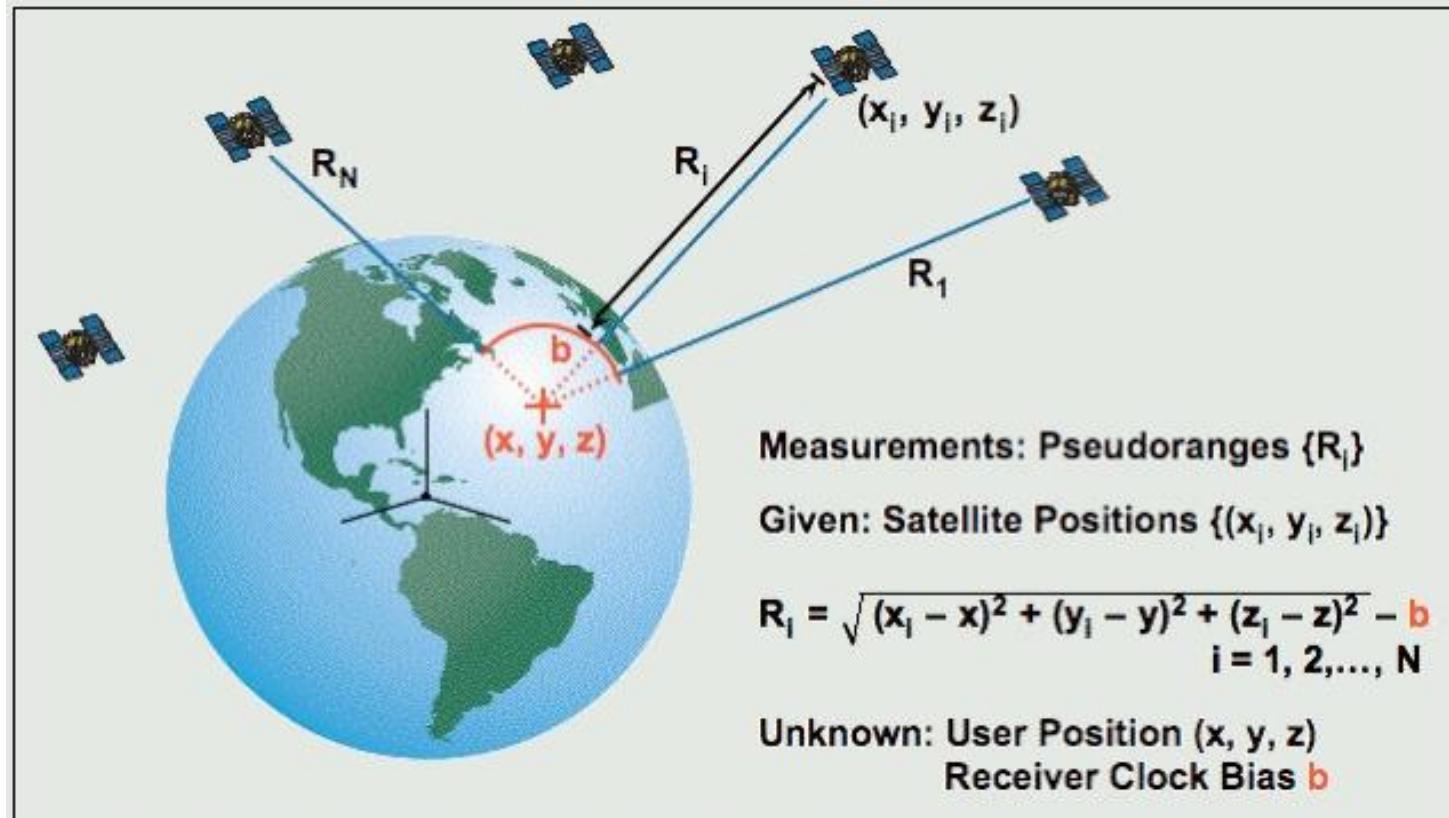
Figure 1.9 The principle of satellite navigation. The user-satellite range measurements based on the times of transmission and receipt of signals are biased by a common amount and are called pseudoranges. Pseudorange measurements are needed from at least four four satellites to estimate the user position and receiver clock bias.

http://www.gpstextbook.com/

GPS: Relativistic corrections

Around the world atomic clock experiment

(Flying clock – Reference clock)

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

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

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

Global Positioning System

Prediction of Relativistic Effects

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

Measured TWTT data

Predicted relativistic effect on flight clock

At end of flight TWTT link quality became degraded

Relativistic Corrections

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

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

Sagnac effect (rotation) $\Delta\tau = -\dfrac{\omega}{c^2}\sum_{i=1}^{N} R_i^2\,\cos^2\phi\,\Delta\lambda_i$
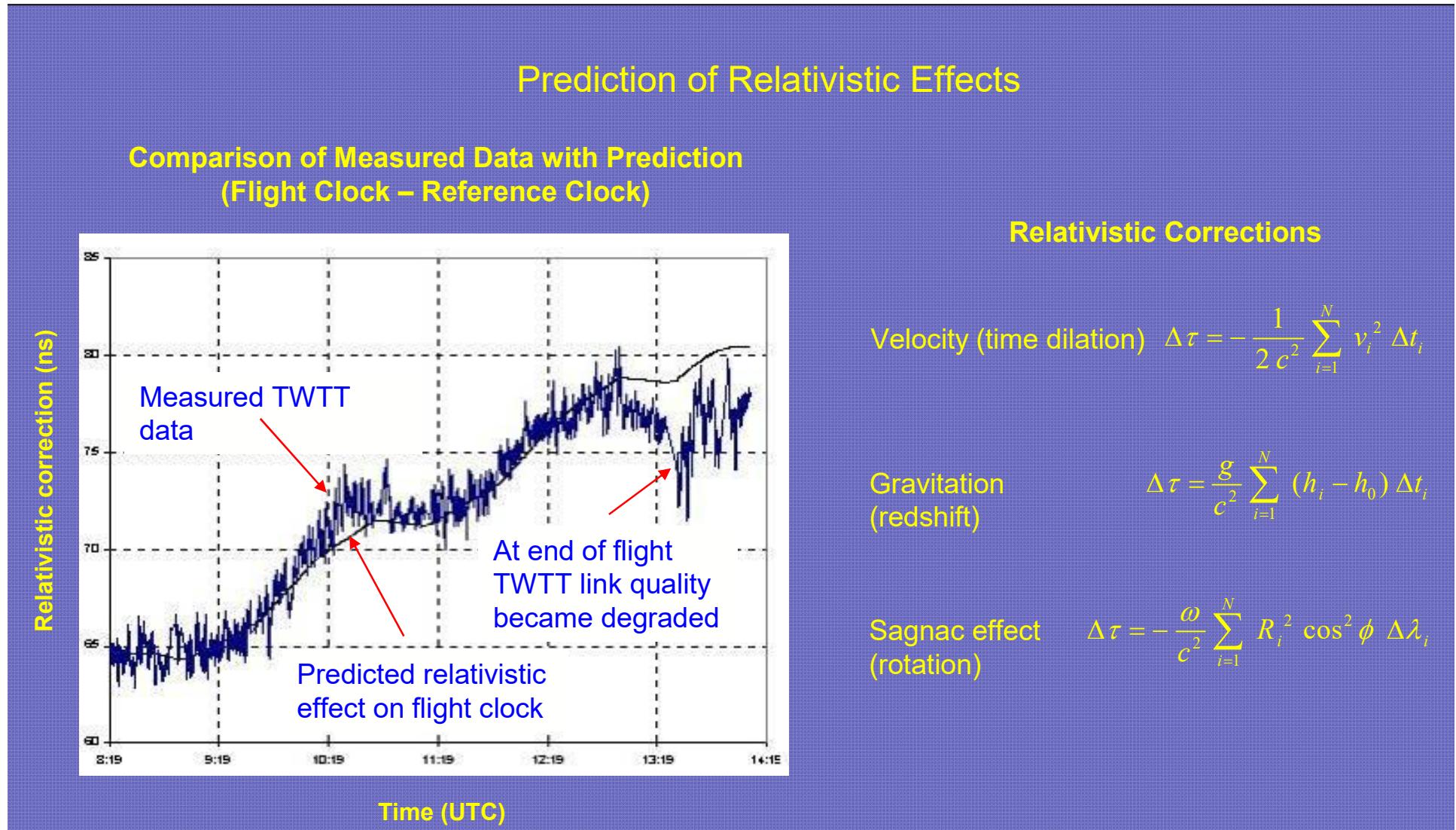
„E pur si muove"

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!
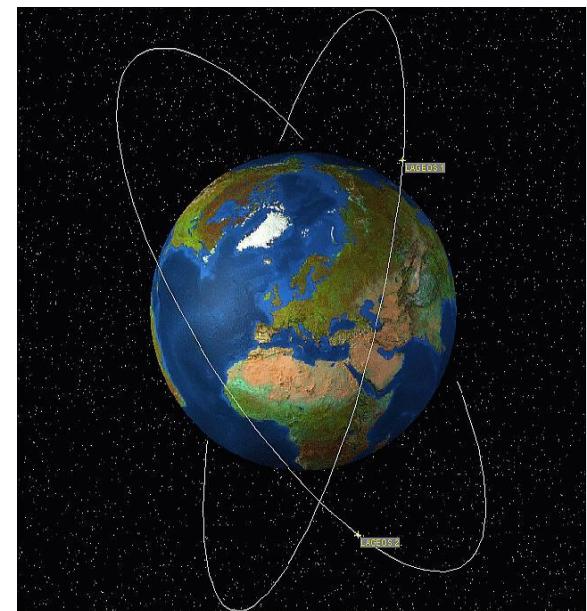
Lageos satellite

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://myfrenchkitchen.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
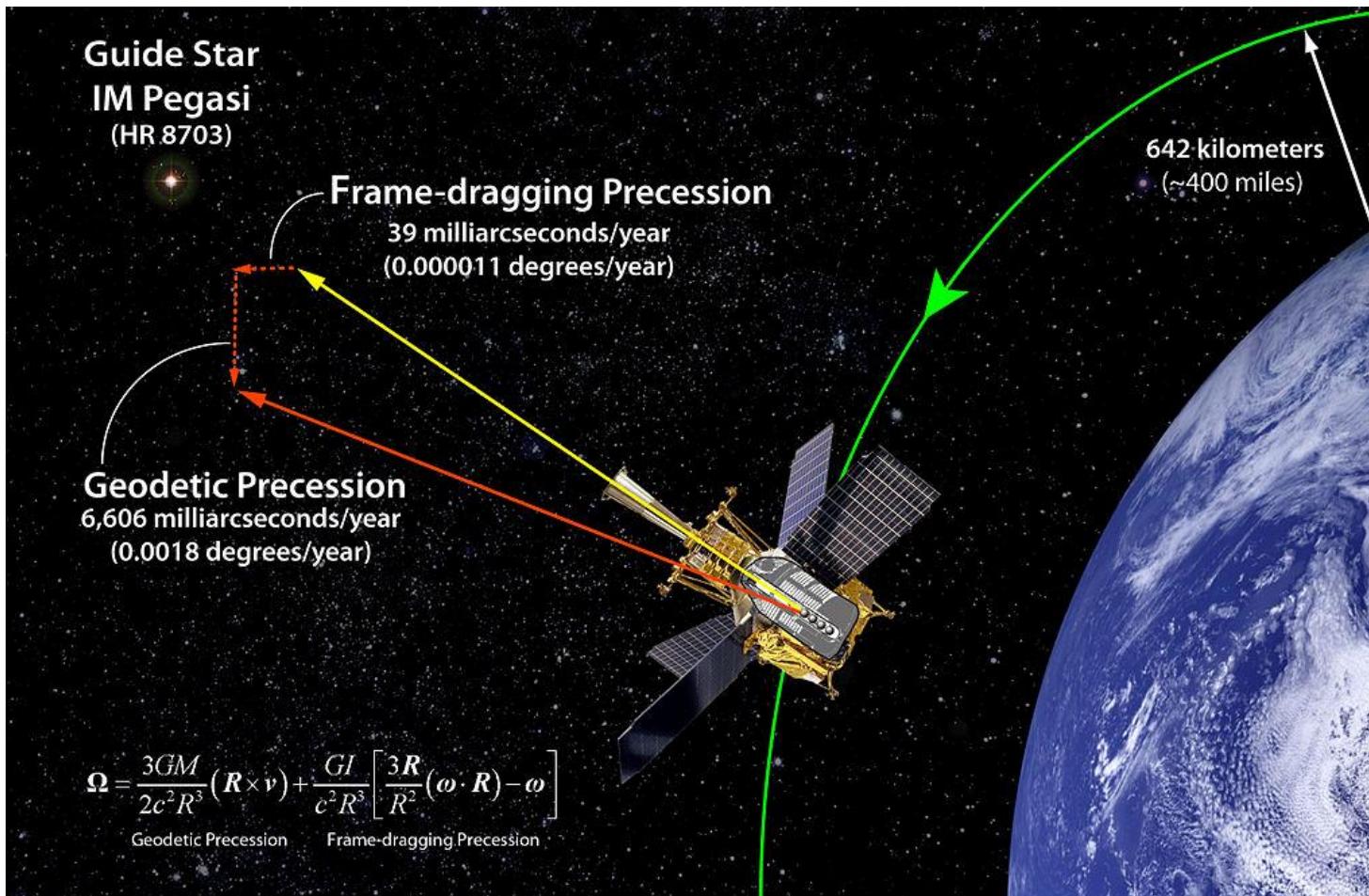
Gravity probe-B

First four terms...

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

Hanford (WA), Livingstone (LO)

In the LIGO facility, a laser beam is split to travel down two perpendicular 4-kilometre tunnels. The beams then reflect back and forth before being recombined at the detector.

4-km-long arm

Beam splitter

Mirror

Laser

Light detector
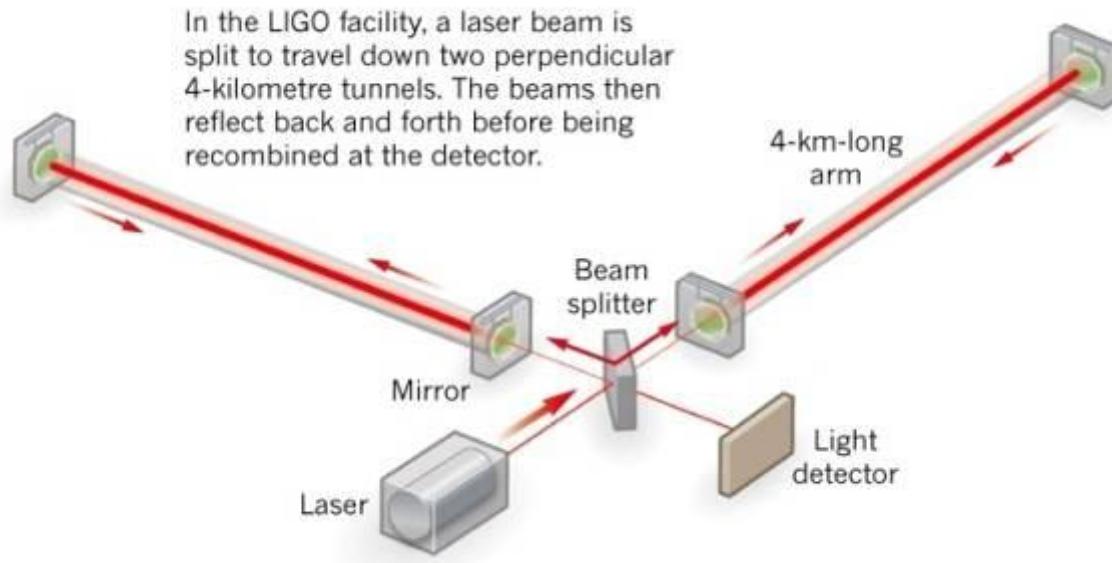
Michelson's laser interferometer

14.09.2015, 11:50:45 CET
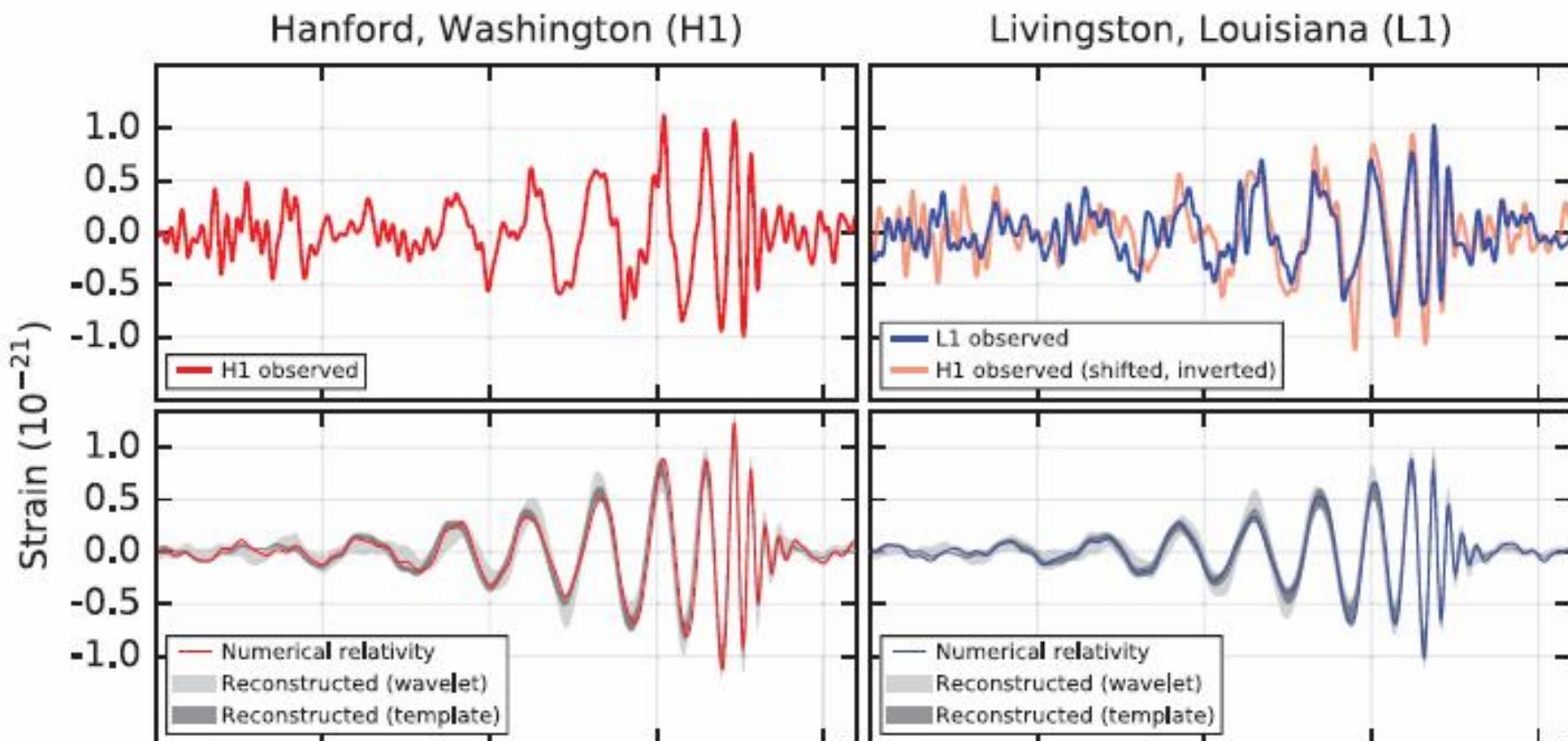
Radius of our Galaxy changed by 1 meter, for 10 microsecond
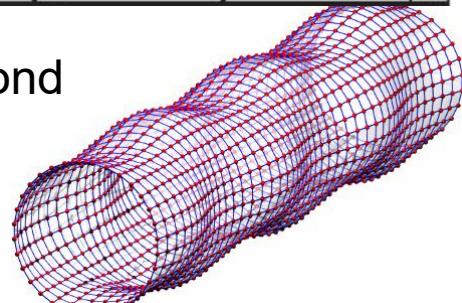
1,3 bln years ago: two black holes collided
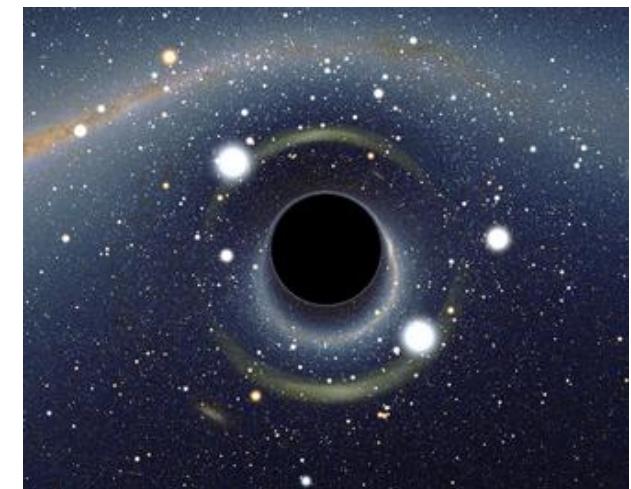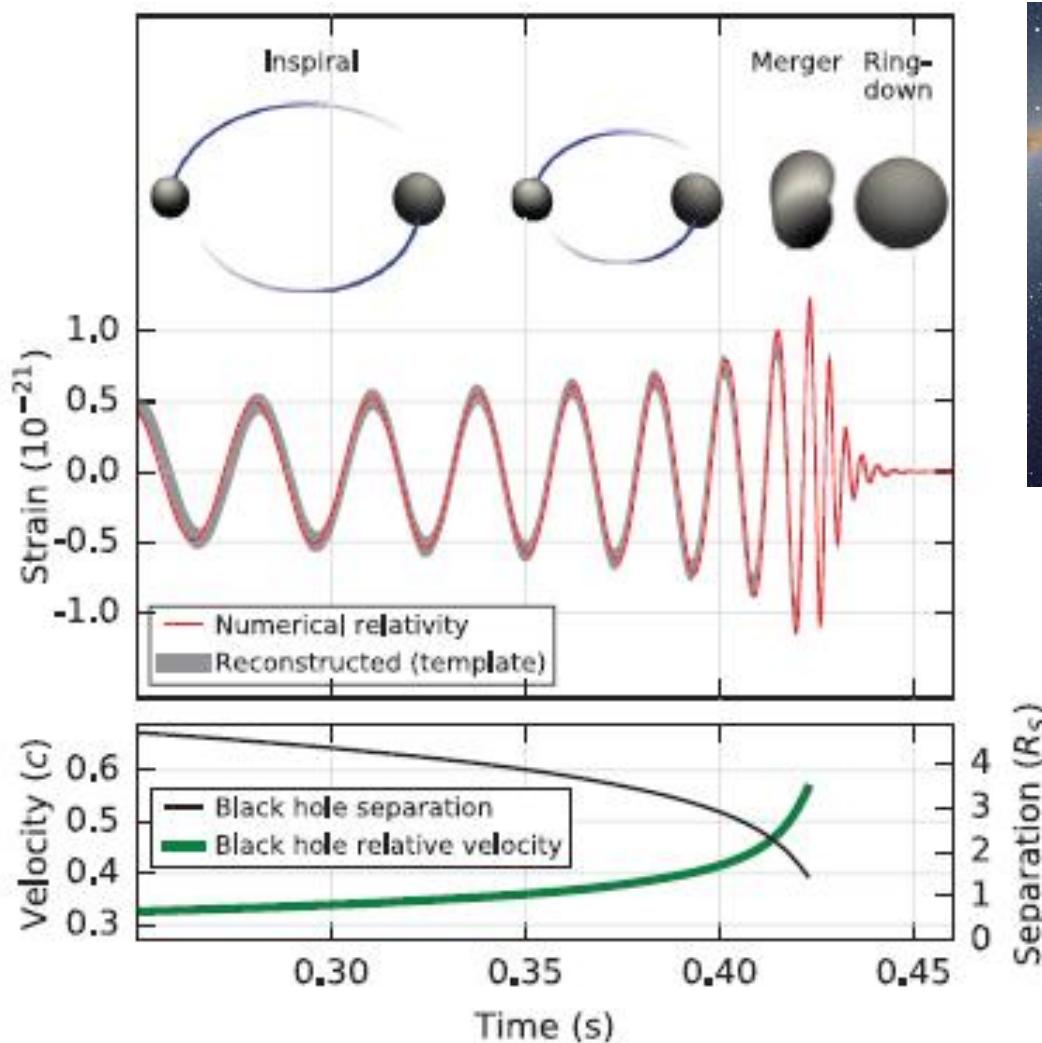
36±4 M_o

29±4 M_o
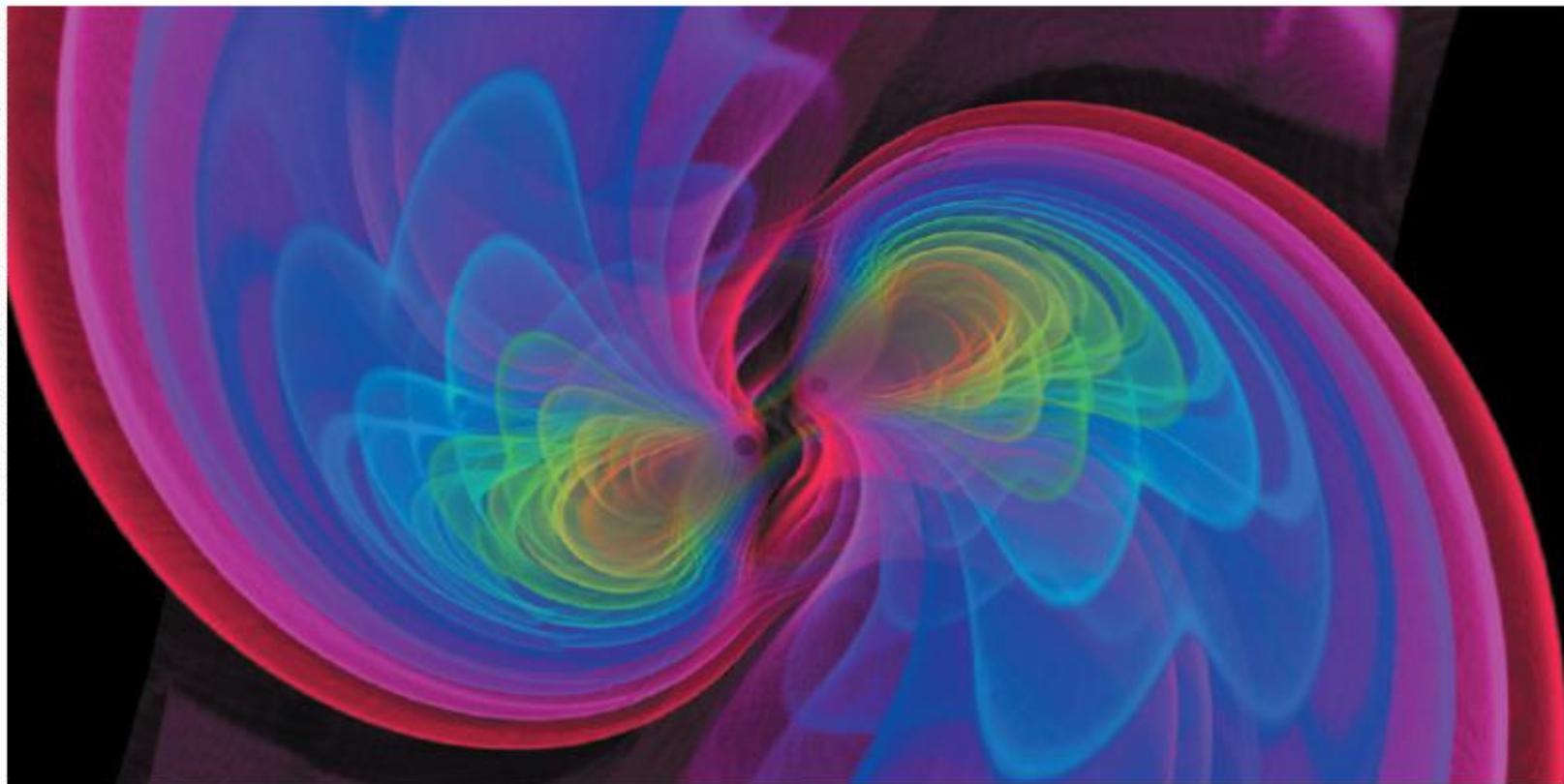
The pair of merging black holes that LIGO detected using gravitational waves — as produced by a computer simulation.

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).
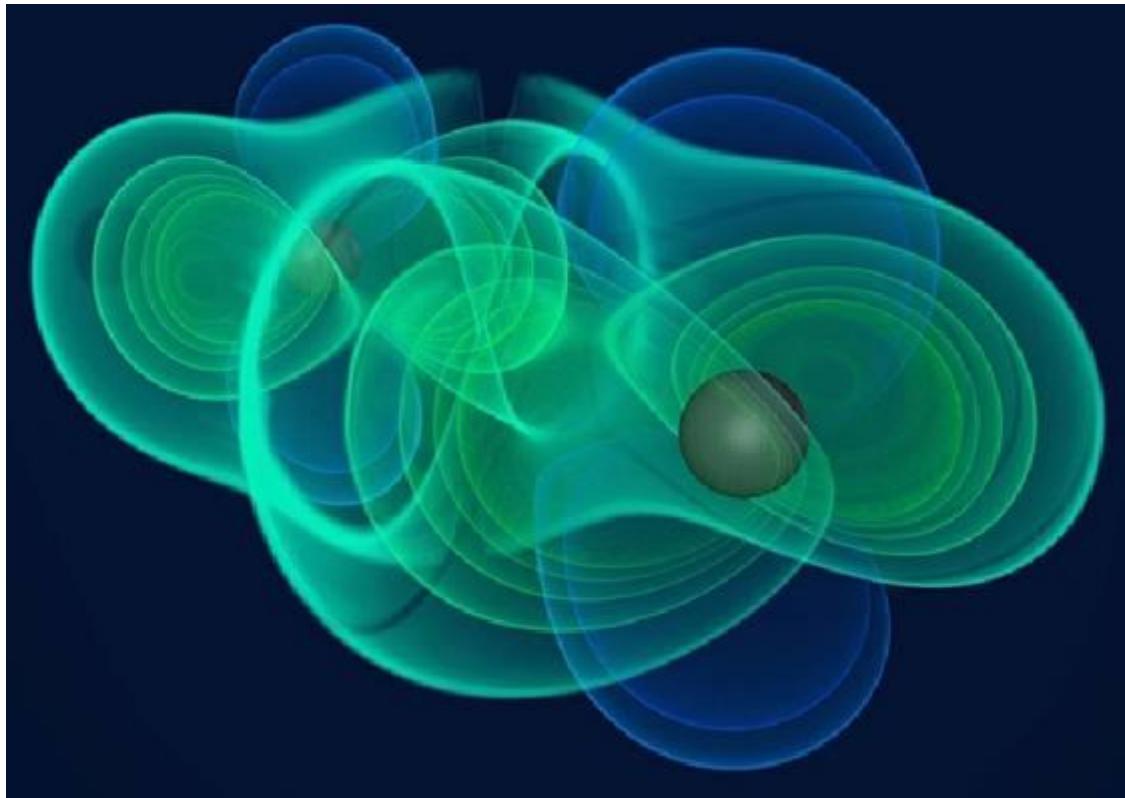
Source: „Nature"

Source: AIP, 16.02.2016

So
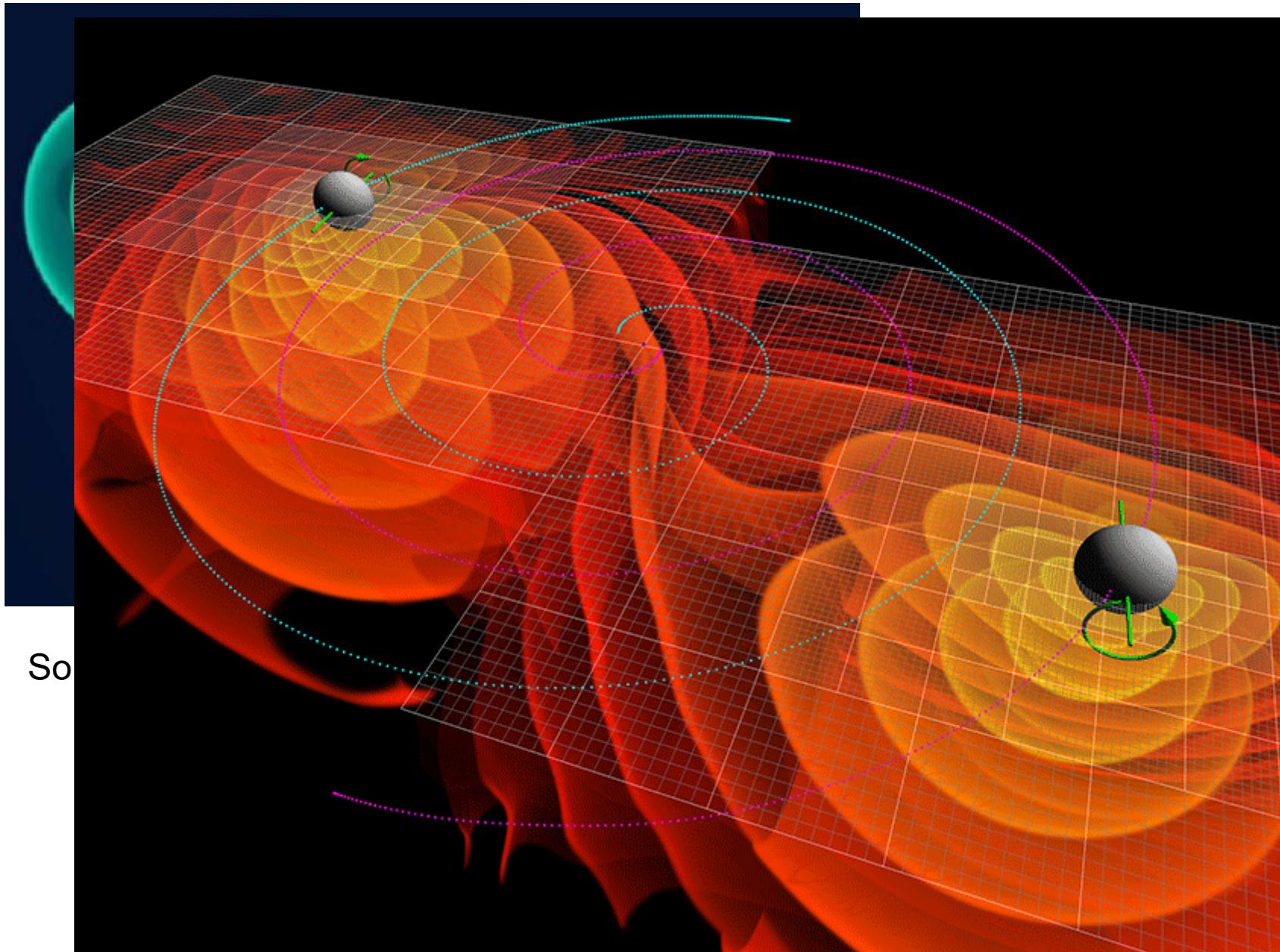
Source: AIP, 16.02.2016

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 Ω_0 which measures the ratio between the density ρ of the studied universe and a particular density, called the critical critical density ρ_c. (about $6 \cdot 10^{-27}$ kg/m^3).

size

$\Omega_0 < 1$

$\Omega_0 = 1$

$\Omega_0 > 1$

time
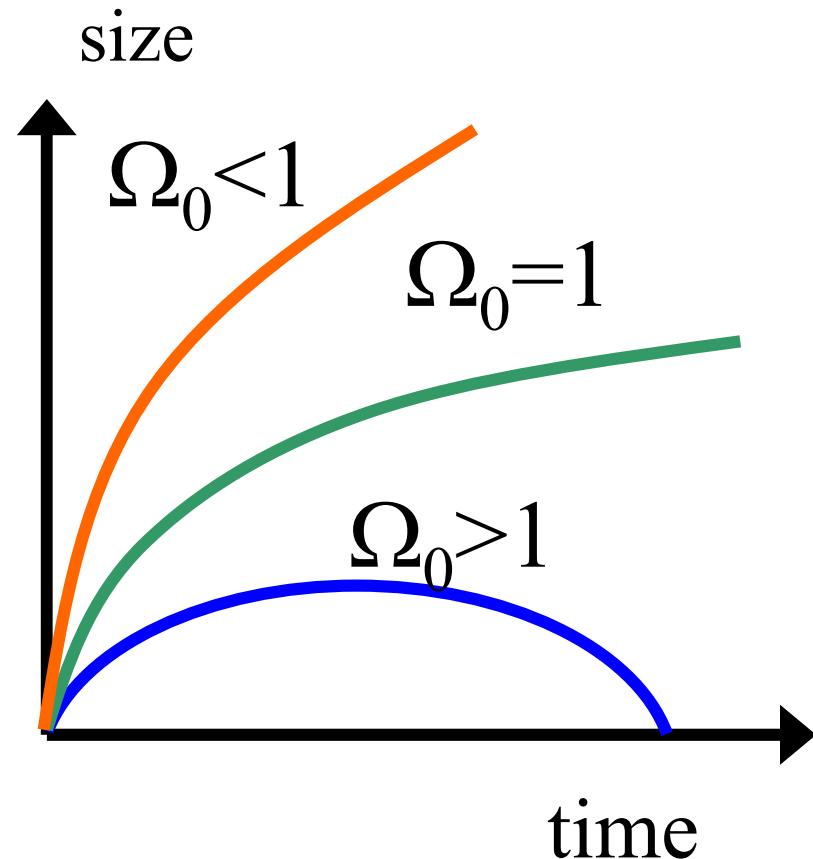
Invisible (gravitational) mass

Kepler law:

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

We lack 75% of mass!

Galaxy Andromeda (2 mln light yrs from us)

How many galaxies in the Universe?
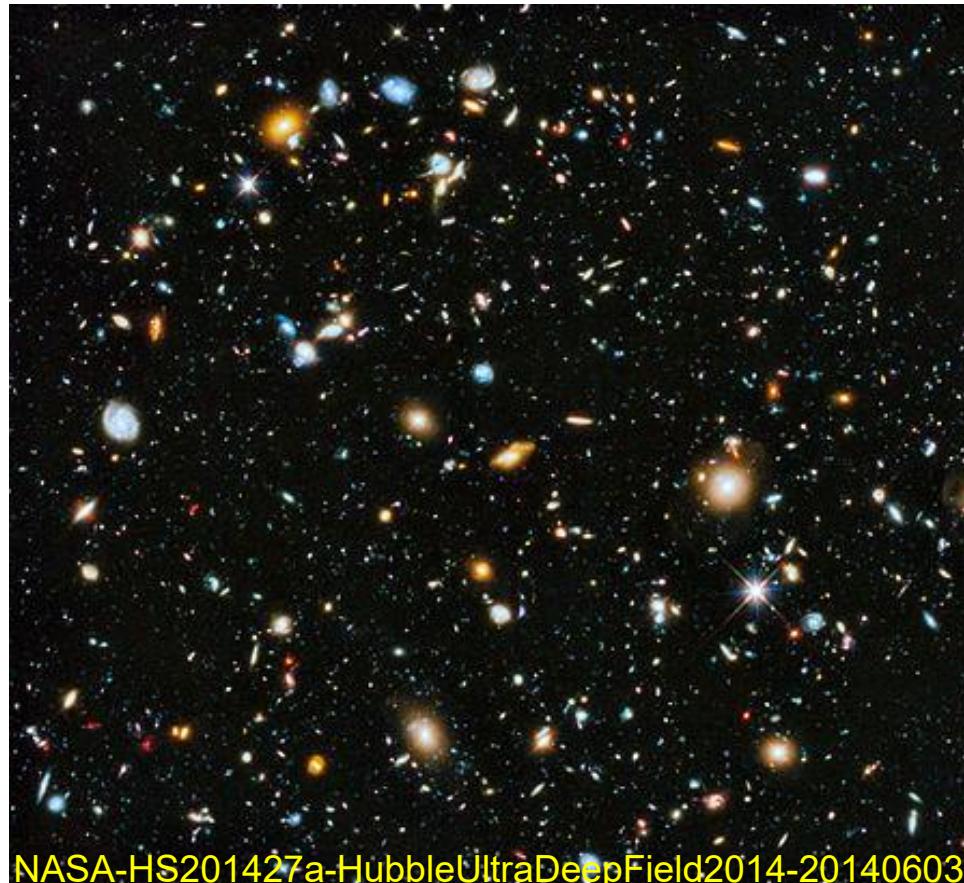
NASA-HS201427a-HubbleUltraDeepField2014-20140603.jpg

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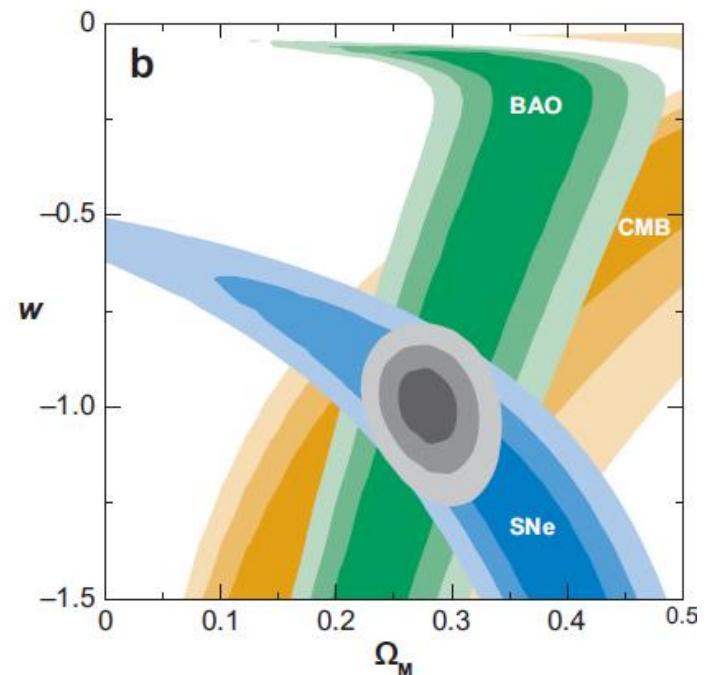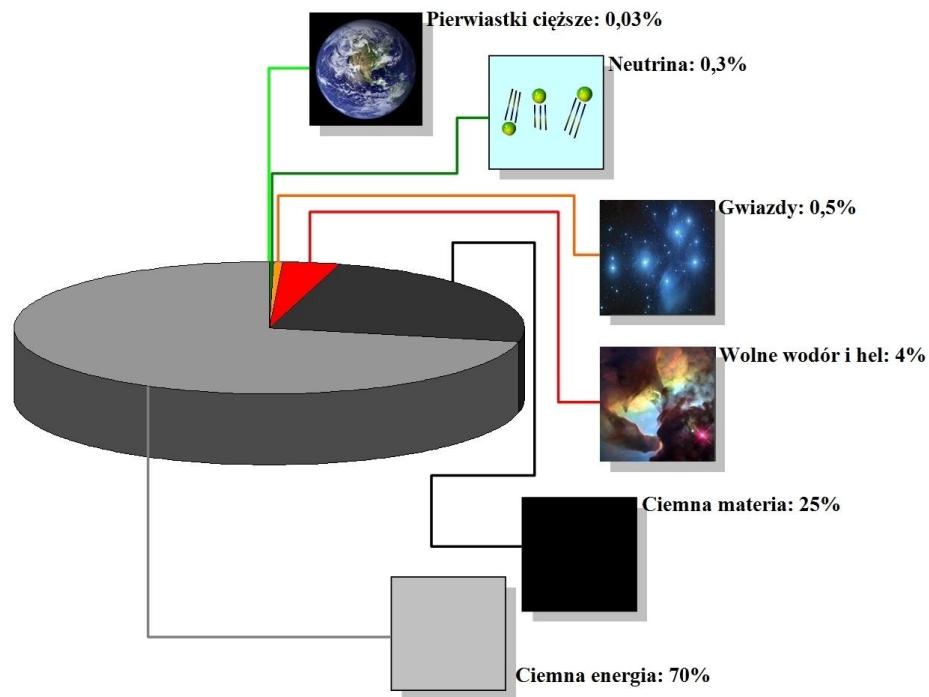
The visible universe (optical, IR, UV, X-Ray, gamma, radio) is only 4% of the existing (gravitationally and as energy) Universe.
What is the remaining 96% we do not have **any** idea!

The shape of Universe?

Some scientist say that time-space is closed, and folded inside like the Swiss cheese. But recent observations show that it is flat, or better, cubic.

Moreover, the Universe **accelerates its expansion** and we do not know why!
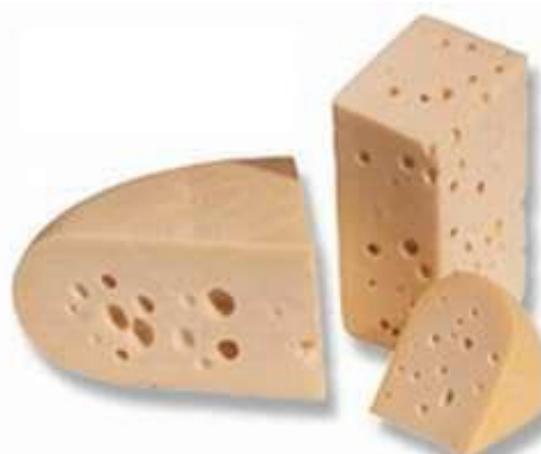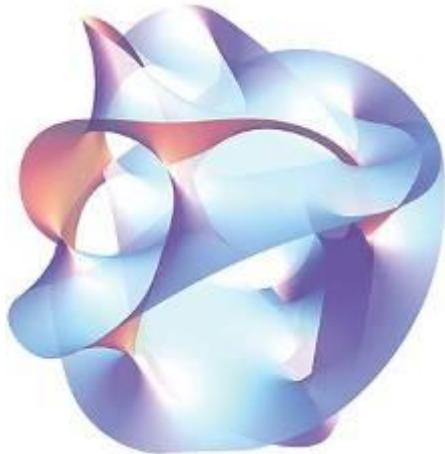
330px-Calabi_yau.jpg

Fingers of God

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