Einstein for pedestrians

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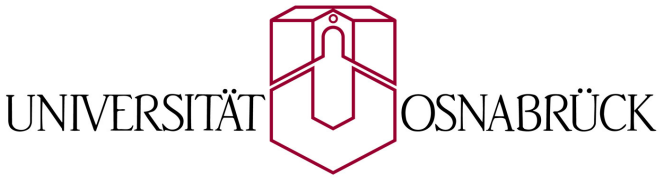
April 2011



Overview

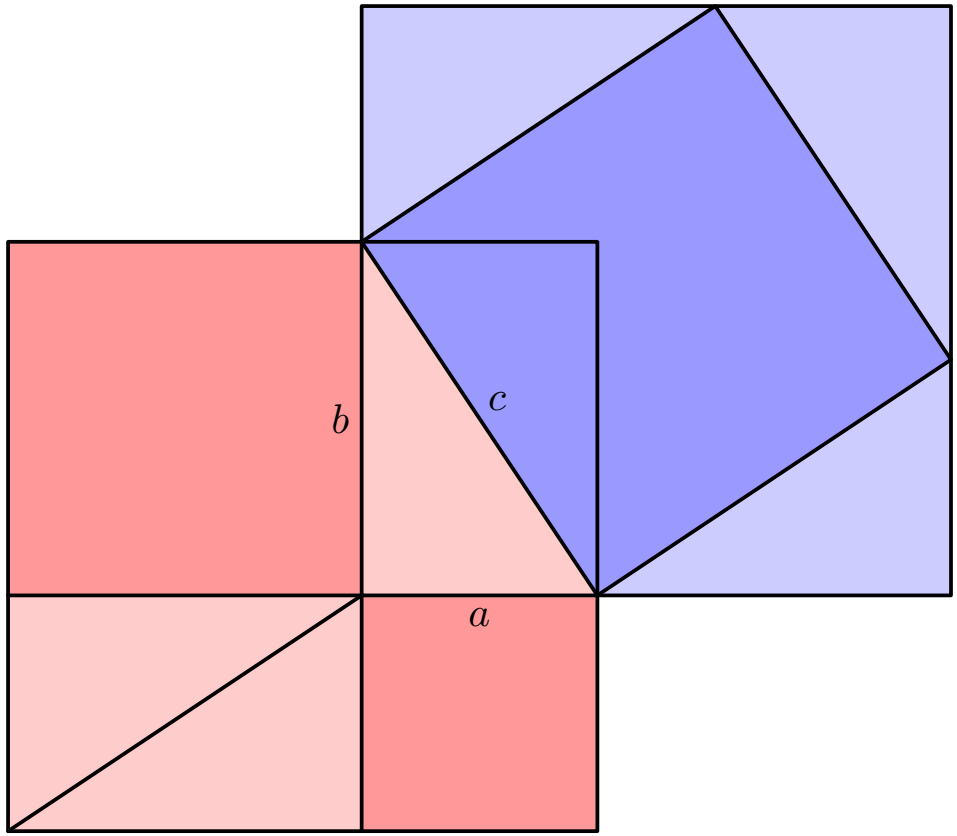
- motion is always relative
- light has always the same speed
- no contradiction!
- twin paradoxon
- mass and energy
- elementary particles, nuclear power, GPS

Pythagoras of Samos (580-495 B.C.)

Pythagoras' theorem

- In any right triangle, the area of the square whose side is the hypotenuse c is equal to the sum of the areas of the squares whose sides are the two legs a and b.
- $c^2 = a^2 + b^2$
- $c = \sqrt{a^2 + b^2}$

One of many proofs



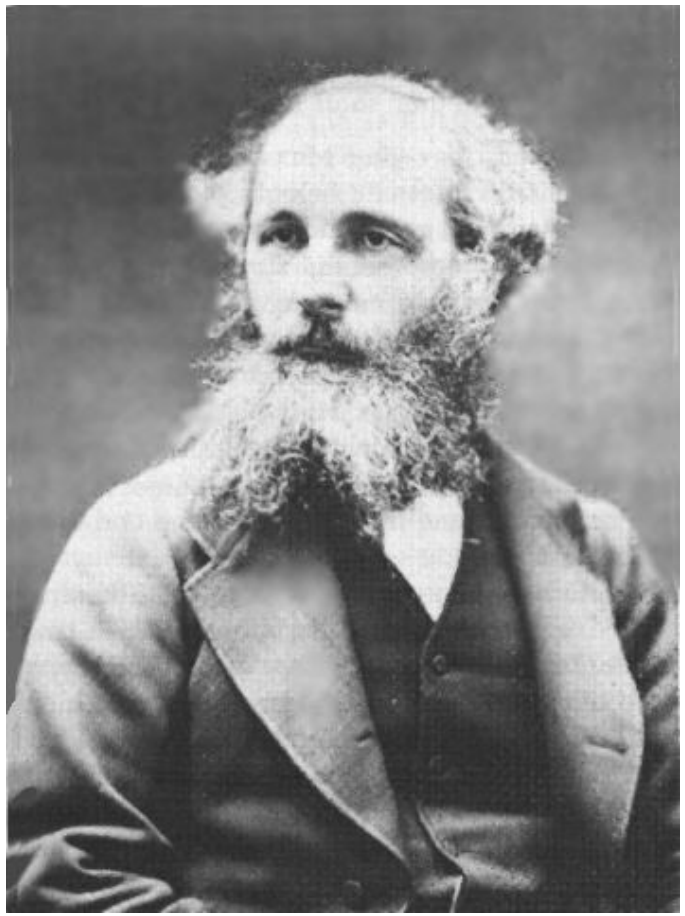
Thabit ibn Qurrah (836-901)

Galileo Galilei (1564-1642)

Space and time

- space is infinite
- bodies are lazy (inert)
- forces change the velocity
- velocity is relative
- all inertial systems are equally good
- addition of velocities vectors

James Clerk Maxwell (1831-1879)



The electromagnet field I

- all electric and magnetic phenomena are described by just a few equations
- electric charges and currents generate the electromagnetic field
- even in the vacuum, there can be electromagnetic fields
- the corresponding waves propagate with always the same velocity c

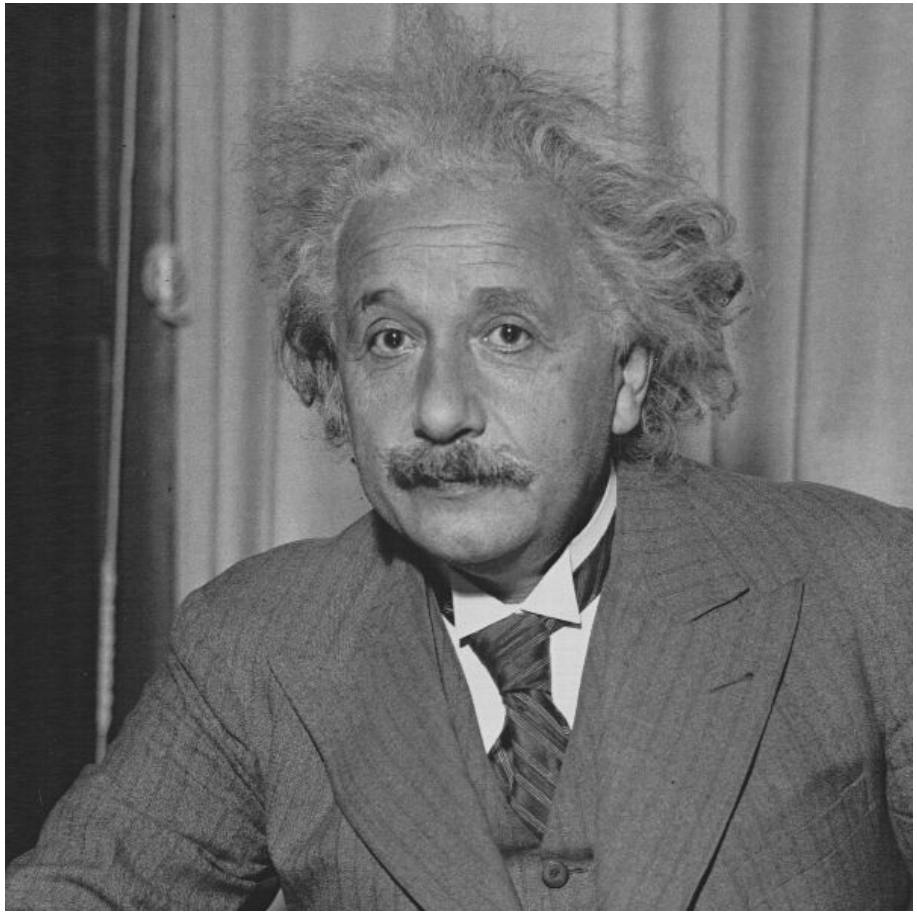
The electromagnetic field II

- $\epsilon_0 \nabla E = \rho$
- $\frac{1}{\mu_0} \nabla \times B - \epsilon_0 \dot{E} = j$
- $\nabla B = 0$
- $\nabla \times E + \dot{B} = 0$
- $c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$

The electromagnetic field III

electric motor, dynamo, transistor, mobile phone, radio, television, computer, light bulb, high voltage power line, battery, hard disc, digital camera, microphone, loudspeaker, GPS, photocopier, light, stars, quartz watches, ECG, EEG, computer tomograpy, X rays, bullet train, 500 km cables in one Airbus 380, glass fibers, internet. . .

Albert Einstein (1879-1955)



Contradiction!

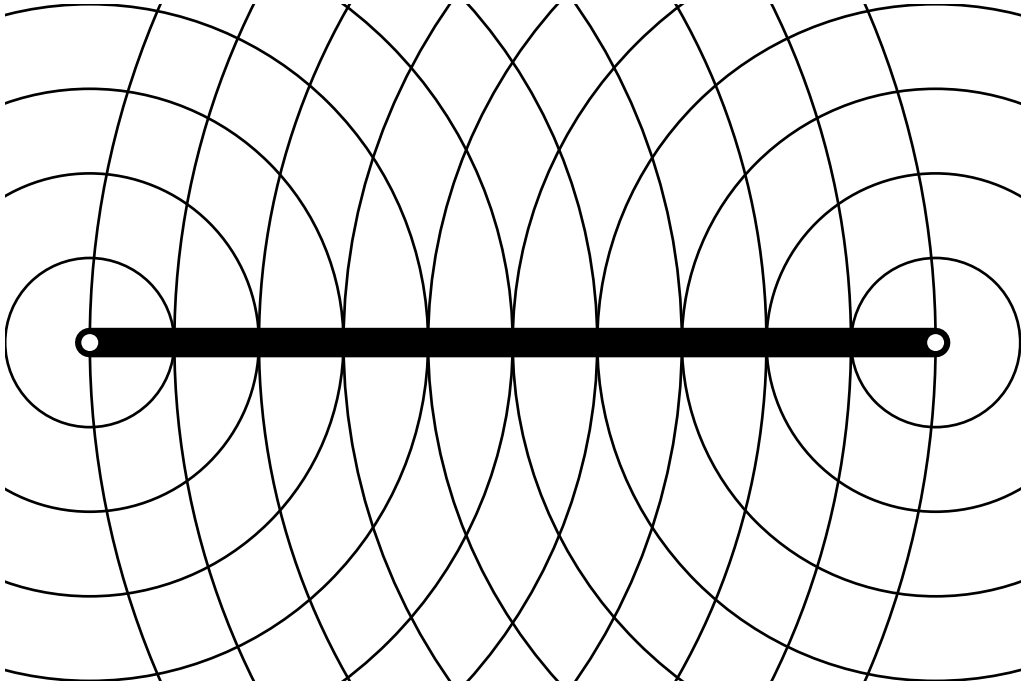
- Galilei and Maxwell disagree. . .
- . . . because $u + c = c$ is nonsense
- *Zur Elektrodynamik bewegter Körper*
- *On the electrodynamics of moving bodies*
- what is time?

Zur Elektrodynamik bewegter Körper (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.

Model clock



clock beat (tic-toc) $\tau = 2\ell/c$

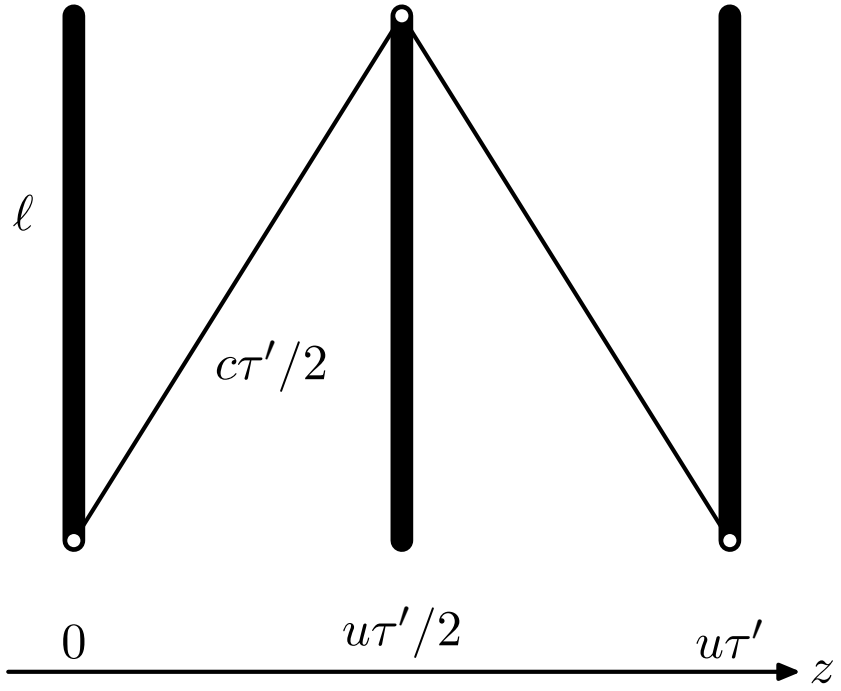
Perpendicular dimension unchanged!

- two equally broad strips
- one at rest, the other moving
- one may become broader
- wich?
- none of the two

$$\ell'_\perp = \ell_\perp$$

The clock

beat is τ'



The clock beat becomes longer!

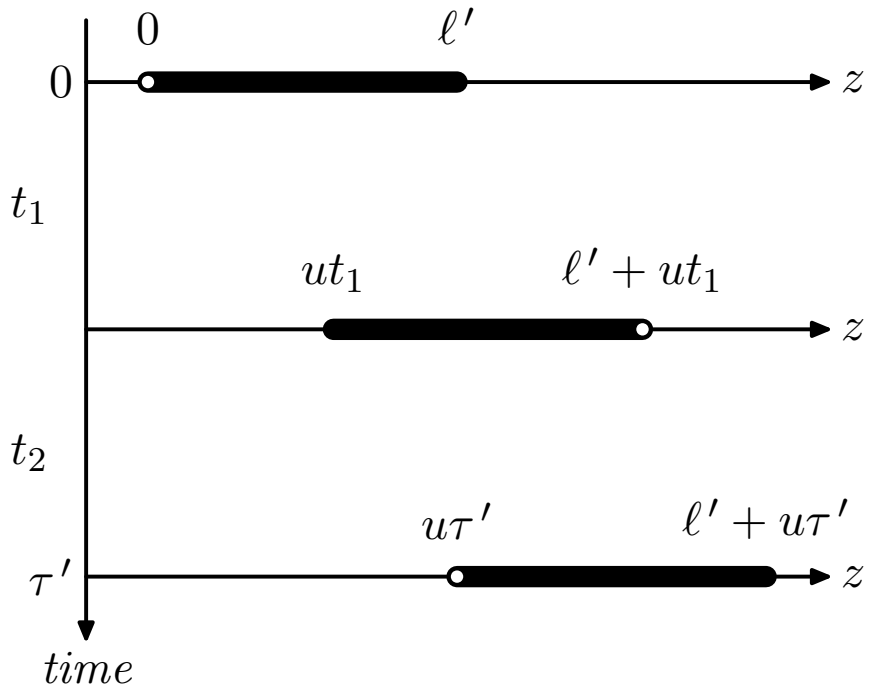
$$(c\tau'/2)^2 = \ell^2 + (u\tau'/2)^2$$
$$\tau'^2(c^2 - u^2) = 4\ell^2$$
$$\tau'^2(1 - u^2/c^2) = 4\ell^2/c^2 = \tau^2$$

therefore

$$\tau' = \frac{\tau}{\sqrt{1 - (u/c)^2}}$$

This clock has the same longer beat

parallel dimension ℓ'



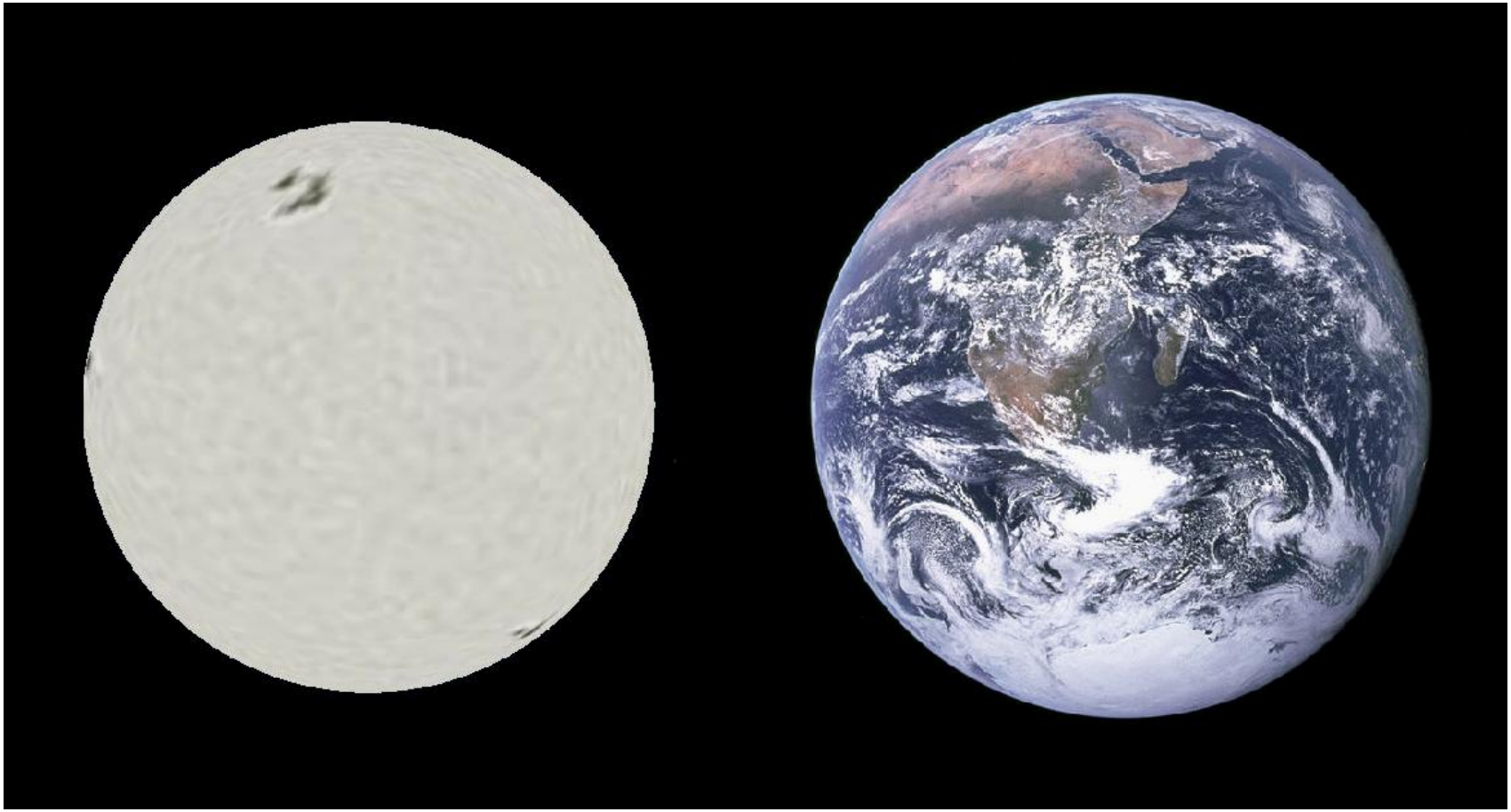
Parallel dimensions become shorter!

$$t_1 + t_2 = \tau'$$
$$ct_1 = \ell' + ut_1$$
$$ct_2 = \ell' + ut_1 - u\tau'$$

this implies

$$\ell'_{\|} = \ell_{\|}\sqrt{1 - (u/c)^2}$$

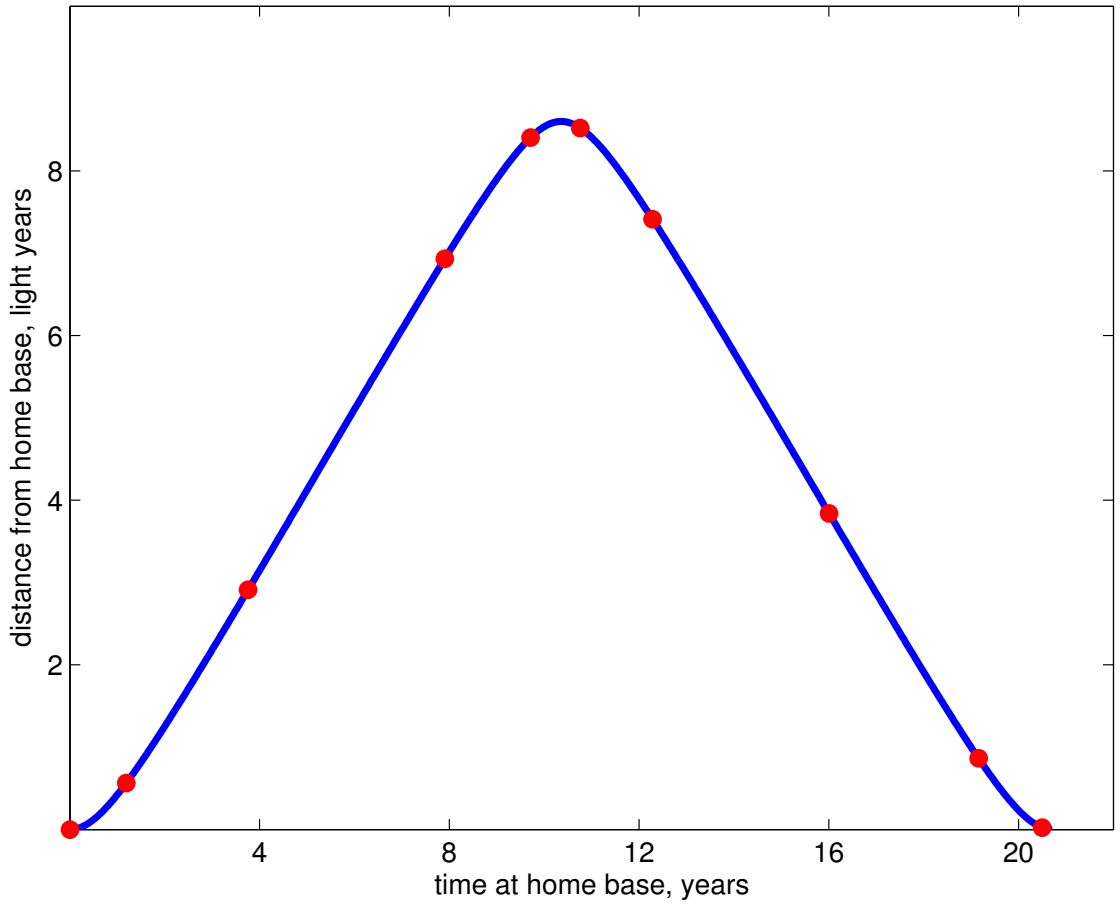
Sirius B, a white dwarf



Twin paradoxon

- Castor (ground personnel) und Pollux (astronaut)
- excursion to Sirius (8.6 light years)
- rocket accelerates 1.0 g
- turn upside down after 1/4 and 3/4 of journey
- upon return, Castor is 21 years older
- ... and Pollux only 9 years!

Time at ground and on board



Tiny effect...

- a pilot flies for 10 years with 1080 km/h $=$ 0.3 km/s

$$v/c = \frac{0.3}{300,000} = 10^{-6}$$

$$\frac{1}{\sqrt{1-(v/c)^2}} = 1 + 0.5 \times 10^{-12}$$

- this makes 0.47 ms more lifetime
- put otherwise, all others are 0.47 ms older

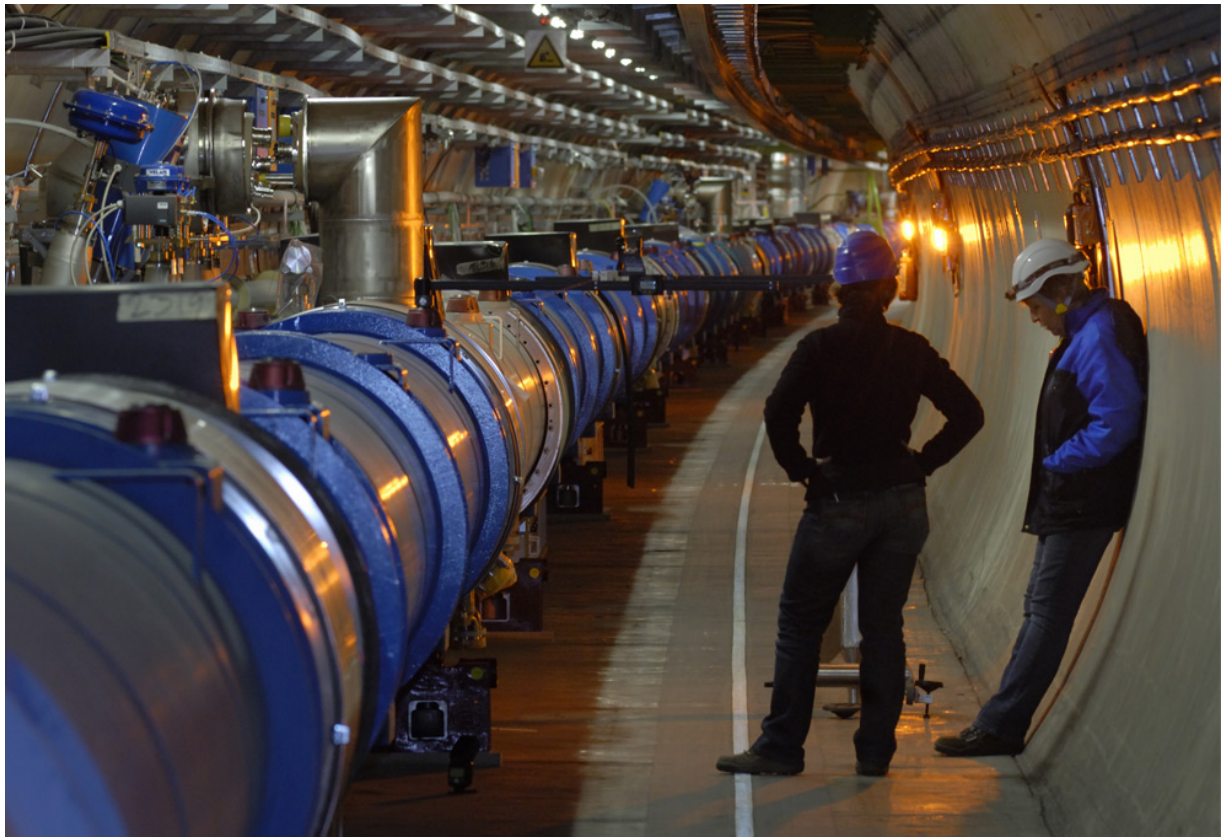
But...

- a mass m has energy

$$E = \frac{mc^2}{\sqrt{1-(v/c)^2}} = mc^2 + \frac{m}{2}v^2 + \dots$$

- nuclear fission and fusion
- elementary prticles (LHC CERN)
- GPS

CERN Large Hadron Collider



Fukushima Nuclear Power Plant

Global Positioning System

- GPS - how does it work?
- technical problems
- basic problems
- *No GPS without Einstein!*

Thank you for listening!

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