Einsteins theory of relativity

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26/10-2018

Special relativity

- The ether and Maxwells equations
- Two postulates
  - Laws of physics are the same in all inertial reference frames
  - Speed of light is constant
- Ground-breaking new ideas
  - Space and time is not independent
  - Simulationous depends upon reference frames
  - Synchronize if: $t_b - t_a = t_c - t_b$

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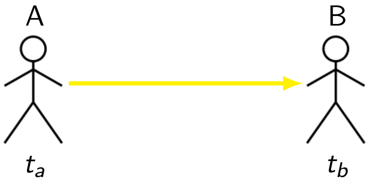

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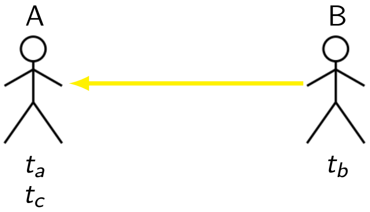

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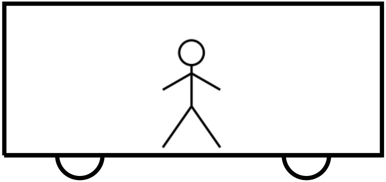

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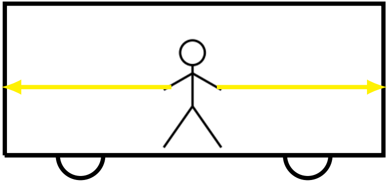

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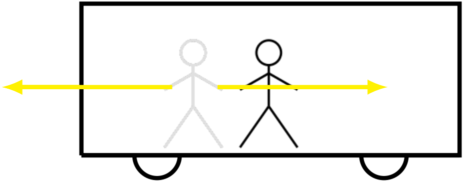


Lorentz transformation

Assuming the two postulates, the transformations between two inertial reference frames moving with a velocity v relative to eachoter in the x-direction is given by the Lorentz transformations.

$$t' = \gamma(t - vx/c^2)$$
$$x' = \gamma(x - vt)$$
$$y' = y$$
$$z' = z$$

where :

$$c = \text{Speed of light}$$
$$\gamma = \frac{1}{\sqrt{(1 - v^2/c^2)}}$$

Consequences of special relativity

$v = 0.87c$

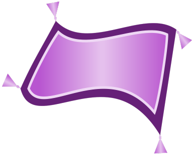
$\gamma = 2$

$x_1 =$ Back of the carpet

$x_2 =$ Front of the carpet

$t_1 =$ Start of flight

$t_2 =$ End of flight



Flying on the magic carpet is the primed reference frame

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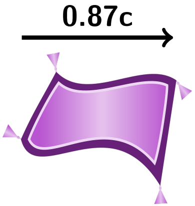

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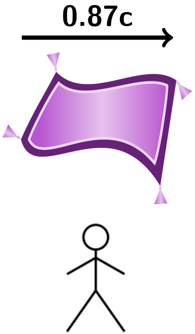

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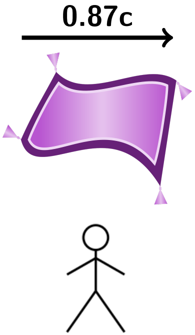

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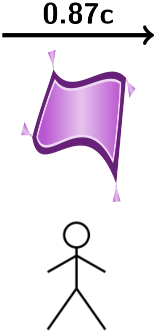

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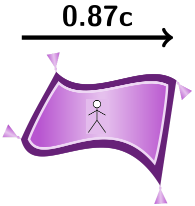

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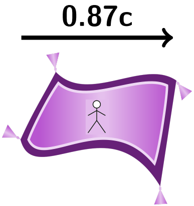

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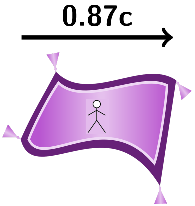

My two hour ride was only one hour(:

Flying on the magic carpet is the primed reference frame

In the real world

- Atomic clocks in flights
- Muons actually reach the earth
- Particle accelerators

Picture by Dave L. Jones

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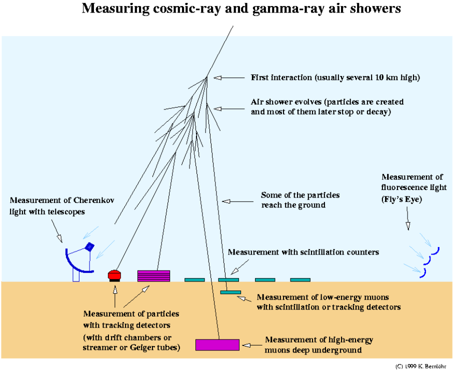

Figure by K.Bernkör

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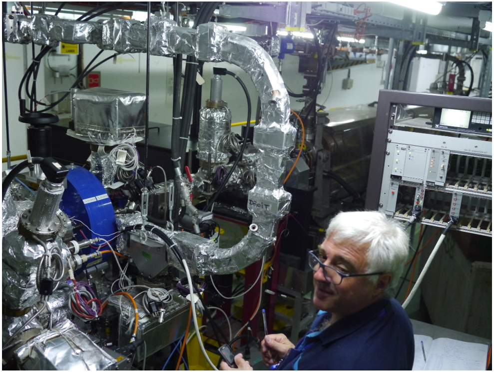

Photo by K.Sjøbæk

General relativity

Is gravity acceleration

- In 1907 Einstein had the “happiest thought of his life”
- There is no difference between being in an accelerated elevator in space or being in a gravitational field
- This was a continuation of the the universality of free fall

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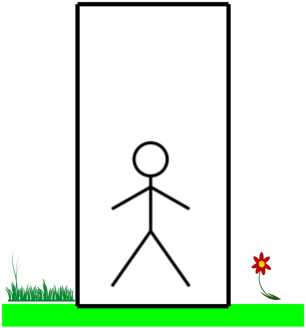

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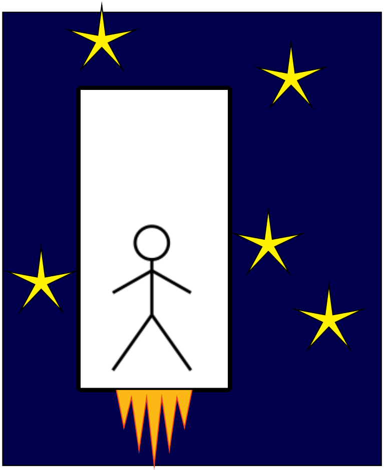

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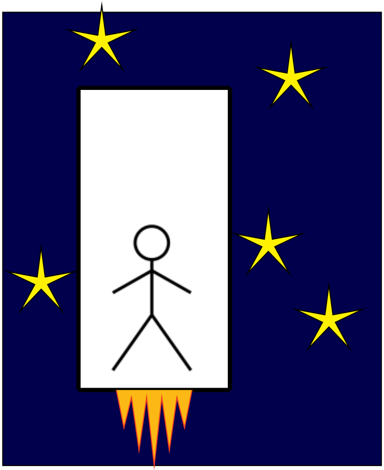

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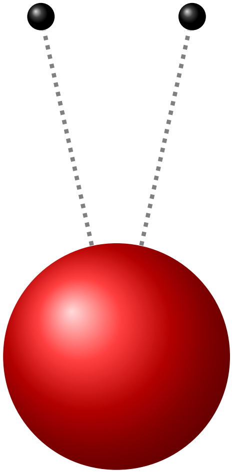

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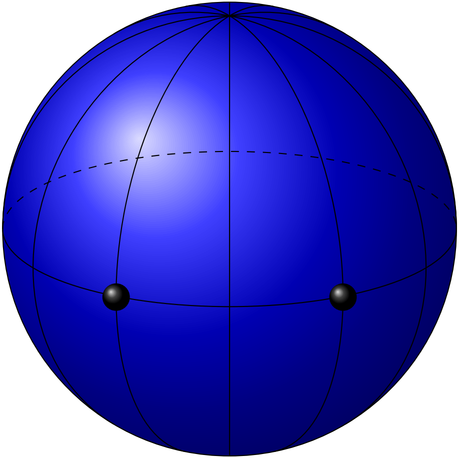

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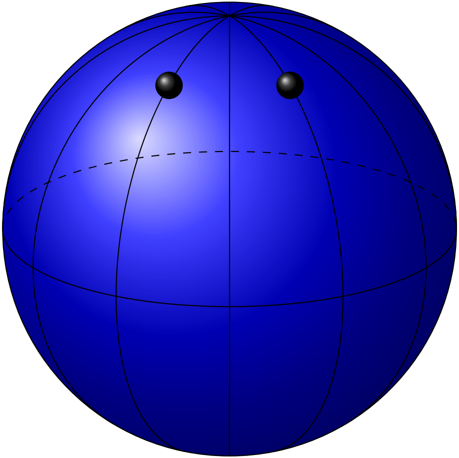

A geometrical model for gravity

- General relativity describes spacetime as a manifold
- A manifold can describe a space that locally is flat, but is curved on larger scale
- The surface of a sphere:
  - Curved on larger scale
  - Locally flat
- Spacetime according to general relativity
  - Locally it a free falling coordinate system, the weak equivalence principle holds
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- Describing spacetime as a manifold gave the theory a mathematical framework (tensor analysis)

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Einsteins field equations

- Left side describes the curvature of space
- Right side describes the content of space
- The metric, $g_{\mu\nu}$, is what we want to solve for
- The metric is the input to the geodesic equation
- Only solvable in special cases, for instance the Schwarzshild solution

Field equations

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + g_{\mu\nu}\Lambda = \frac{8\pi G}{c^4} T_{\mu\nu}$$

$$\begin{aligned} R_{\mu\nu} &= \text{Ricci curvature tensor}(f(g_{\mu\nu})) \\ g_{\mu\nu} &= \text{The metric} \\ \Lambda &= \text{Cosmological constant} \\ T_{\mu\nu} &= \text{Stress-energy tensor} \end{aligned}$$

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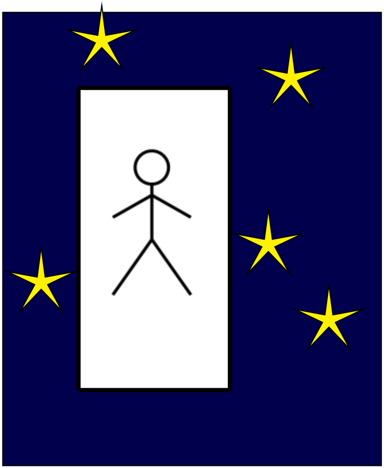
Gravitational redshift

- Line segment λ
- $y'(y+\lambda) = y + \lambda + \frac{g}{2}\left(\frac{y+\lambda}{c}\right) - y + \frac{g}{2}\left(\frac{y}{c}\right) = \lambda + \frac{gy\lambda}{c^2} + \frac{1g\lambda^2}{2c^2} \approx \lambda + \frac{gy\lambda}{c^2}$
- As seen the the wavelength increases as a function of y, this is the gravitational redshift
- The frequency of the lights can not be changed, because then the light would be fill up the elevator, more lightwaves in than out
- In order to get all the waves out of the elevator the time also has to move faster at



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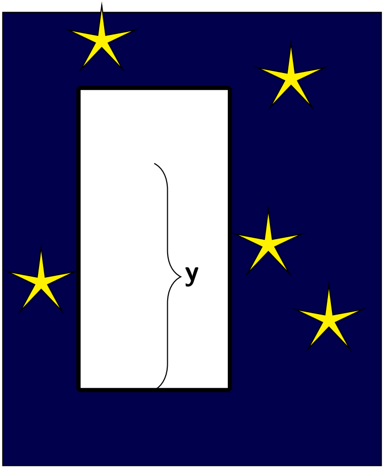

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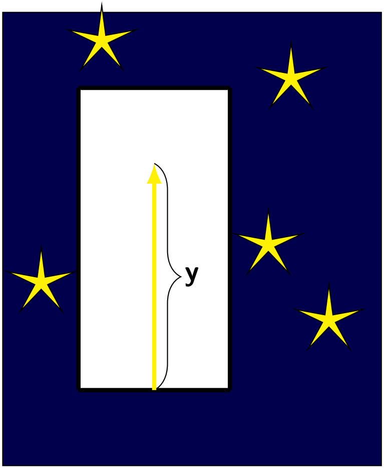
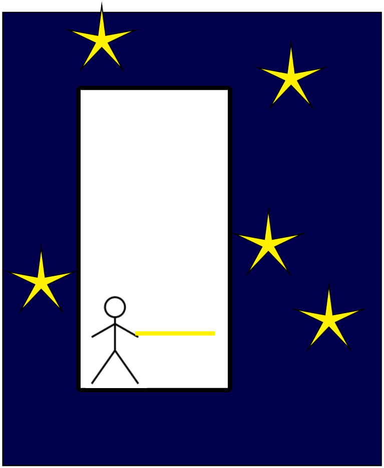


Gravity and light

- The equivalence principle predicts that light is being bent by gravitational fields
- What happens to position of stars
- This can be tested, when there is a solar eclipse



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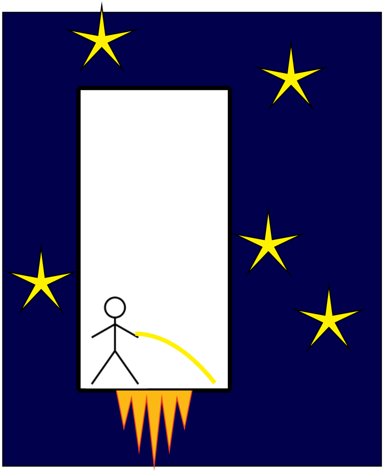

Solar eclipse

- Light is bent by the sun
- Wrong position of stars
- Only possible to see during a solor eclipse
- Solar eclipse 1919
- No bending, Newton bending or general relativity bending
- GR bending predicted by the Schwarzschild solution
- Turned out that GR was right