



**Space,
Time &**

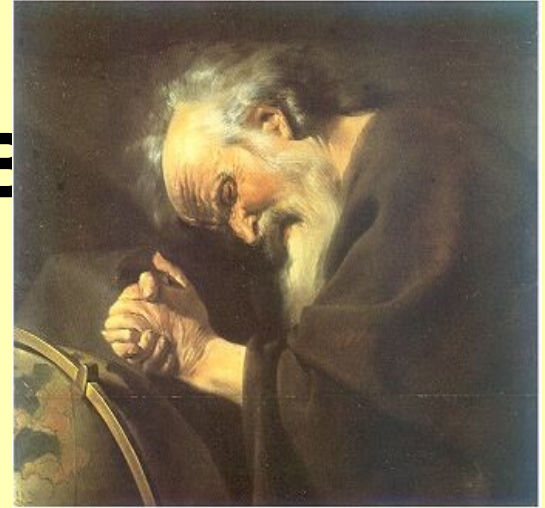
Space-time

Franjo Sokolić

PMF, Split

Time: the idea of change

- **Heraklit (~ 550 - 440 B.C.)**



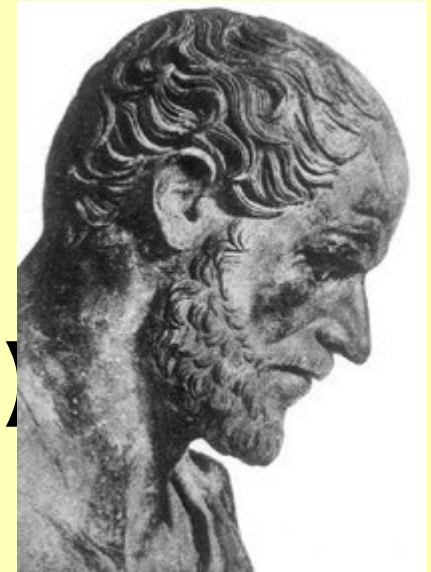
- „Panta rhei”
- „Nothing is eternal except change”
- „No man ever steps in the same river twice”
- Intuitive idea that everything changes

Paradox of time and motion

- **Parmenid (~ 500 BC)**
- **Zenon (490 - 430 BC)**
- The idea of change implies: How something can exist and not exist at the same time?
- Zenon paradoxes: Ahiles and the turtle; ...

Aristotel conception of change

- **Platon (428 - 348 BC)**
- Myth of the circular motion
- **Aristotel (384 - 322 BC)**
- Stationary Cosmos
- Description of change and motion
- Fundamental difference between the rest and the motion
- Motion: natural and violent
- Time as a measure of motion



What is motion?

- What is the relation between matter, time and space?
- Can they exist independently of each other?
- Is it possible to define motion if there is only one body in the Universe?
- Problem of the reference frame

Galileo's description of motion

- **Galileo Galilei (1564 -1642)**

- The principle of relative motion
- Heliocentric system
- Inertial motion
- The same laws apply to Earth and Universe
- Galileo's transformations:

$$\mathbf{r}' = \mathbf{r} - \mathbf{V} t$$

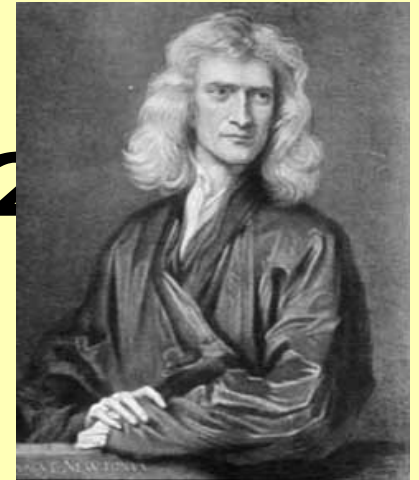
$$\mathbf{v}' = \mathbf{v} - \mathbf{V}$$

$$\mathbf{a}' = \mathbf{a}$$



Space and time in classical mechanics

- **Isaac Newton (1642 - 1727)**
- Absolute space and time
- Time exists independently of the motion
- Newton's principles of mechanics

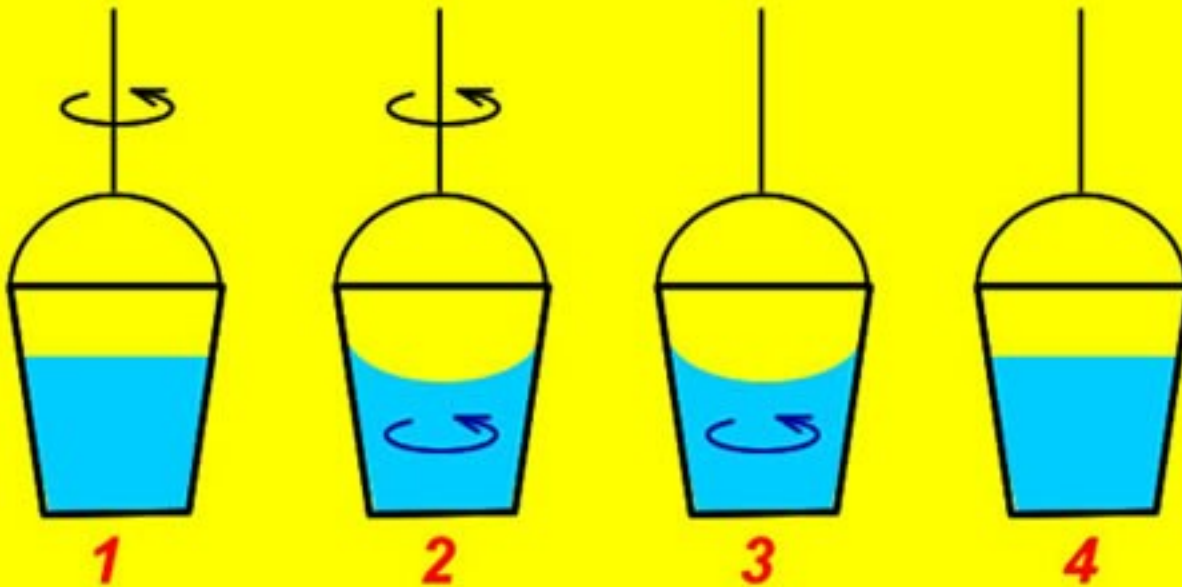


$$\vec{F} = \frac{d}{dt}(m\vec{v})$$

- Universal gravitational law

Absolute motion

Newton's bucket experiment



Leibniz's critics of Newton

- **Wilhelm Leibniz (1646 - 1716)**



- Correspondence Leibniz - Clarke
- Space: relation between bodies
- Identity of indiscernibles
- Principle of sufficient reason

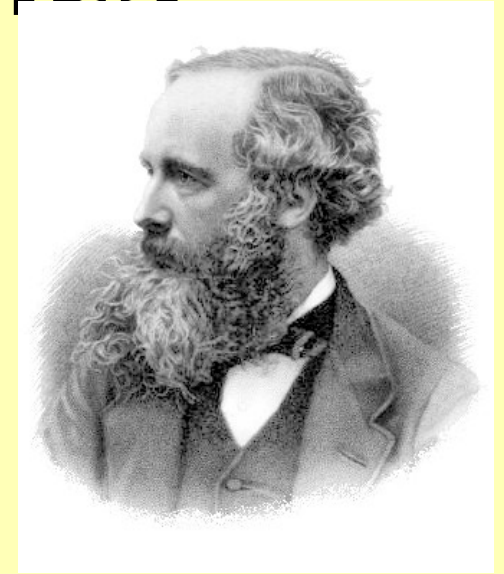
Critics of the absolute motion

- **Ernst Mach (1838 - 1916)**
- Positivism
- Origin of inertia
- Geometry as a convention



The laws of electrodynamics

- **James Clerk Maxwell
(1831 -1879)**



$$\left(\nabla^2 - \mu\epsilon \frac{\partial^2}{\partial t^2} \right) \mathbf{E} = 0$$

$$\left(\nabla^2 - \mu\epsilon \frac{\partial^2}{\partial t^2} \right) \mathbf{B} = 0$$

$$c = \frac{1}{\sqrt{\mu\epsilon}}$$

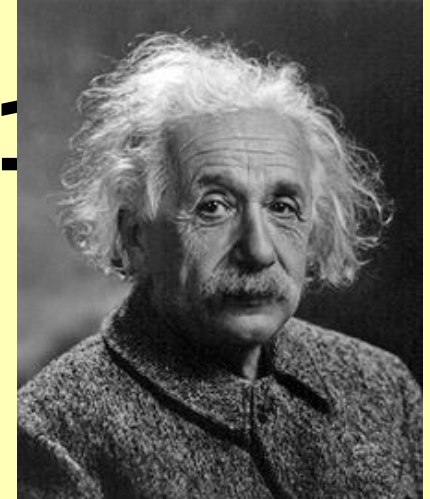
Speed of light

Theory of relativity: space-time

- **Albert Einstein (1879 - 1955)**

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- Special theory of relativity
- Notion of simultaneity is relative
- Space and time are related
- Lorentz transformations

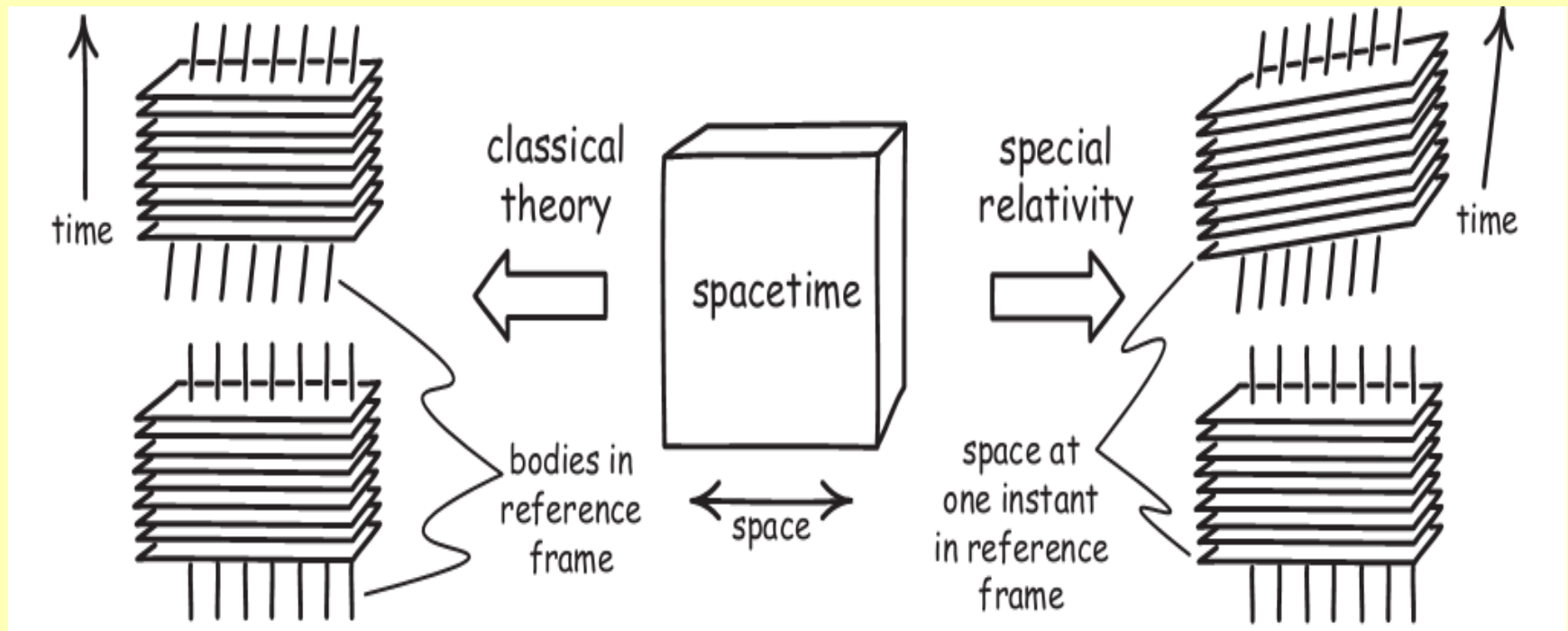


$$x' = \frac{x - vt}{\sqrt{1 - \frac{v^2}{c^2}}}$$

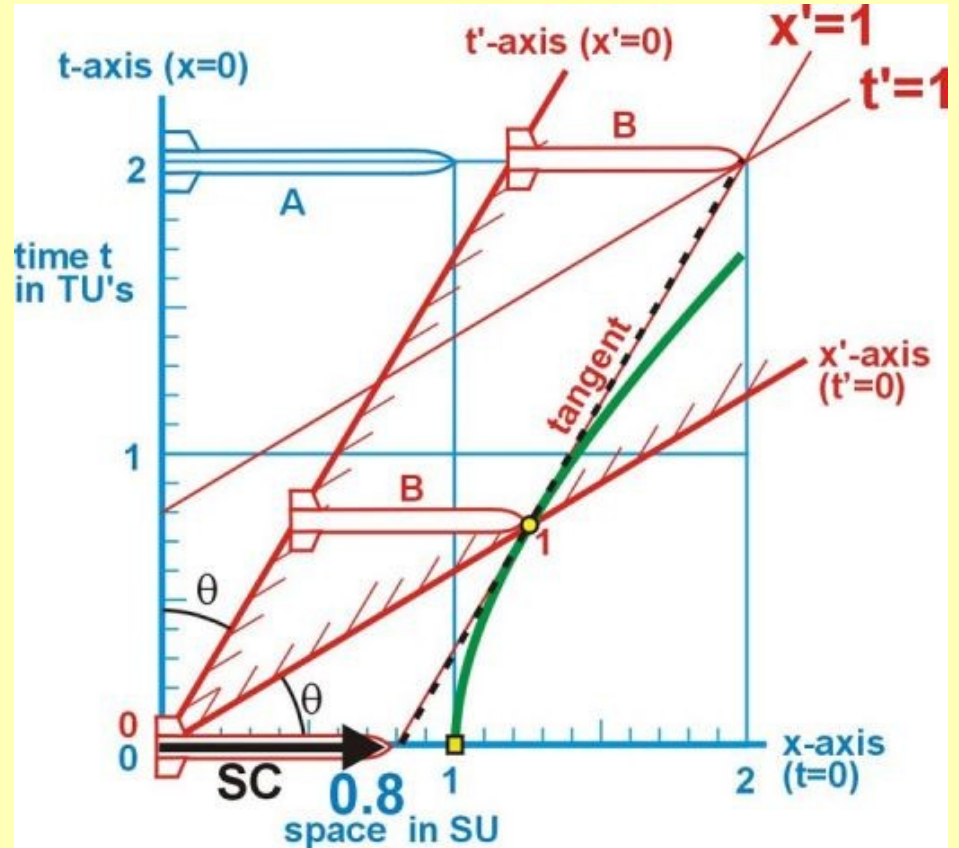
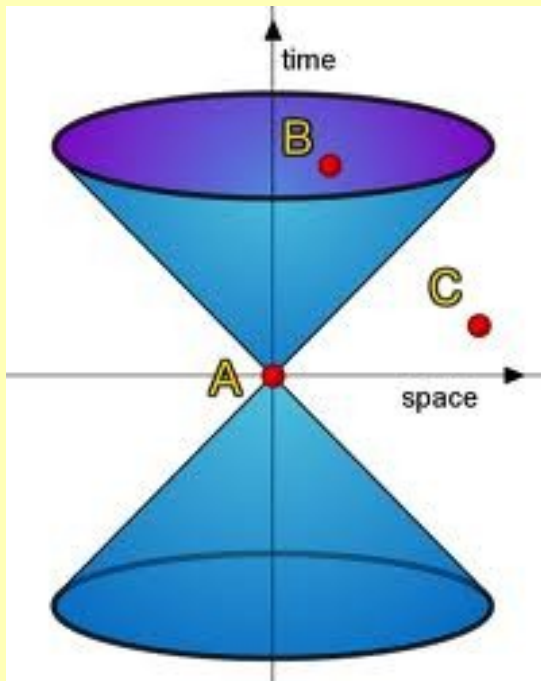
$$y' = y$$
$$z' = z$$

$$t' = \frac{t - \frac{v}{c^2} \cdot x}{\sqrt{1 - \frac{v^2}{c^2}}}$$

The notion of space and time in classical physics and in special theory of relativity

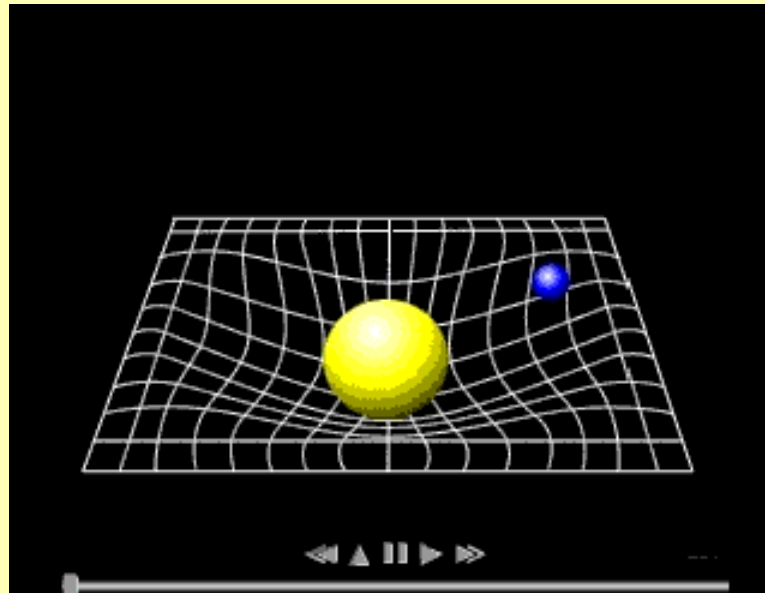


Special theory of relativity



General theory of relativity

- Equivalence of inertial and gravitational mass
- Gravitation – property of space
- Noneuclidian geometry



Time in quantum mechanics

- Quantum mechanics paradox (Einstein, Podolsky, Rosen)
- Locality
- Separability

- What about the notion of time?
- Does time really exist?