Astronomy 350L

(Spring 2005)

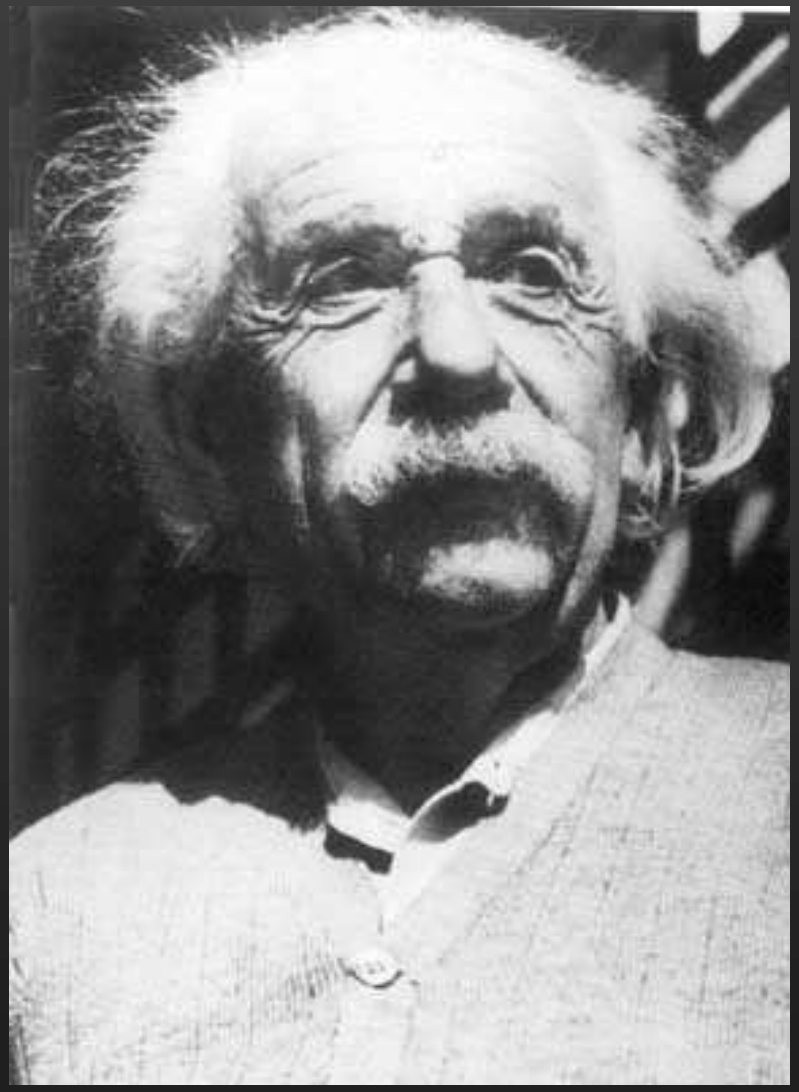
The History and Philosophy of Astronomy

(Lecture 21: Einstein I)

Instructor: Volker Bromm
TA: Amanda Bauer

The University of Texas at Austin

Albert Einstein: Revolutionary of Physics

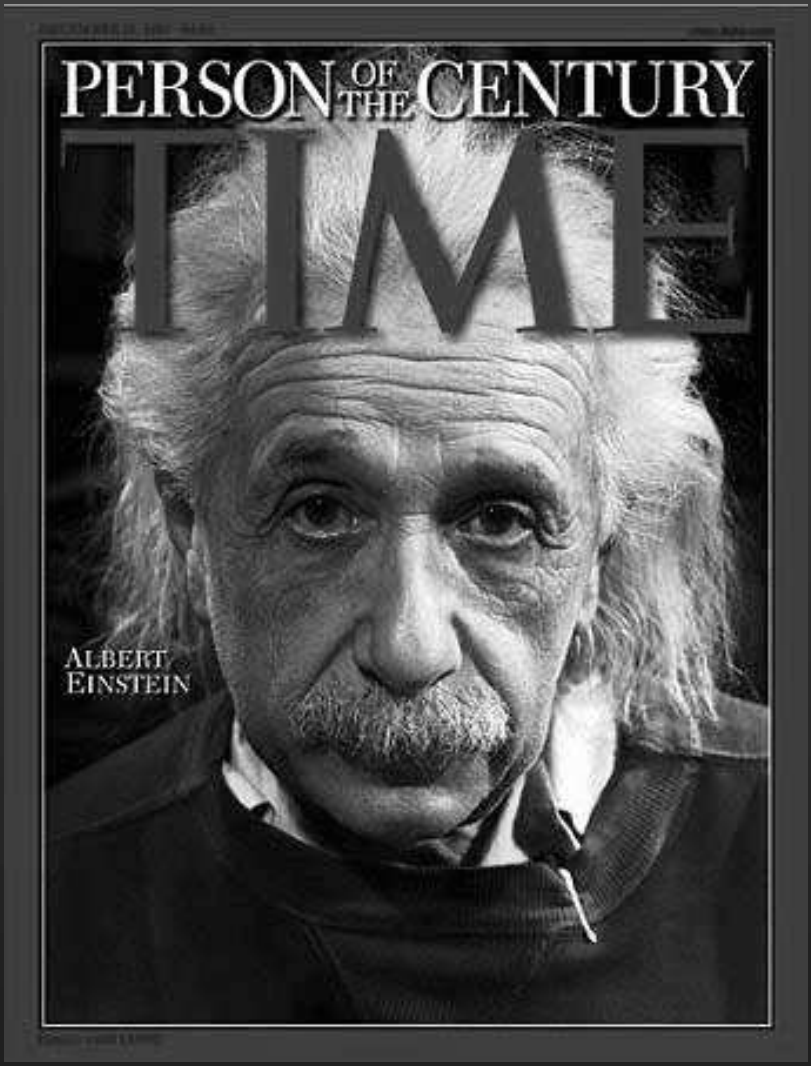


- 1879 (Ulm) – 1955 (Princeton)

- revolutionized concepts of space, time, and gravity
  - Special Relativity (1905):
    à $E=mc^2$
  - General Relativity (1915):
    à new theory of gravity

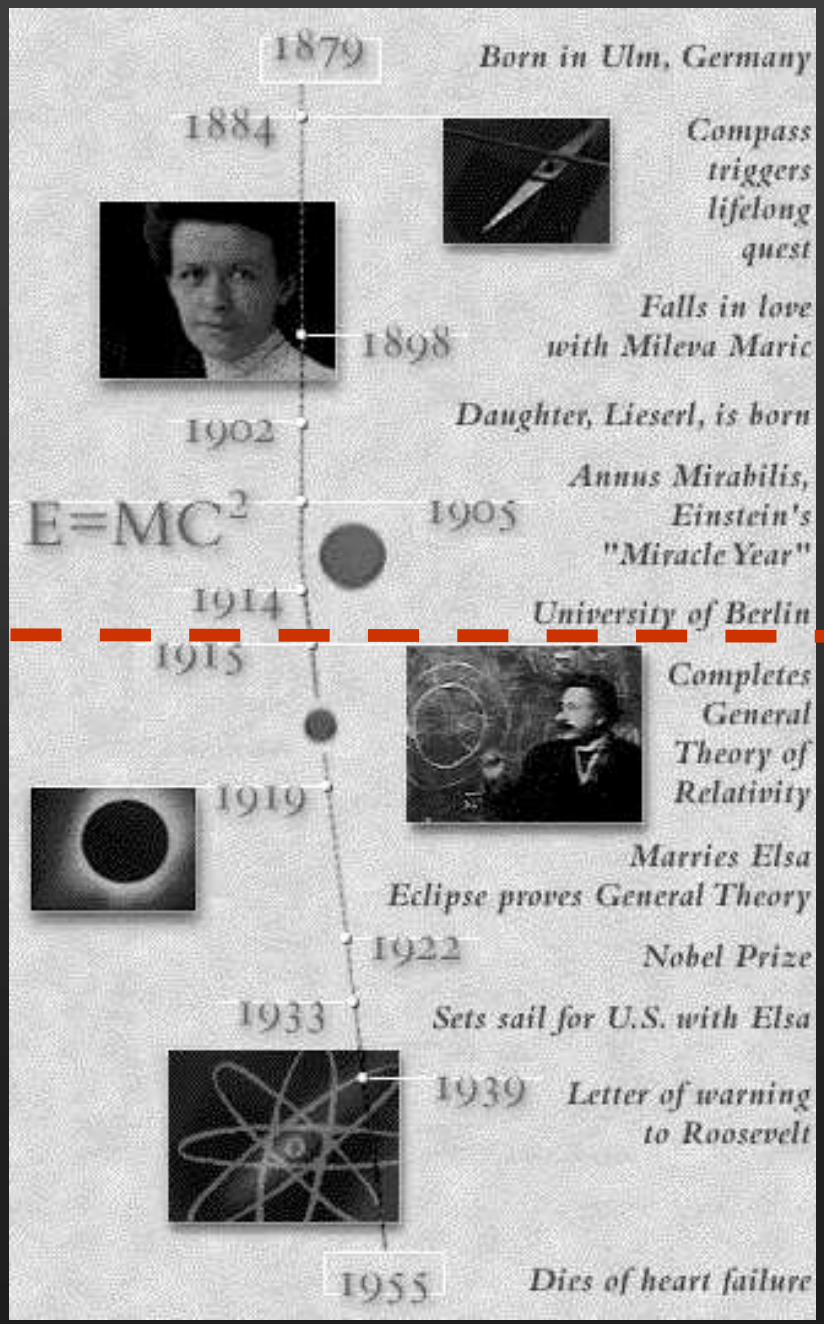
- co-founder of quantum theory
  à photons

Albert Einstein: Person of the Century



- pre-eminent scientist of 20th century
- acquired world-wide fame after 1919 (eclipse experiment proves his theory of gravity correct)
- influence in politics
  - urges FDR to build atomic bomb
  - leading supporter of pacifism

Overview: Einstein's Life

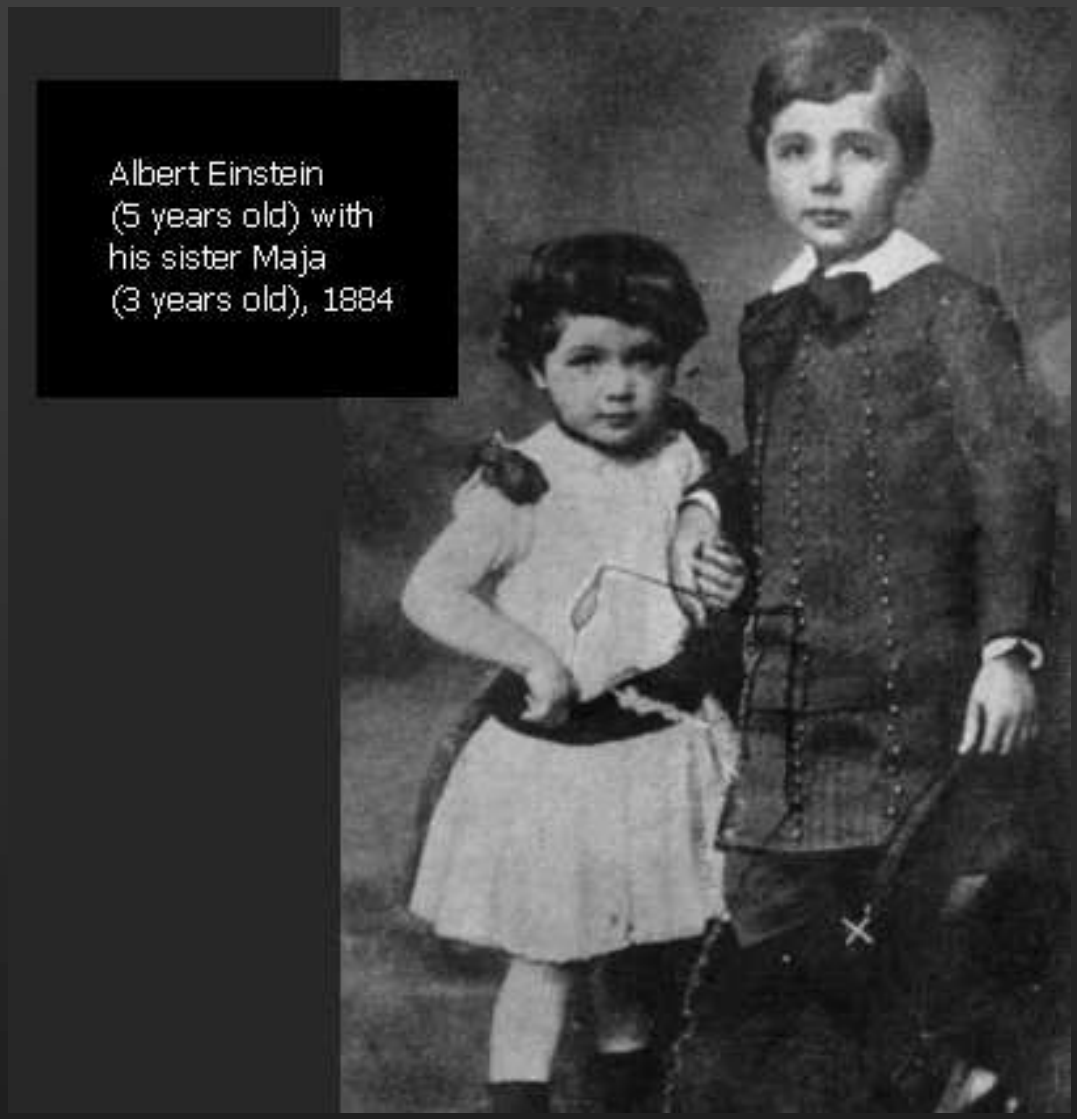


April 7

April 12

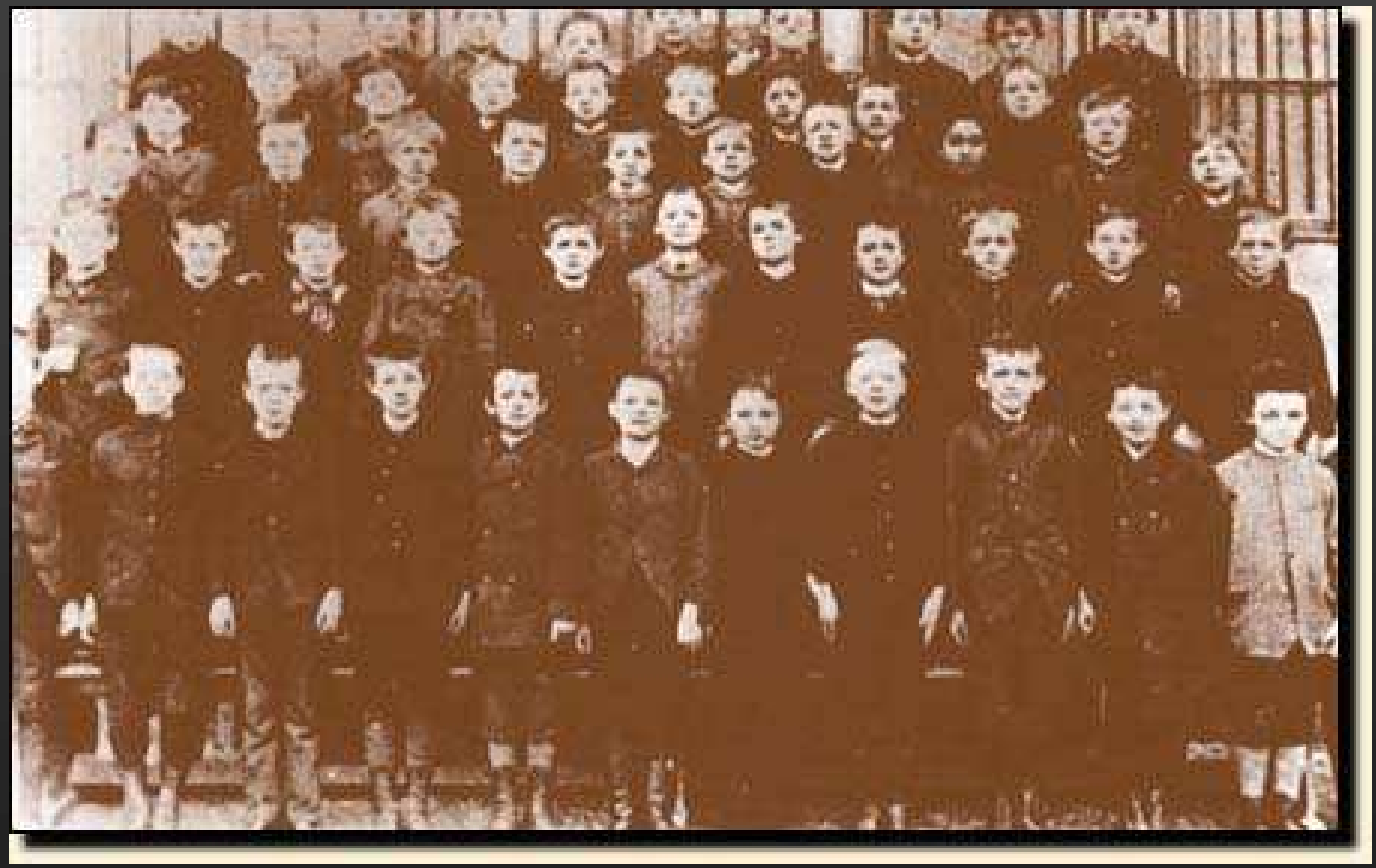
Birth in Ulm (1879)

Youth in Munich (1880-1894)



- cozy, middle-class childhood in Bavaria’s capital

Youth in Munich (1880-1894)



- traumatic experience in authoritarian school system!

Early Life in Switzerland (1895-1914)

Prep-school in Aarau (1895-1896)

- Einstein enjoys more liberal Swiss school system!

Prep-school in Aarau (1895-1896)

School leaving certificate,
Aarau, Aargau Canton,
Switzerland
October 3, 1896
The highest grade was 6

German 5
Geometry 6
French 5
Descriptive Geometry 6
English —
Physics 6
Italian 5
Chemistry 5
History 6
Natural History 5
Geography 4
Artistic Drawing 4
Algebra 6
Technical Drawing 4

- a good school leaving certificate!

University Student in Zurich (1896-1900)

- studies at Swiss Federal Institute of Technology (ETH)
- his professors don’t like him à he is too independent

Patent Office Clerk in Bern (1902-1909)

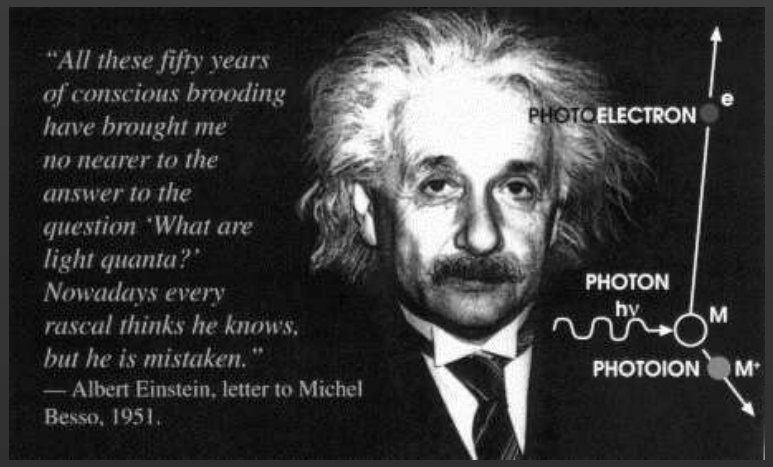
- Expert 3rd class
- 1905: Annus Mirabilis
  - Special Relativity
  - Photons
  - Reality of atoms
- Marriage and children

1st Marriage and Children

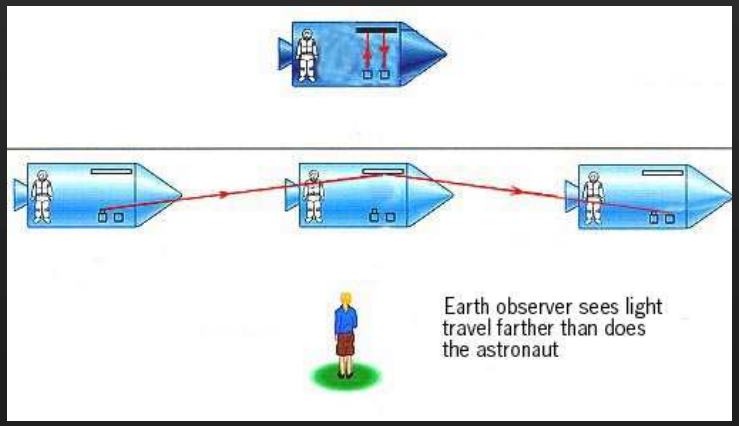
- marriage with Mileva Maric (1903-1919)

1905: Annus Mirabilis

- Quantum Theory: particles of light (photons)

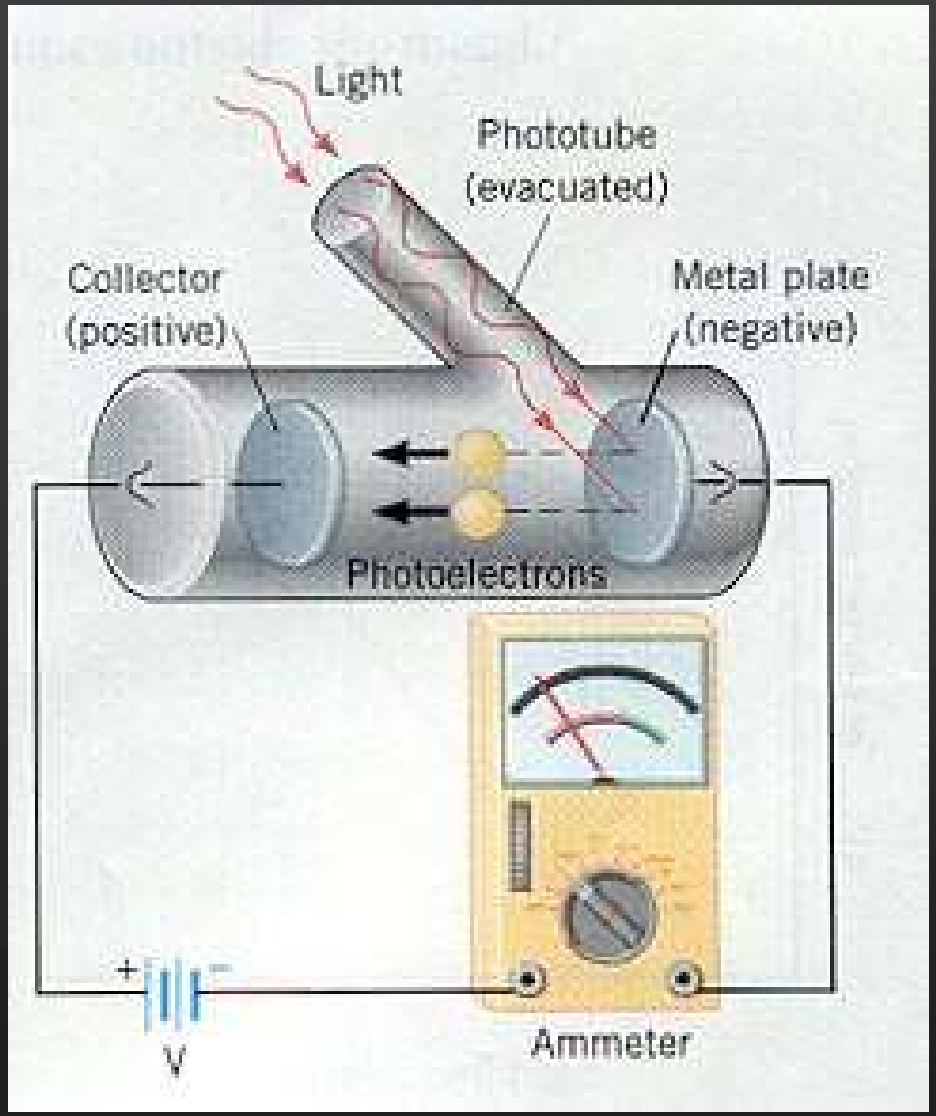


- Special Relativity: new concept of space and time



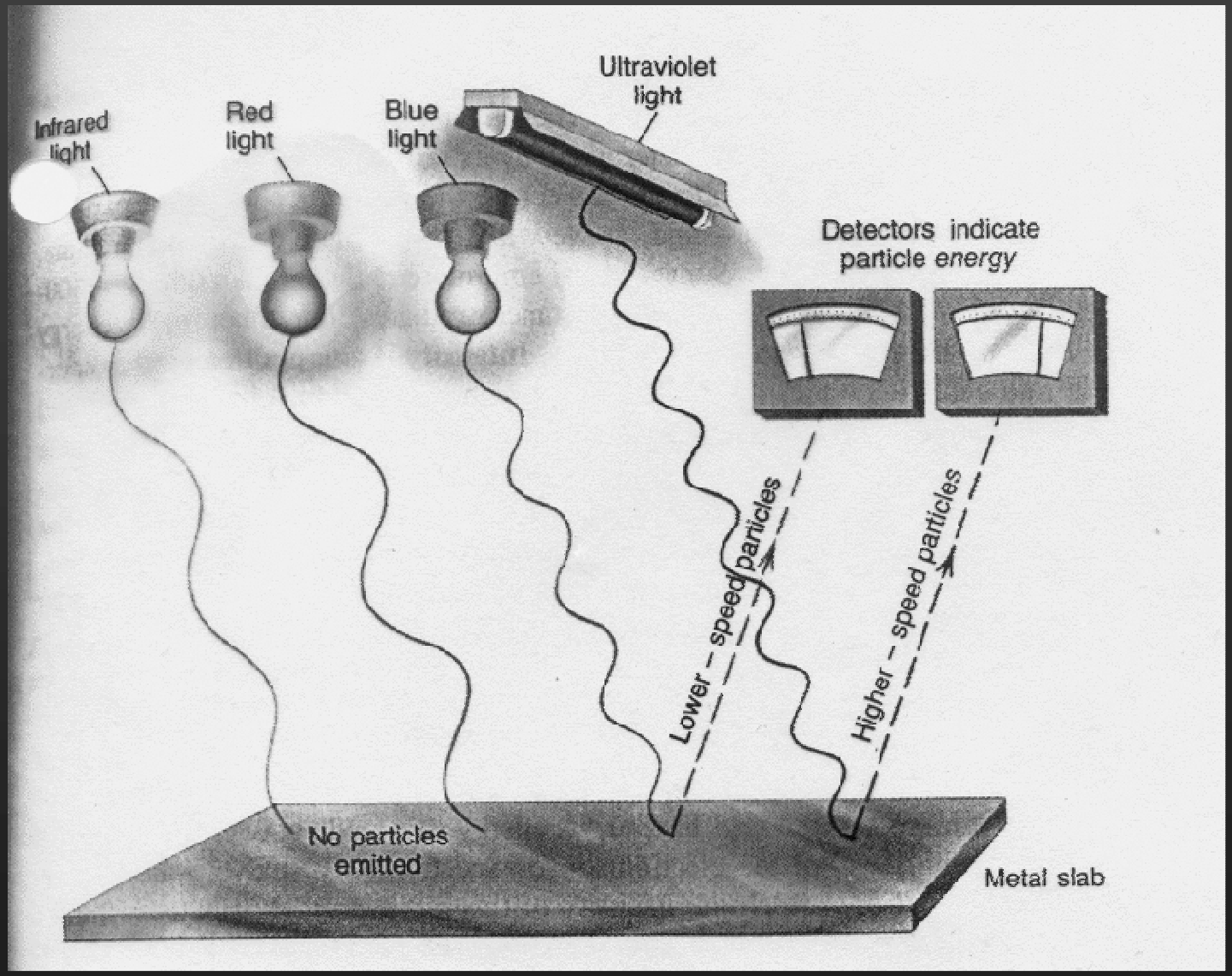
- Brownian motion: prove reality of atoms

Annus Mirabilis I: Light quanta



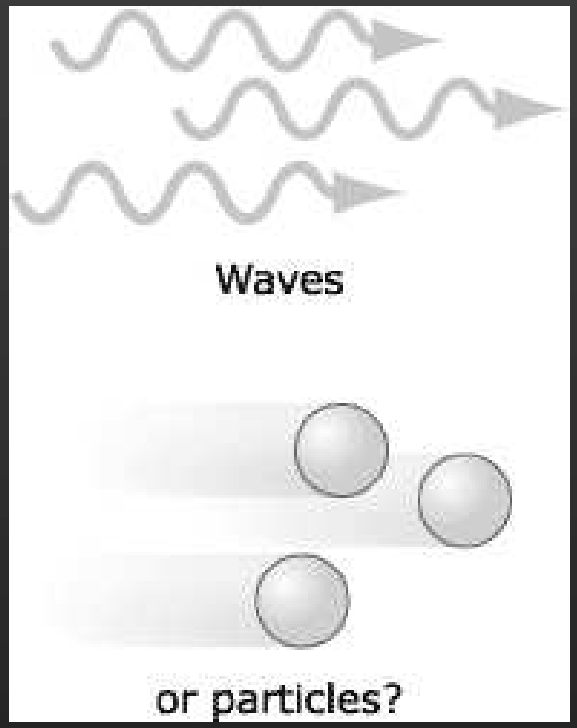
- photoelectric effect

Annus Mirabilis I: Light quanta



- Frequency counts, not intensity!

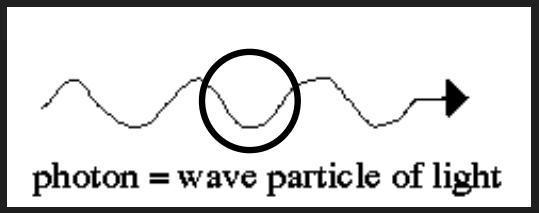
Annus Mirabilis I: Light quanta



- Einstein's idea: light can be *both* particle and wave!

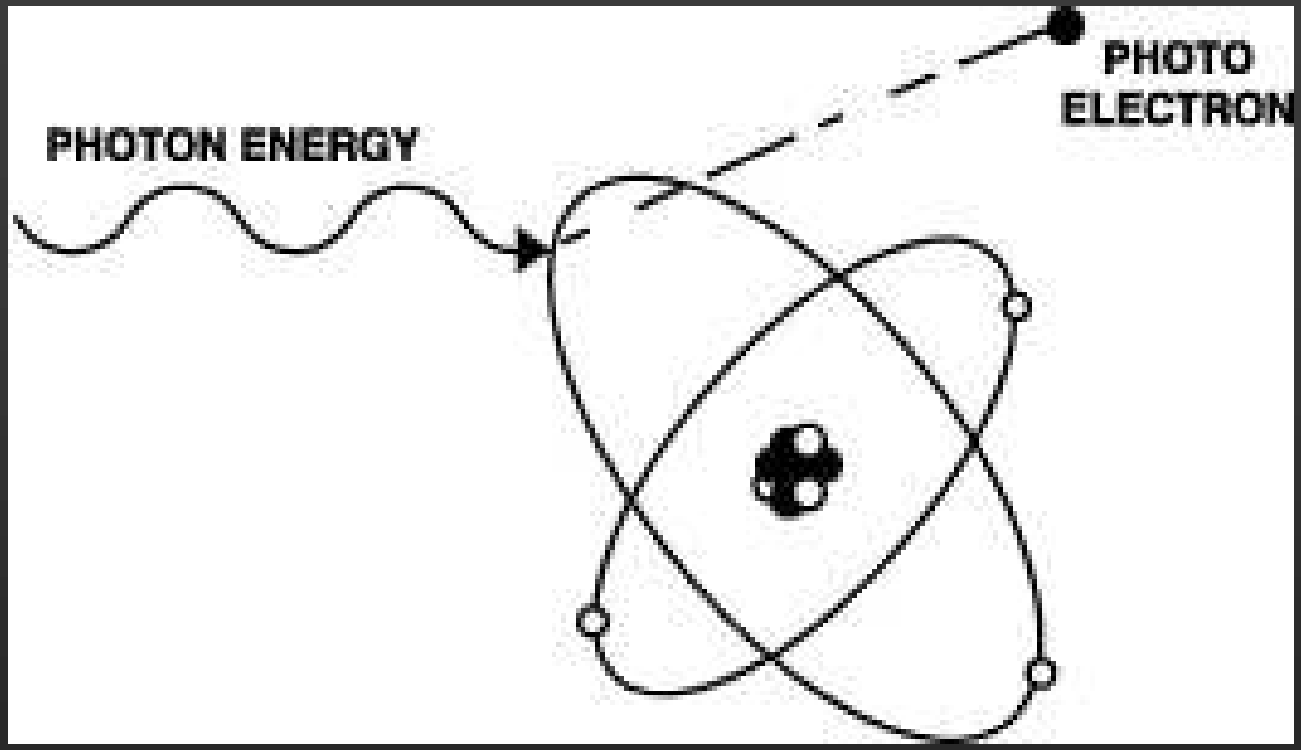
à Low energy!

à High energy!



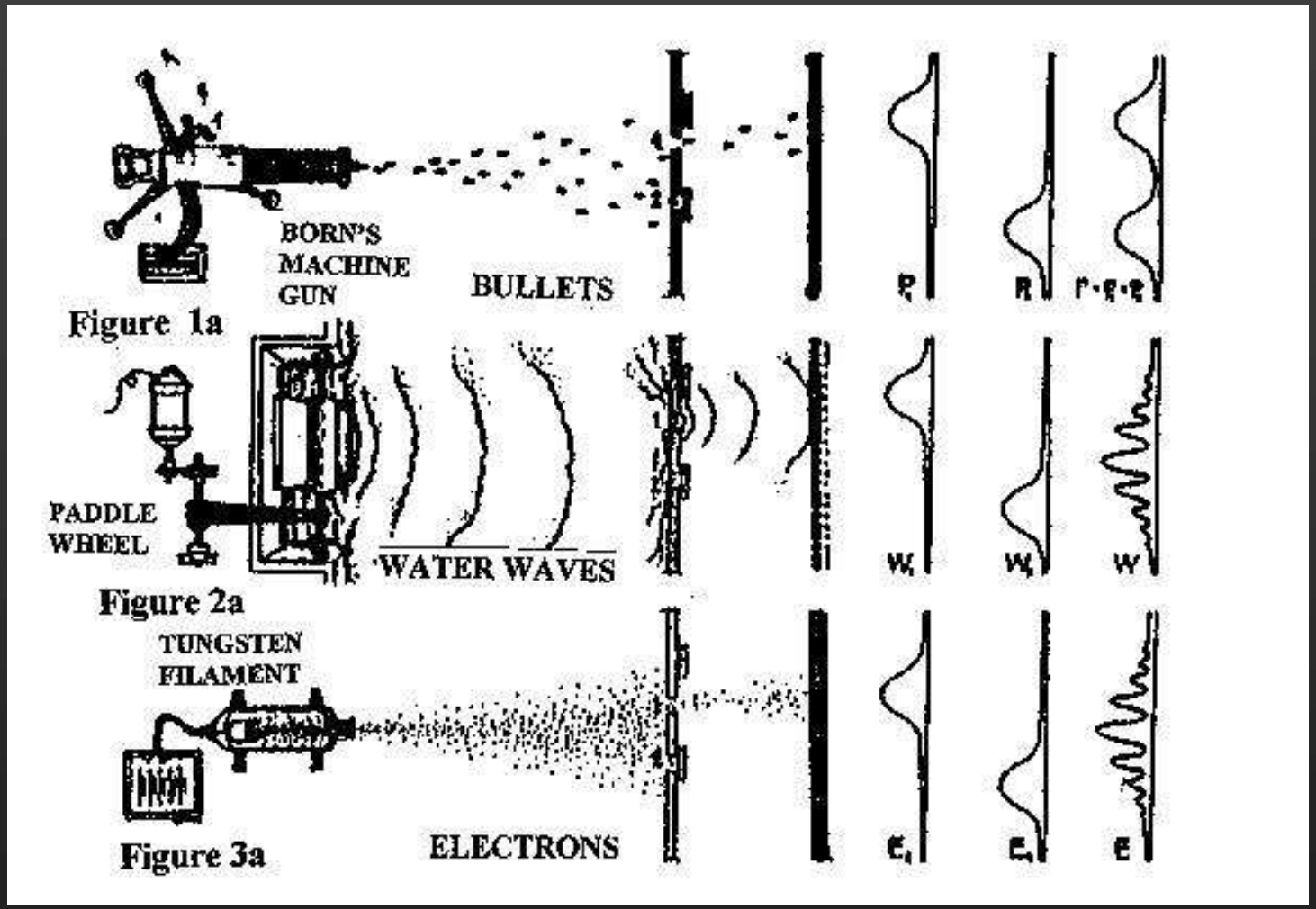
$$\text{energy} = h\nu = \frac{hc}{\lambda}$$

Annus Mirabilis I: Light quanta



- Einstein’s explanation: Need sufficiently energetic light particle (photon) à ultraviolet!

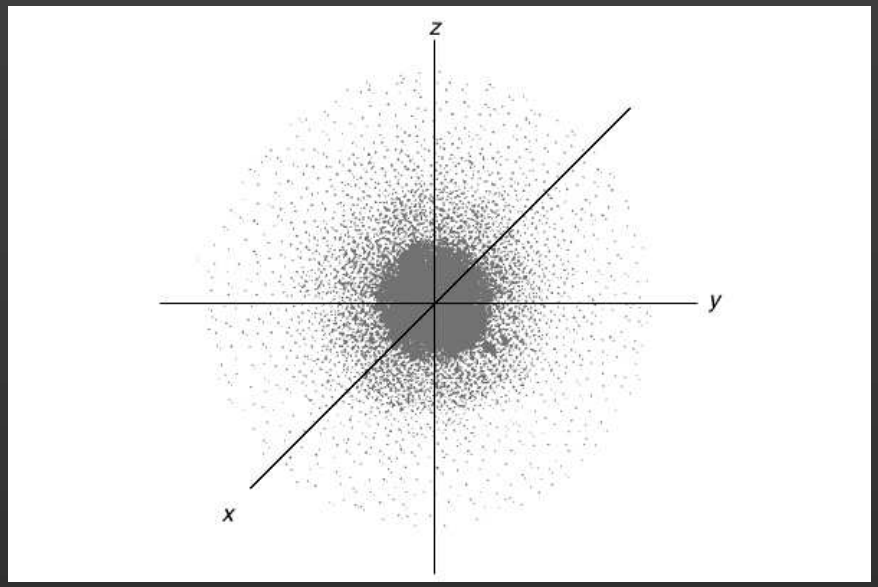
The Meaning of Quantum Theory



- Quantum theory is weird!

The Meaning of Quantum Theory

Einstein: rejects probability interpretation (“God does not play dice!”); postulates `hidden parameters’



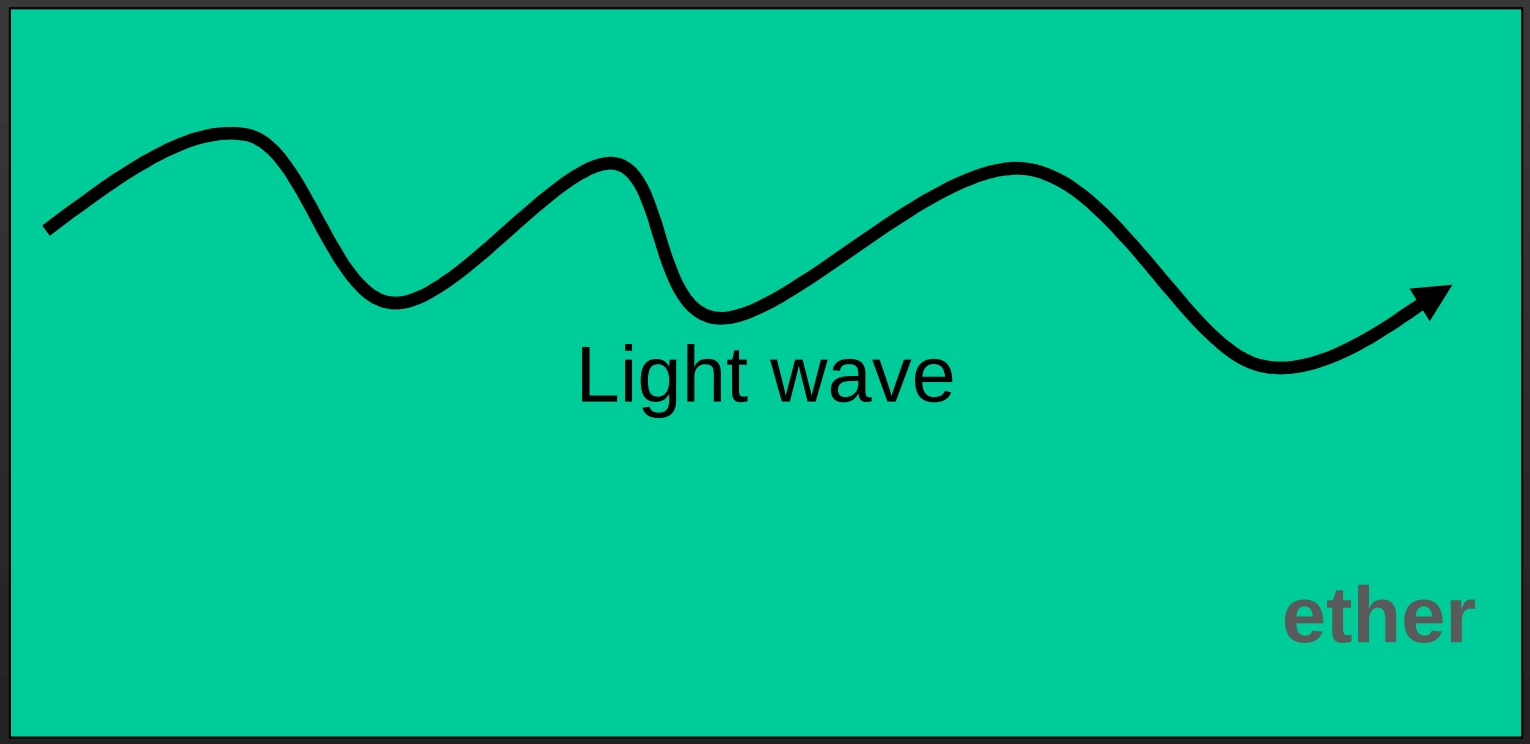
Bohr: we can only know probabilities (Copenhagen Interpretation)

Annus Mirabilis I: Light quanta

- 1921: Nobel Prize in Physics

Annus Mirabilis II: Special Relativity

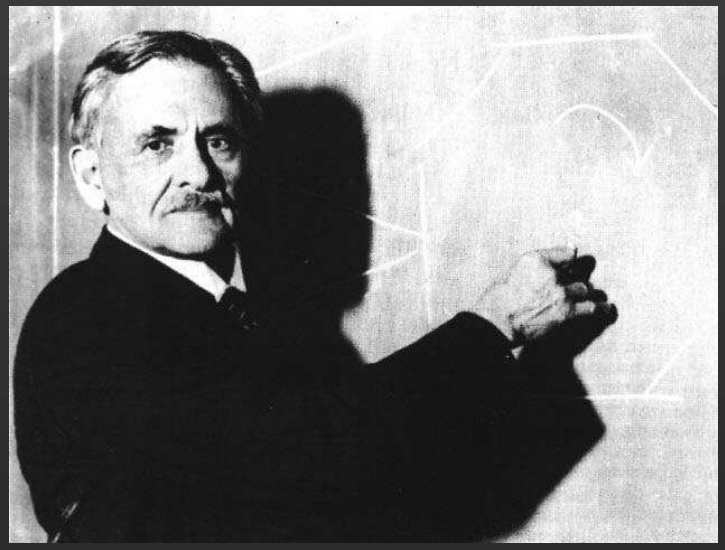
- Big question for 19th century: What is the ether?



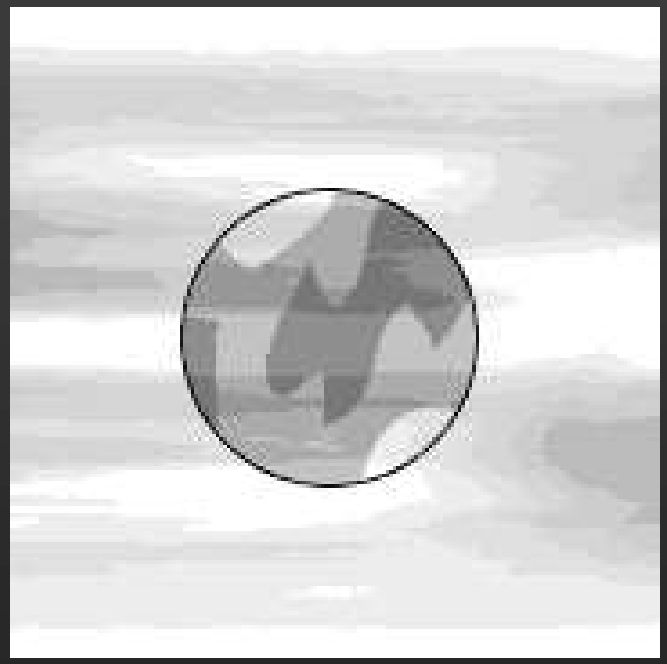
- known: speed of light (c) with respect to ether
  - c = 300,000 km s^{-1}

Annus Mirabilis II: Special Relativity

- Big question for 19th century: What is the ether?



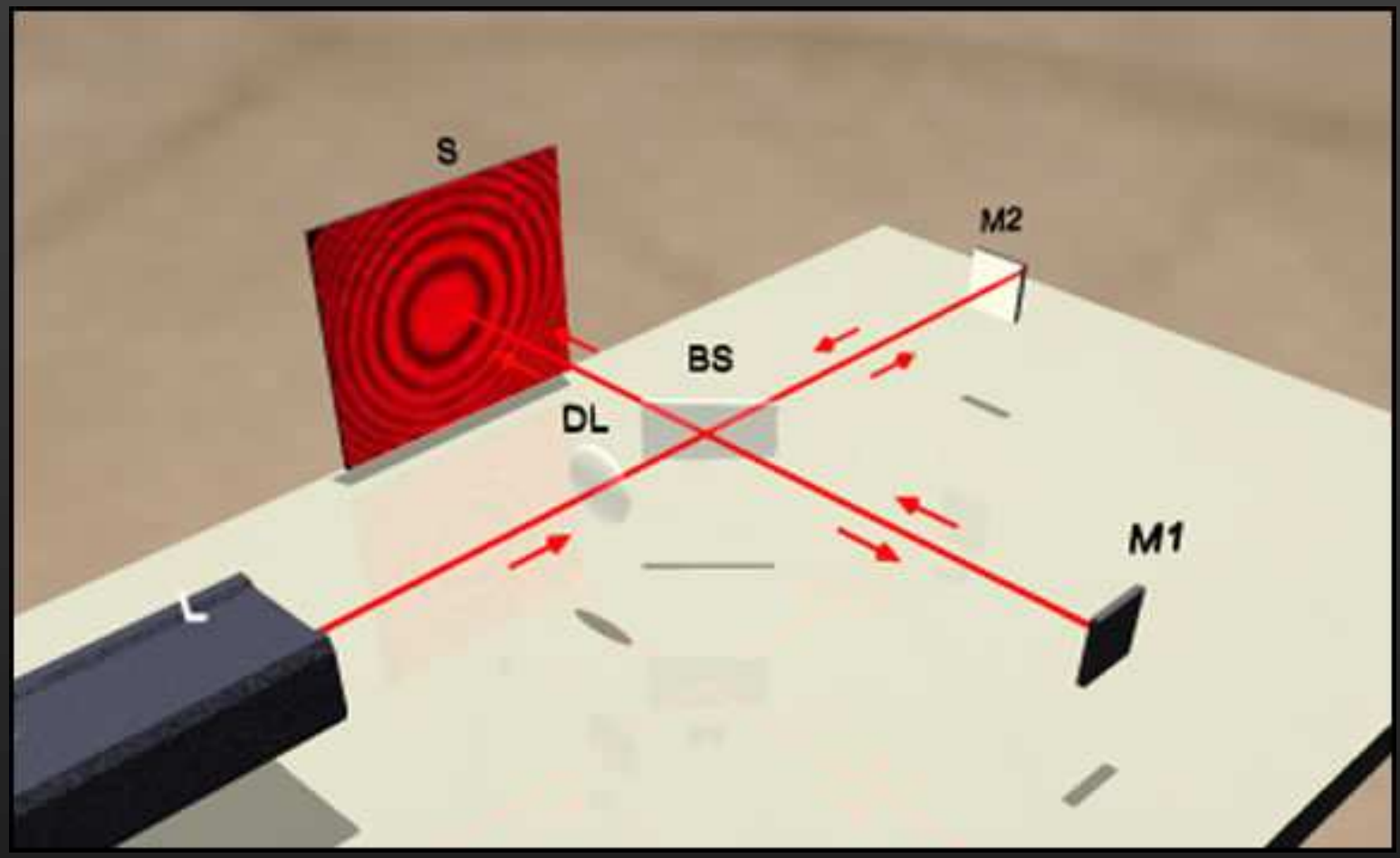
Albert Michelson (1852-1931) - America's 1st Nobel Laureate in physics (1907)



- Michelson's idea: detect effect of "ether wind"

Annus Mirabilis II: Special Relativity

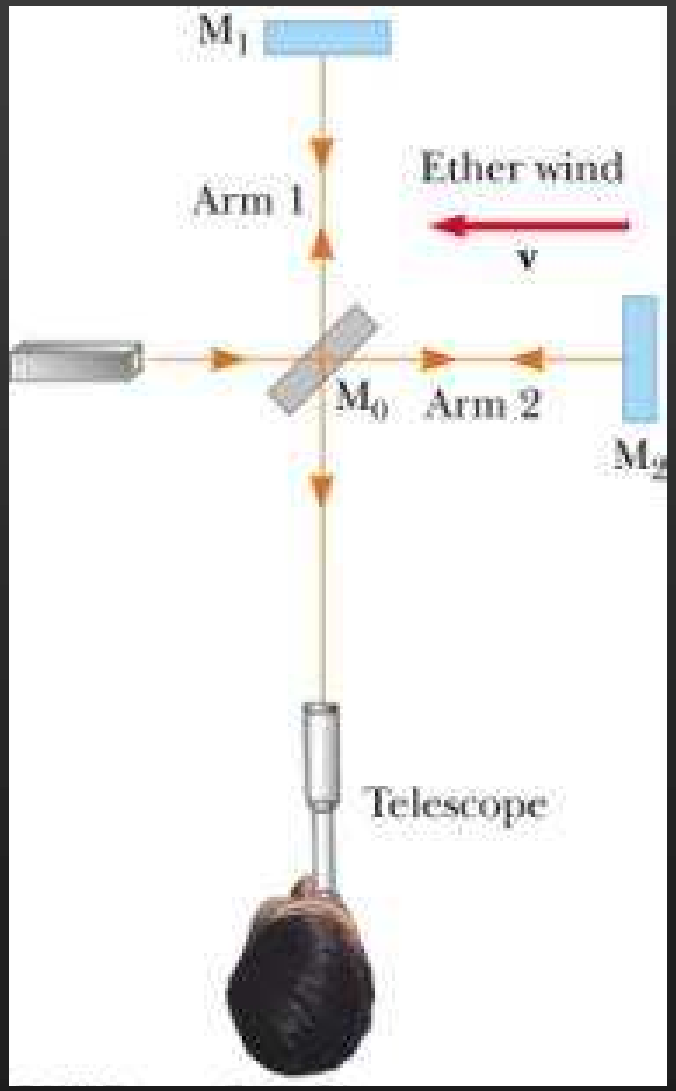
- 1887: Michelson-Morley experiment



- `Michelson interferometer': measures tiny differences in light-travel time

Annus Mirabilis II: Special Relativity

- 1887: Michelson-Morley experiment



- Shocking result: No detectable difference in light-travel time for perpendicular directions!

  à no difference in speed of light!

  à the ether does not exist!!!

- most famous “null result” in history!

Annus Mirabilis II: Special Relativity

- Big Q: Relative to what do we measure speed of light if there is no light-carrying ether???

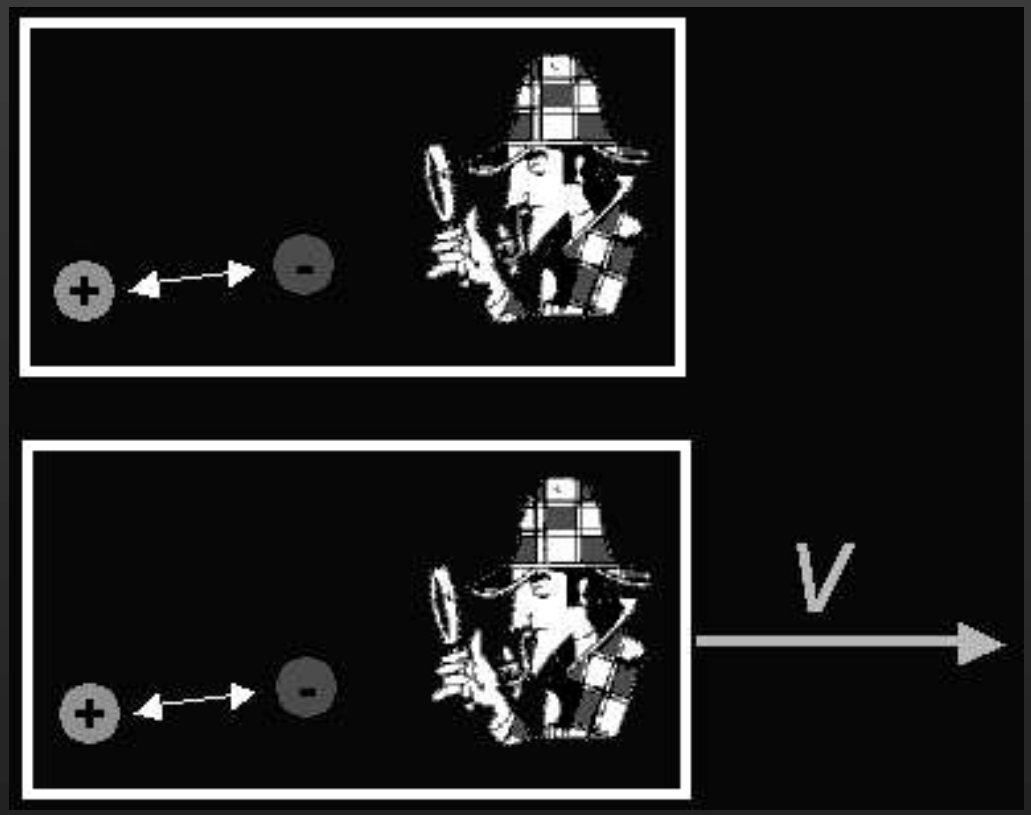
- Einstein's idea: Relative to the observer!

  - And: *All* observers are equal, as long as they move with constant speed ! (Principle of Relativity)

  - And: *All* observers measure *same* speed of light!

Annus Mirabilis II: Special Relativity

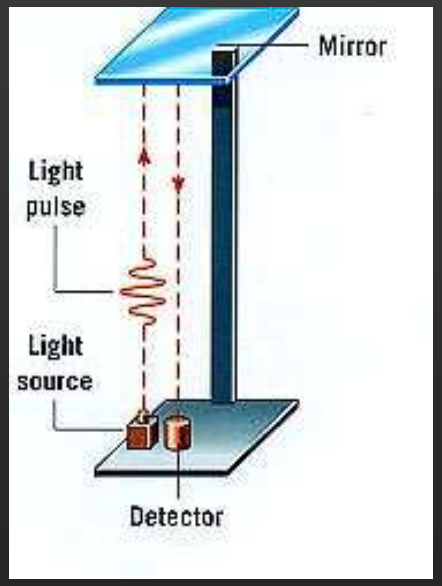
- Principle of Relativity (first proposed by Galileo)



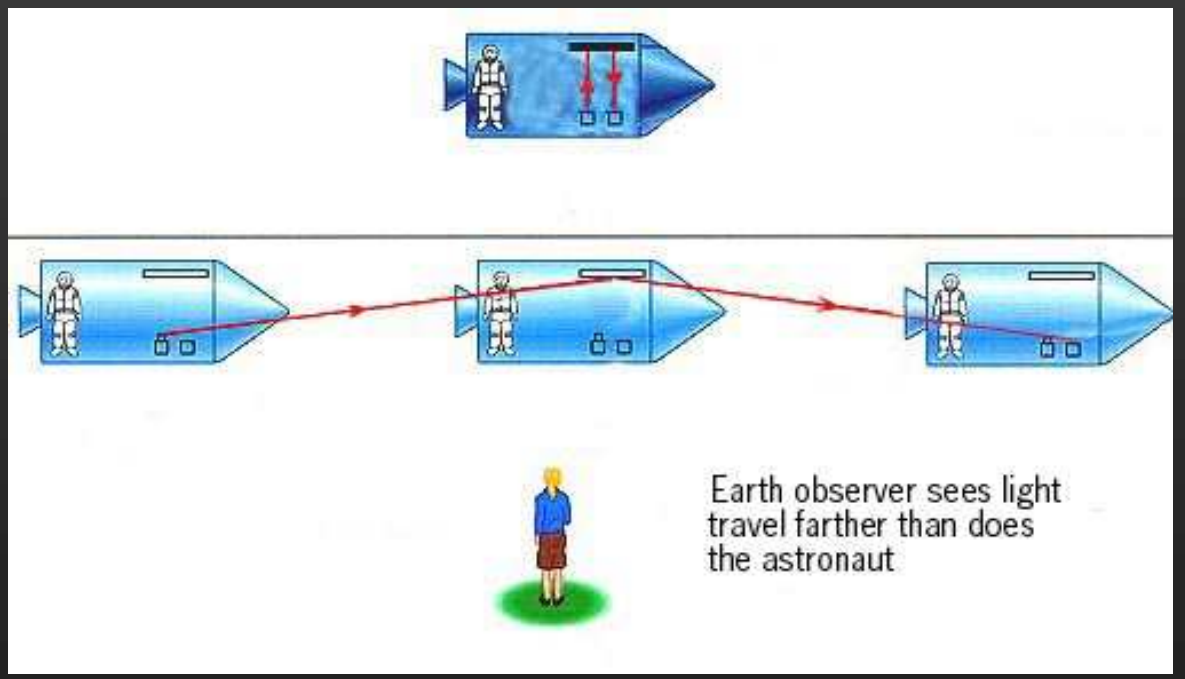
- All observers (moving at constant speed) experience same physics!

Annus Mirabilis II: Special Relativity

- fundamental change in our understanding of space and time: **Time Dilation**



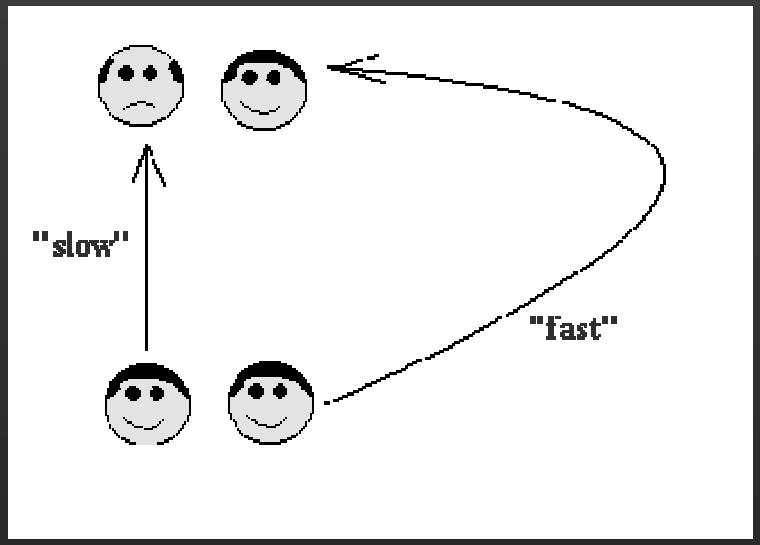
Light clock

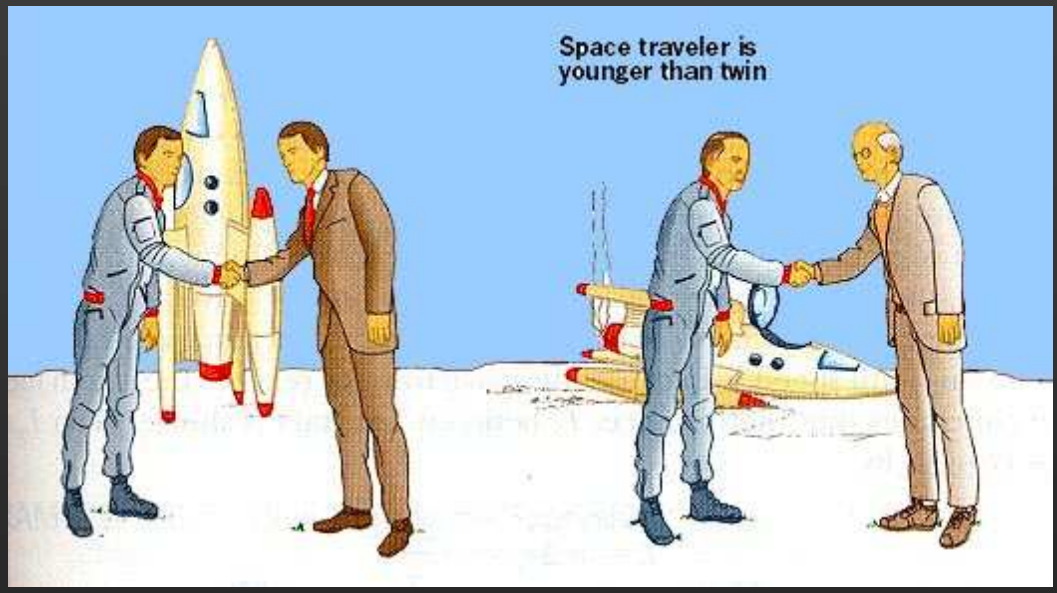


- astronaut: 1 sec
- observer on Earth: 10 sec

Annus Mirabilis II: Special Relativity

- Consequence of time dilation: **Twin Paradox**

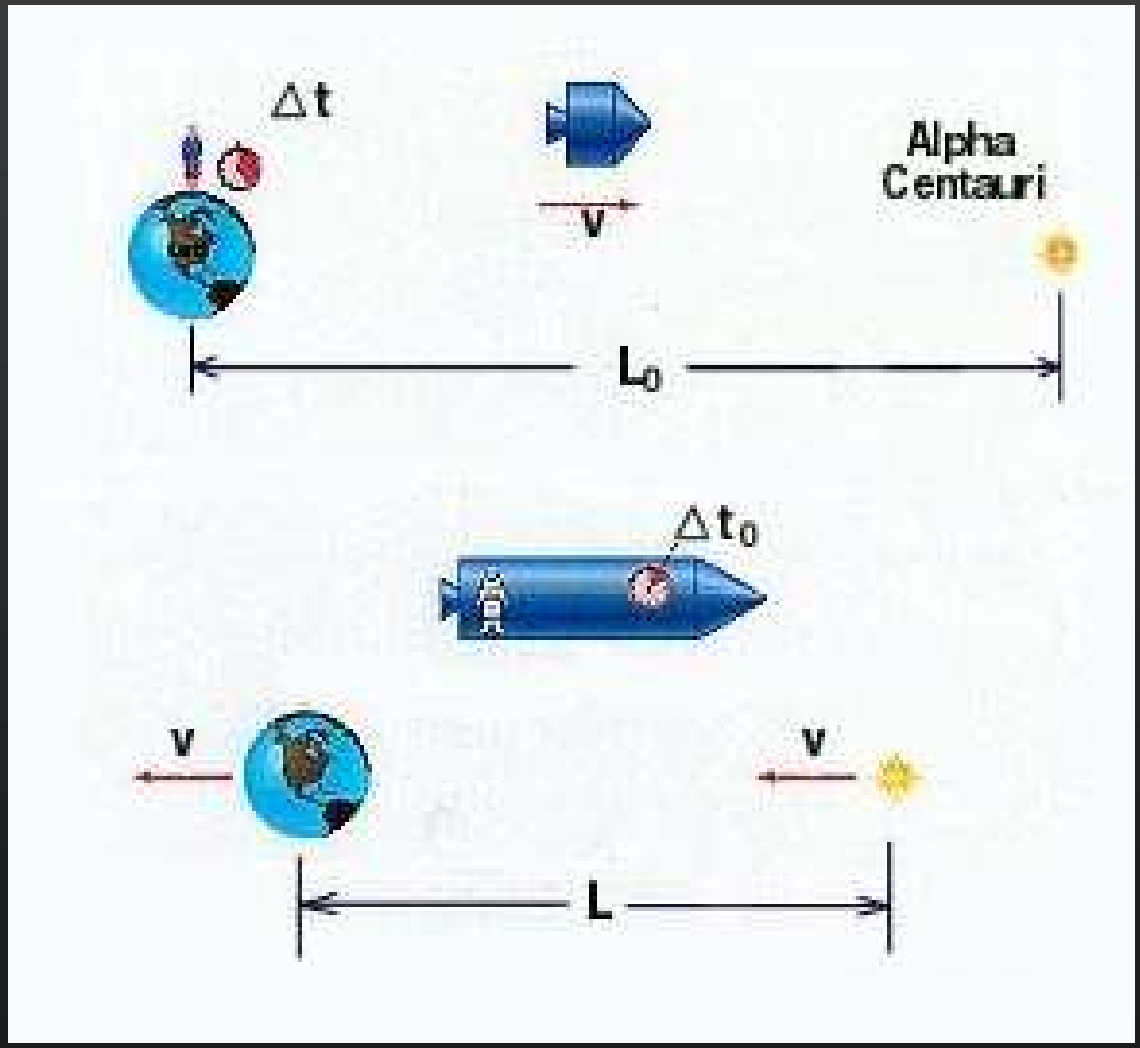




- fast-moving twin ages less!

Annus Mirabilis II: Special Relativity

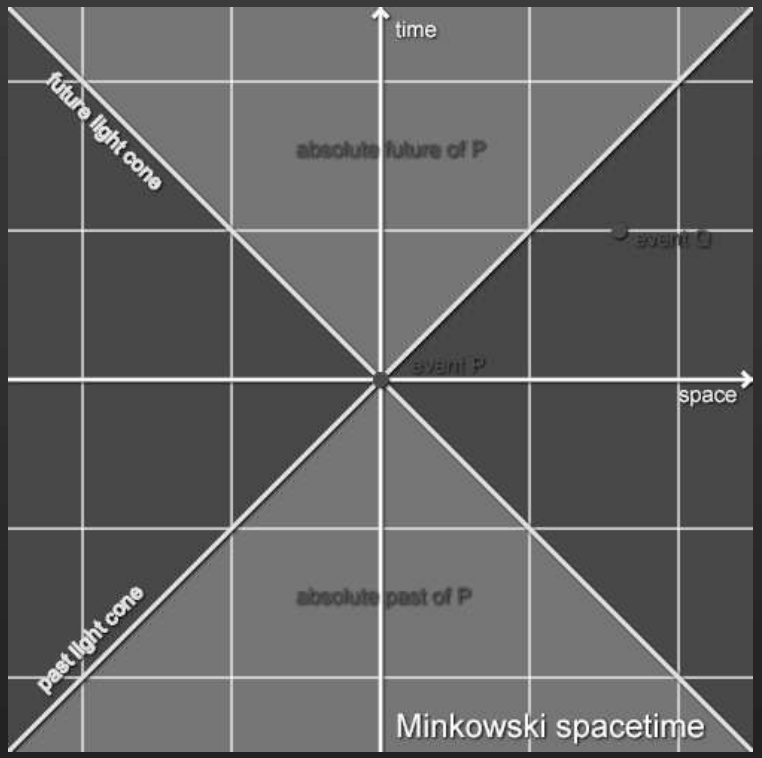
- fundamental change in our understanding of space and time: **Length Contraction**



Annus Mirabilis II: Special Relativity

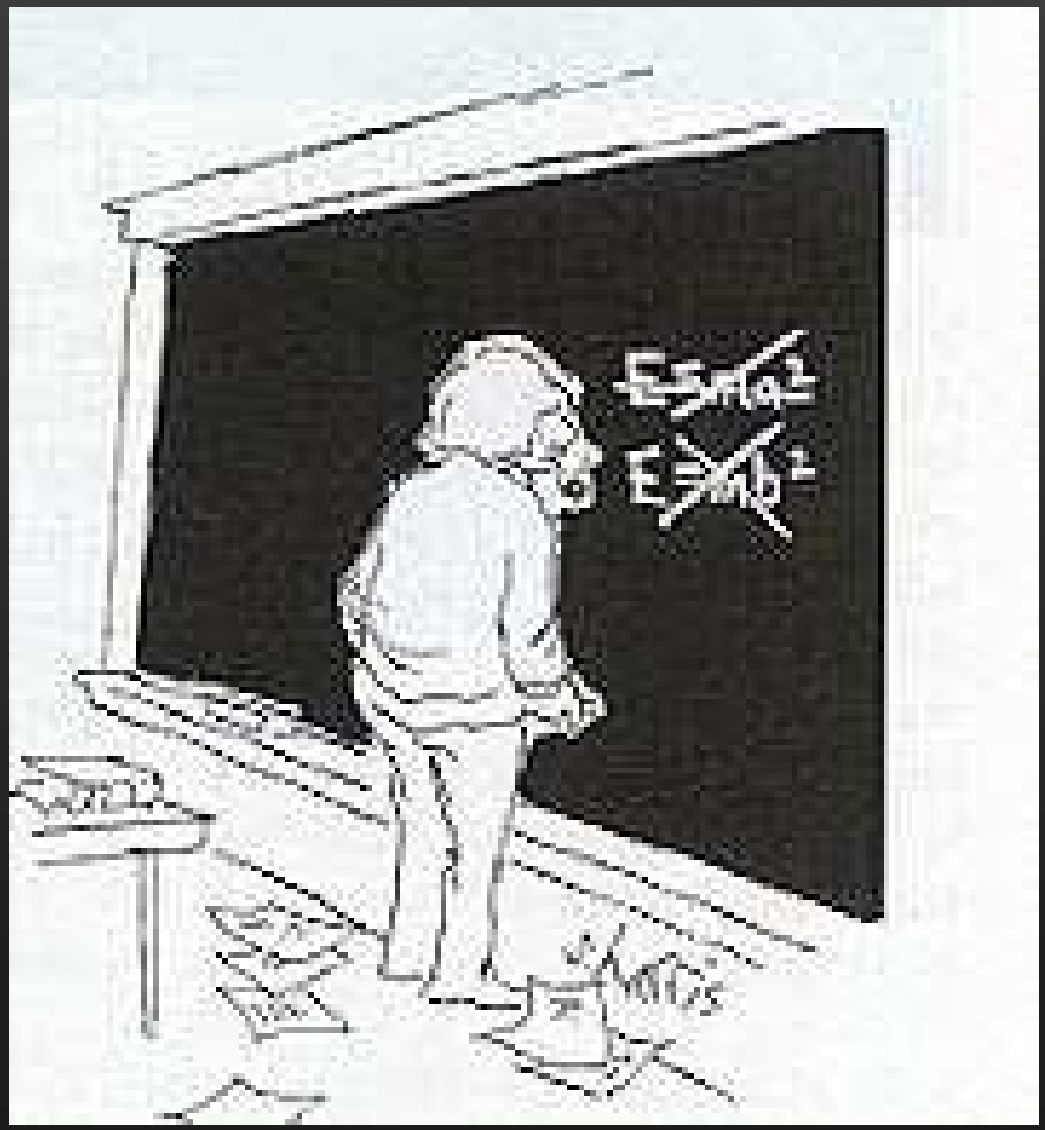
- space and time can be transformed into each other!
  à **concept of spacetime!**

Hermann Minkowski



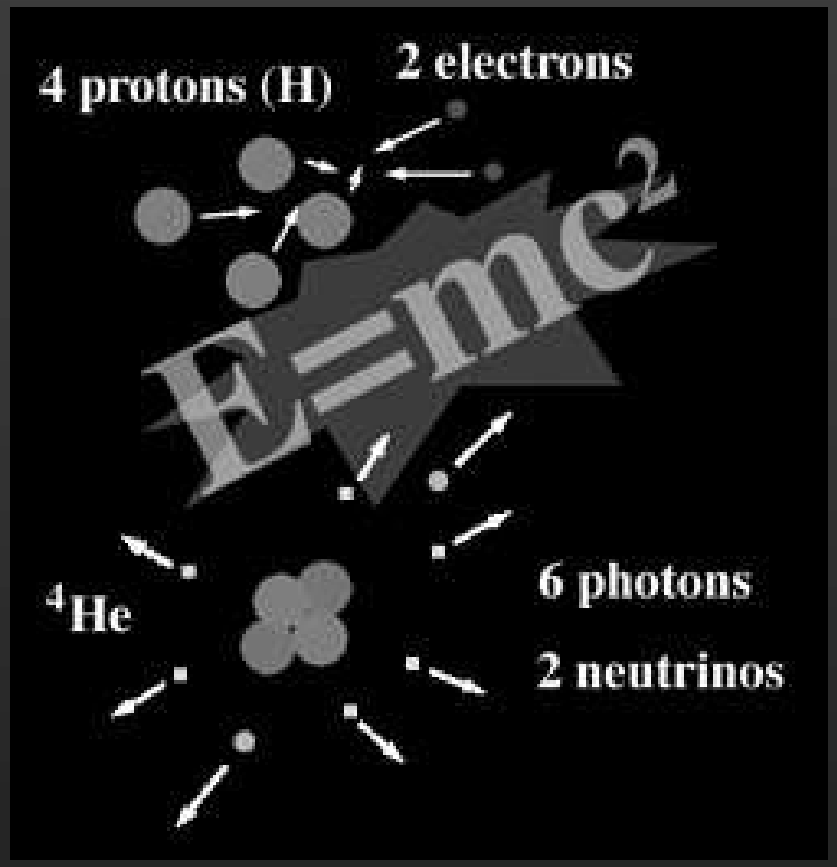
Annus Mirabilis II: Special Relativity

- equivalence of mass and energy:



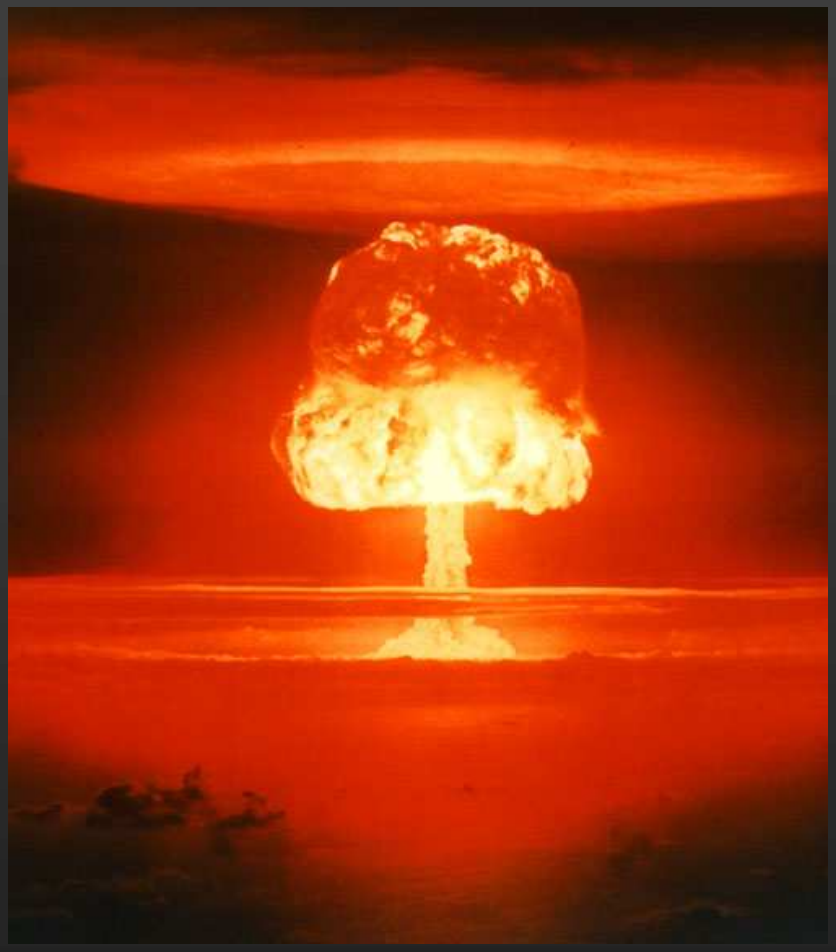
$$E = mc^2$$

Energy Source of the Stars:



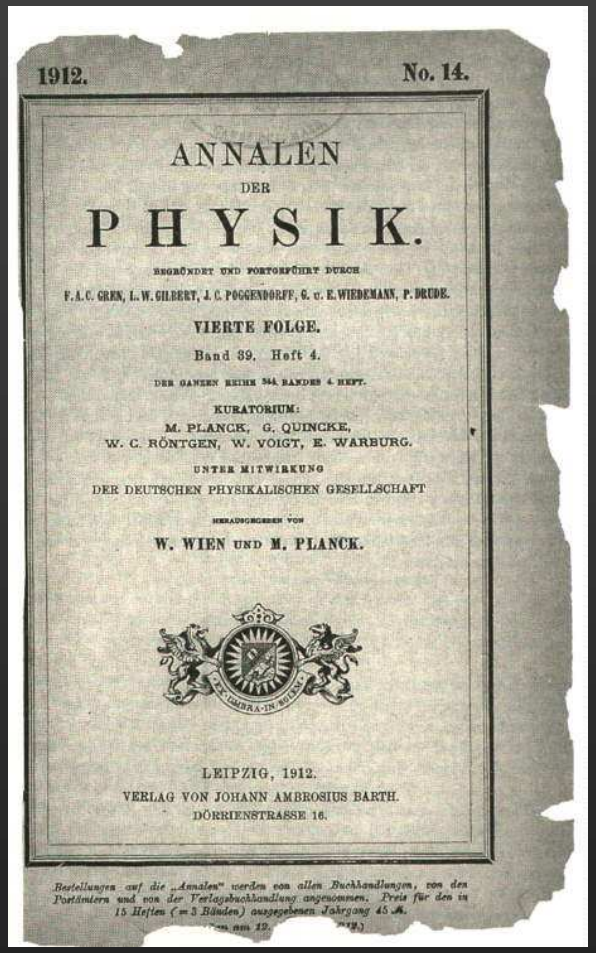
- nuclear fusion:
  4 protons (H)
  à 1 helium (He) nucleus
- He nucleus has a bit less mass than sum of 4 protons (mass defect)
- missing mass = energy (Einstein's $E=m\,c^2$)

Astrophysics and the Bomb



- Hiroshima bomb: 1 gram of uranium

Einstein’s Genius Recognized



1912. No. 14.

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DER
PHYSIK.

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HERAUSGEGEBEN VON
W. WIEN UND M. PLANCK.

LEIPZIG, 1912.
VERLAG VON JOHANN AMBROSIUS BARTH.
DÖRRIENSTRASSE 16.

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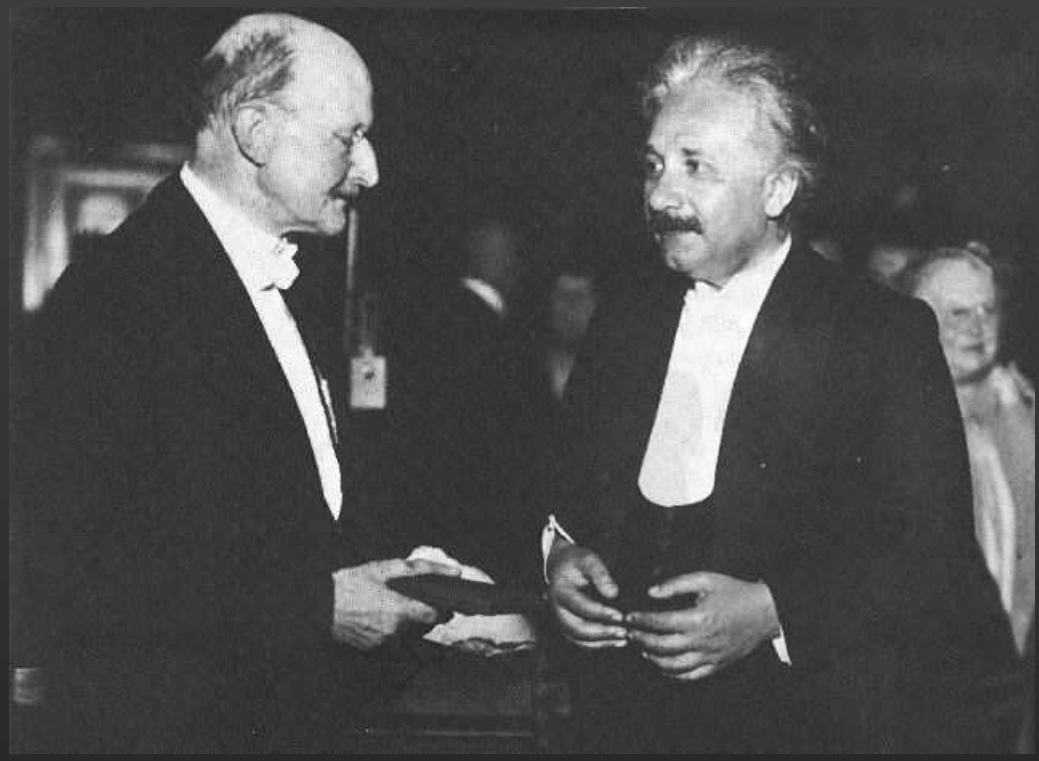

- Max Planck becomes ardent supporter of Einstein early on!

Einstein’s Genius Recognized

- 1914: Max Planck secures Einstein’s appointment as professor in Berlin

Einstein (part 1)

- Early Life:
  - 1879: Born in Ulm, Germany
  - School (Gymnasium) in Munich
  - since 1895 in Switzerland
  - 1896-1900: Attends ETH
  - 1902-09: Patent clerk in Bern
  - 1903: marries Mileva Maric

- Annus Mirabilis (1905):
  - Special Relativity
  - Quantum theory (photons)