



Astronomy 350L
(Fall 2006)



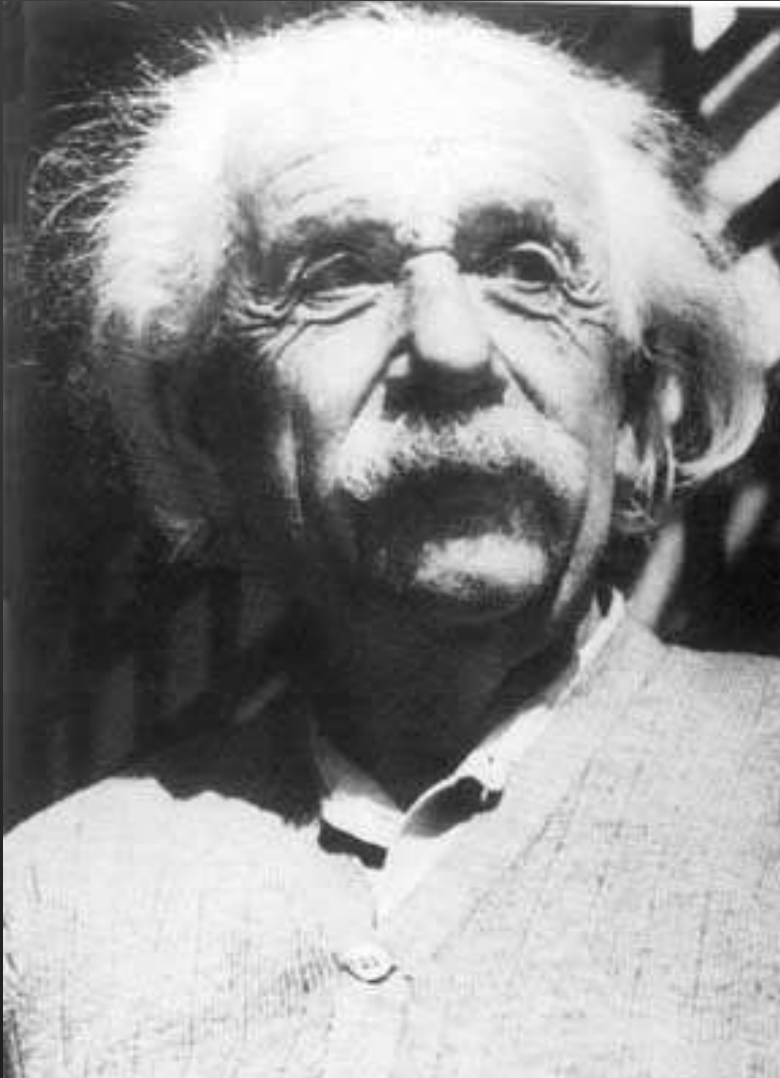
**The History and Philosophy
of Astronomy**

(Lecture 18: Einstein I)

Instructor: Volker Bromm
TA: Jarrett Johnson

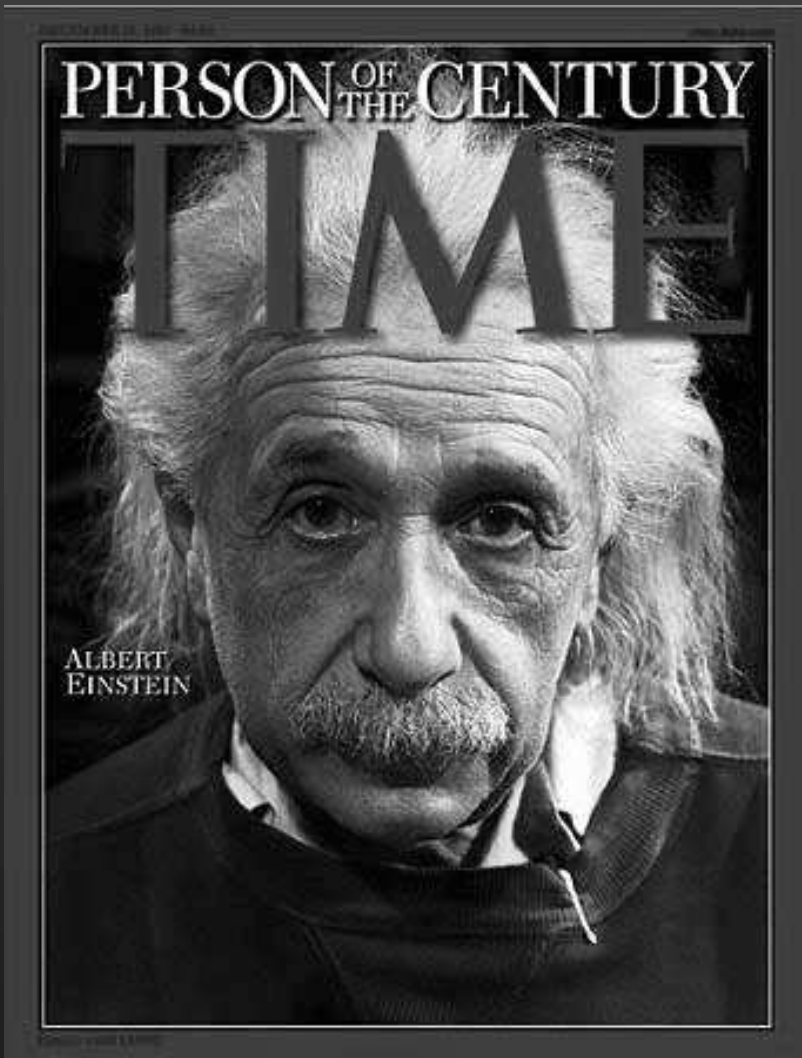
The University of Texas at Austin

Albert Einstein: Revolutionary of Physics



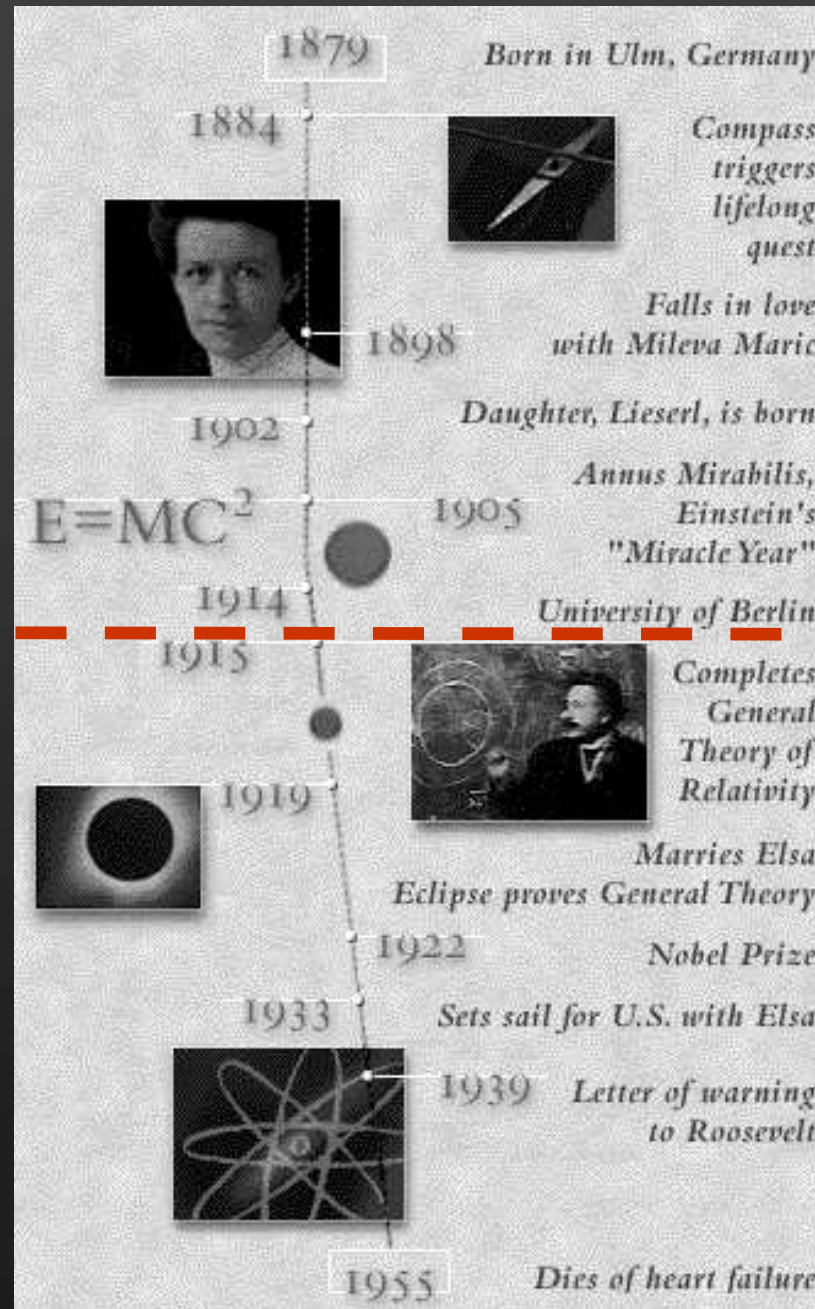
- 1879 (Ulm) – 1955 (Princeton)
- revolutionized concepts of space, time, and gravity
 - Special Relativity (1905):
à $E=mc^2$
 - General Relativity (1915):
à new theory of gravity
- co-founder of quantum theory
à photons

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



Nov. 2

Nov. 7

Birth in Ulm (1879)



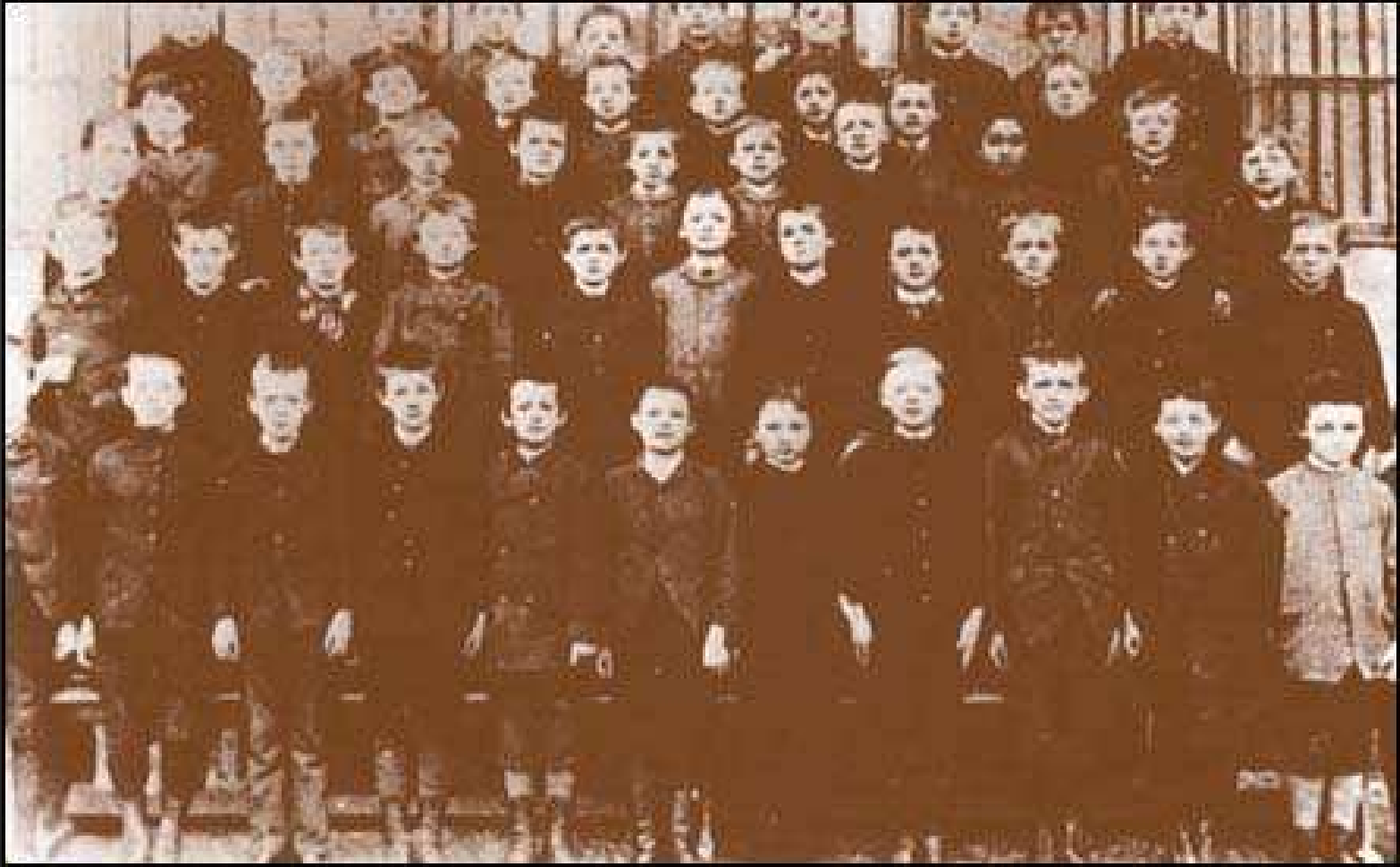
Youth in Munich (1880-1894)

Albert Einstein
(5 years old) with
his sister Maja
(3 years old), 1884



- 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!

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

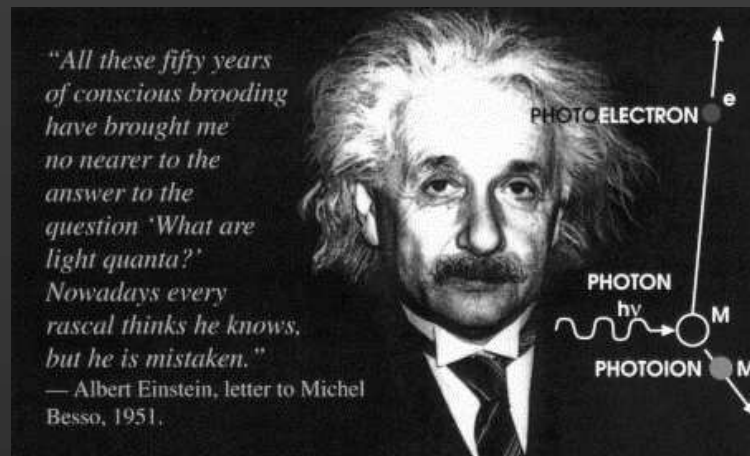
1st Marriage and Children



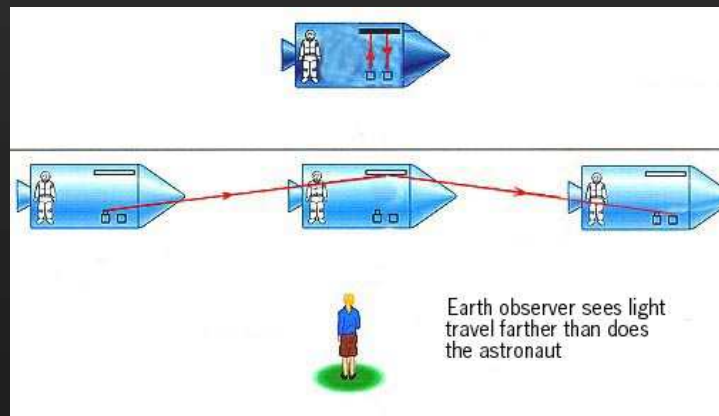
- marriage with Mileva Maric (1903-1919)

1905: Annus Mirabilis

- Quantum Theory: particles of light (photons)

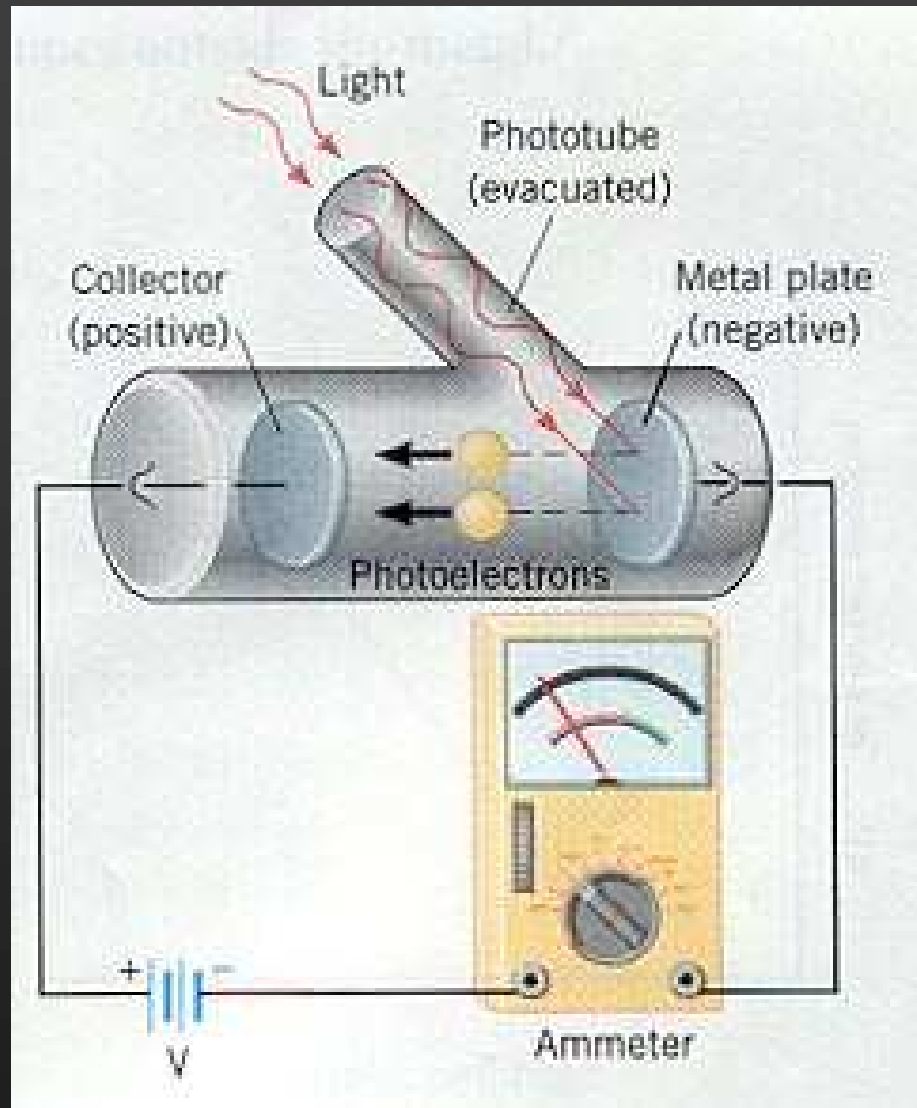


- Special Relativity: new concept of space and time



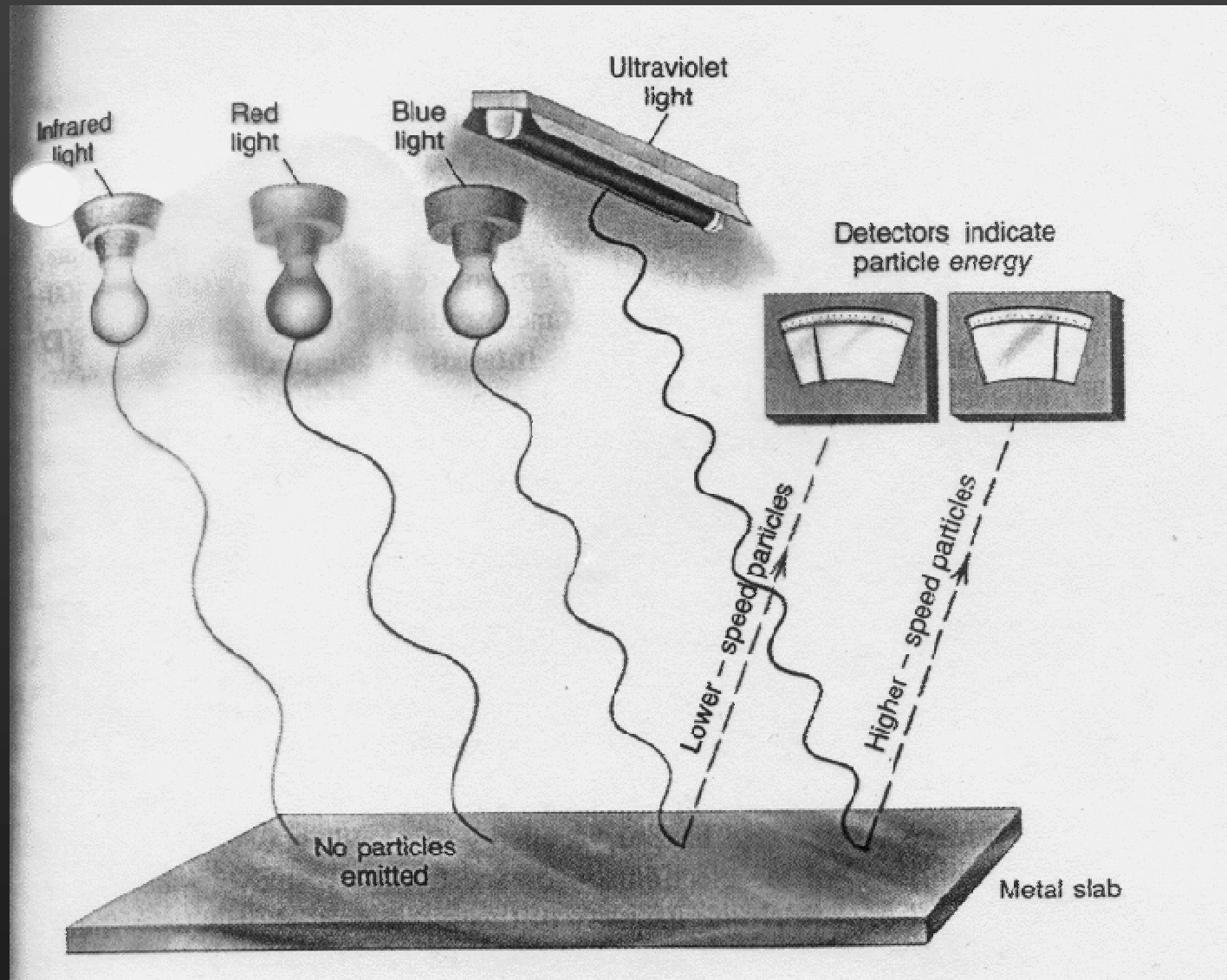
- Brownian motion: prove reality of atoms

Annus Mirabilis I: Light quanta



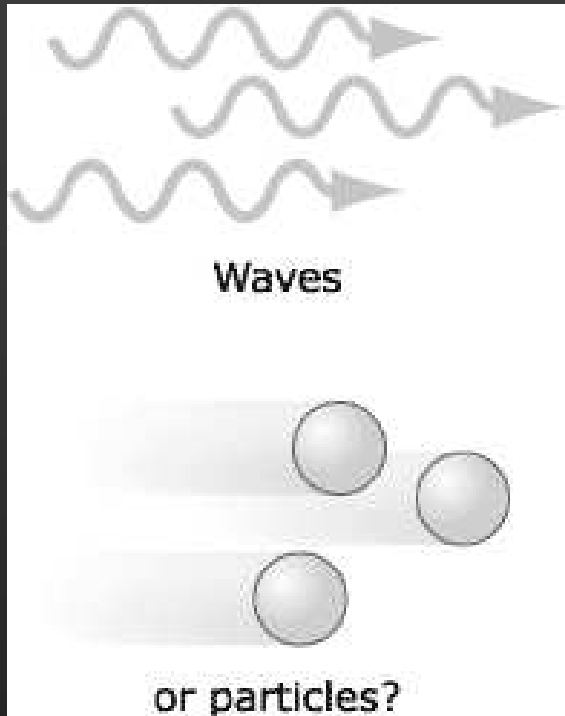
- photoelectric effect

Annus Mirabilis I: Light quanta



- Frequency counts, not intensity!

Annus Mirabilis I: Light quanta



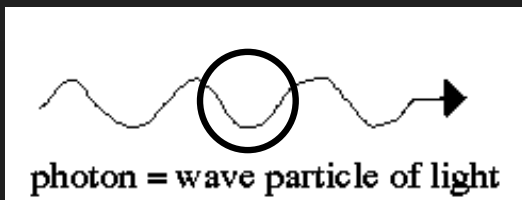
- Einstein's idea: light can be *both* particle and wave!



à Low energy!

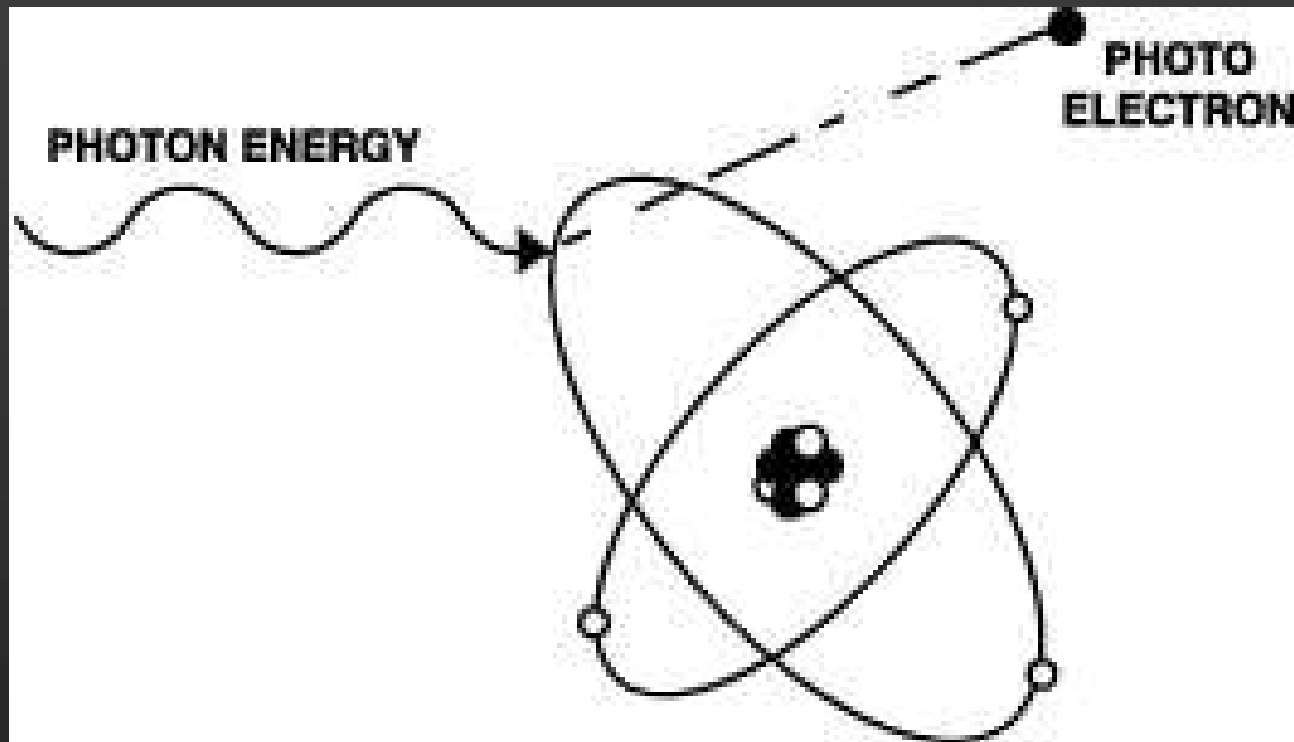


à High energy!



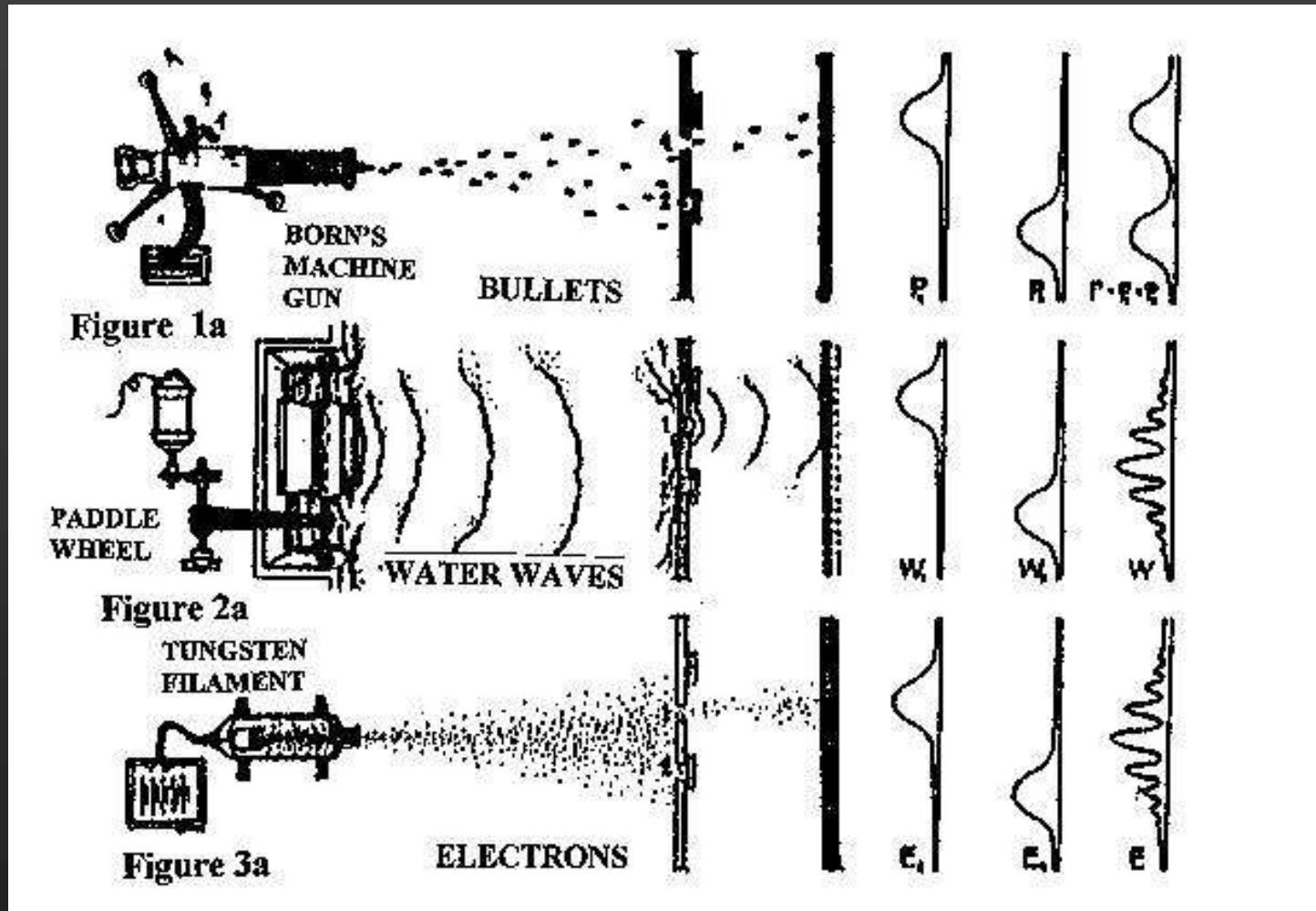
$$\text{energy} = h\nu = \frac{hc}{\lambda}$$

Annus Mirabilis I: Light quanta



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

The Meaning of Quantum Theory

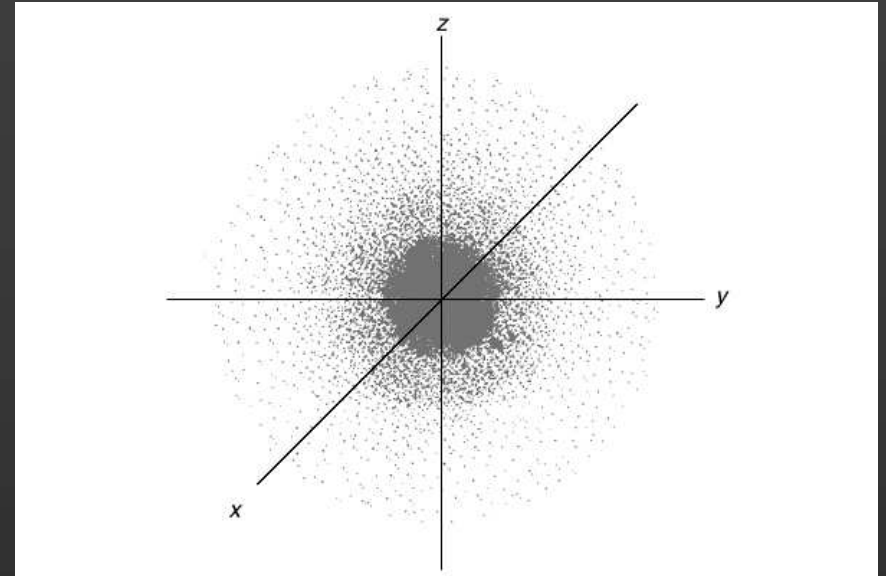


- Quantum theory is weird!

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)

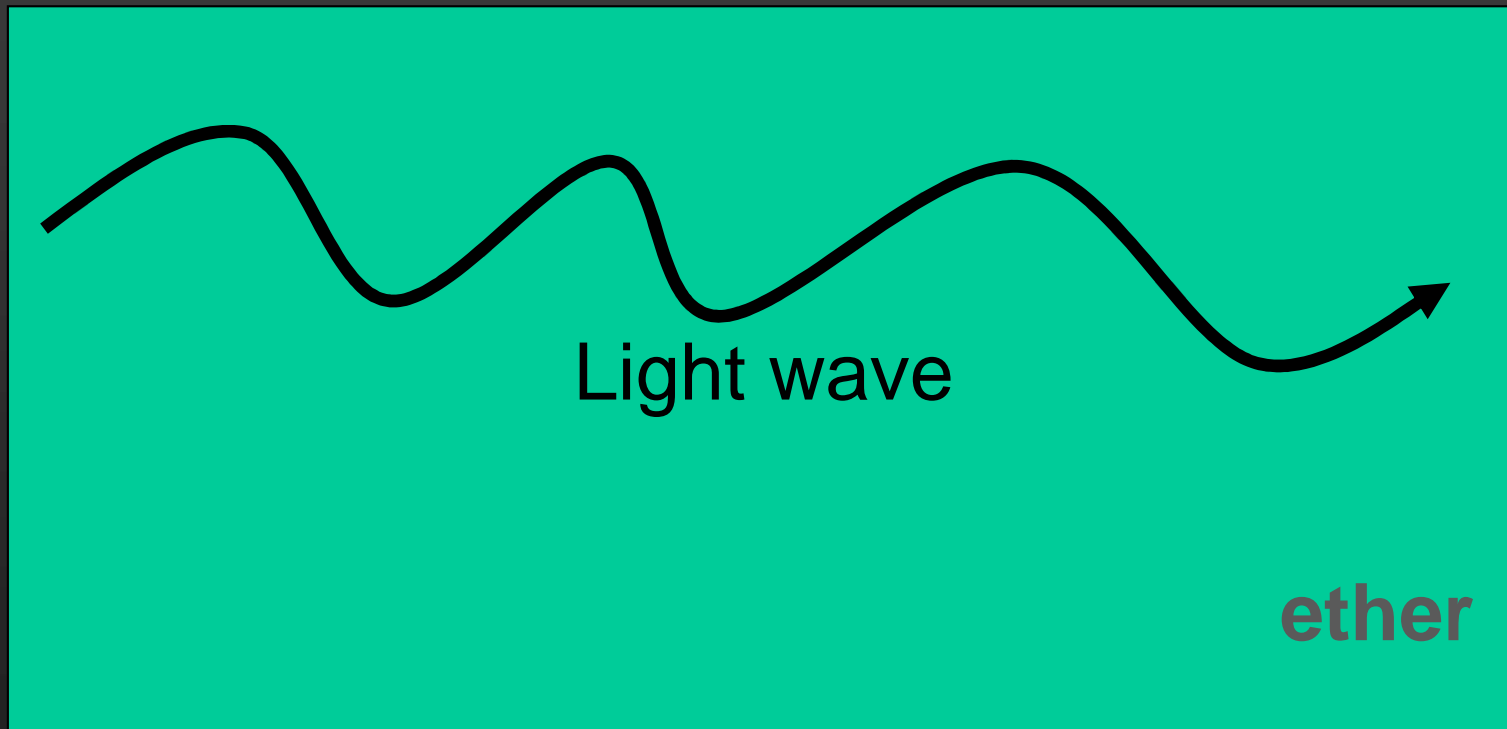
Annus Mirabilis I: Light quanta



- 1921: Nobel Prize in Physics

Annus Mirabilis II: Special Relativity

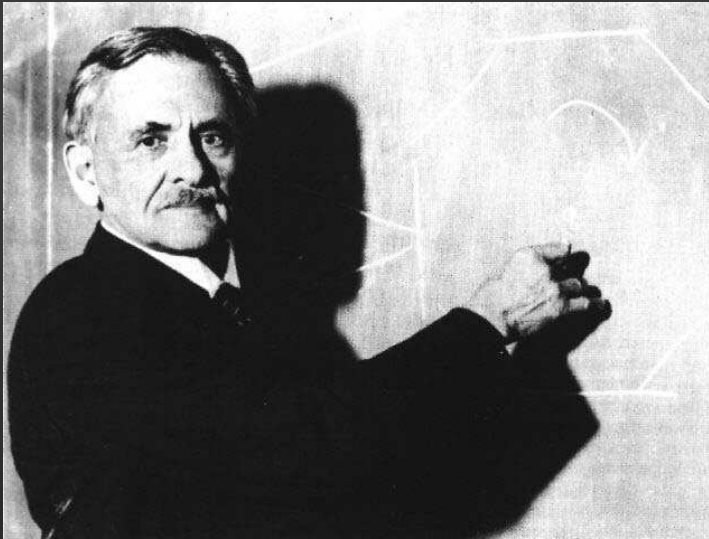
- Big question for 19th century: What is the ether?



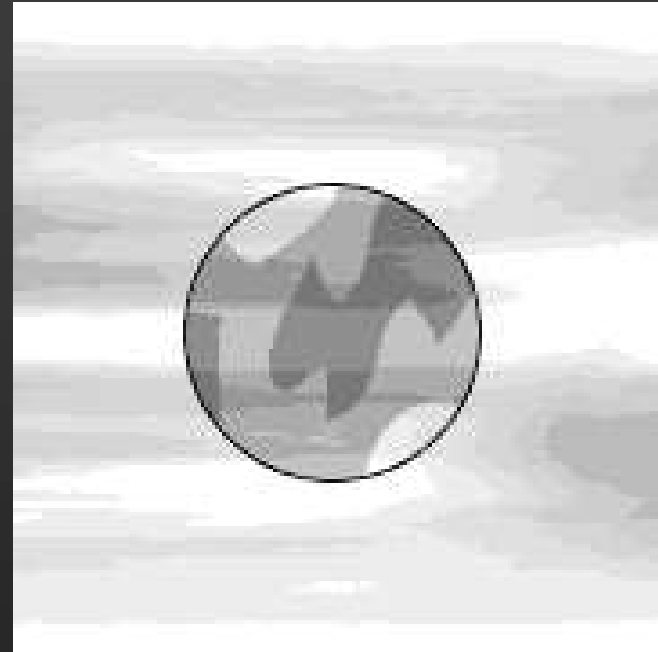
- known: speed of light (c) with respect to ether
 - $c = 300,000 \text{ km s}^{-1}$

Annus Mirabilis II: Special Relativity

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



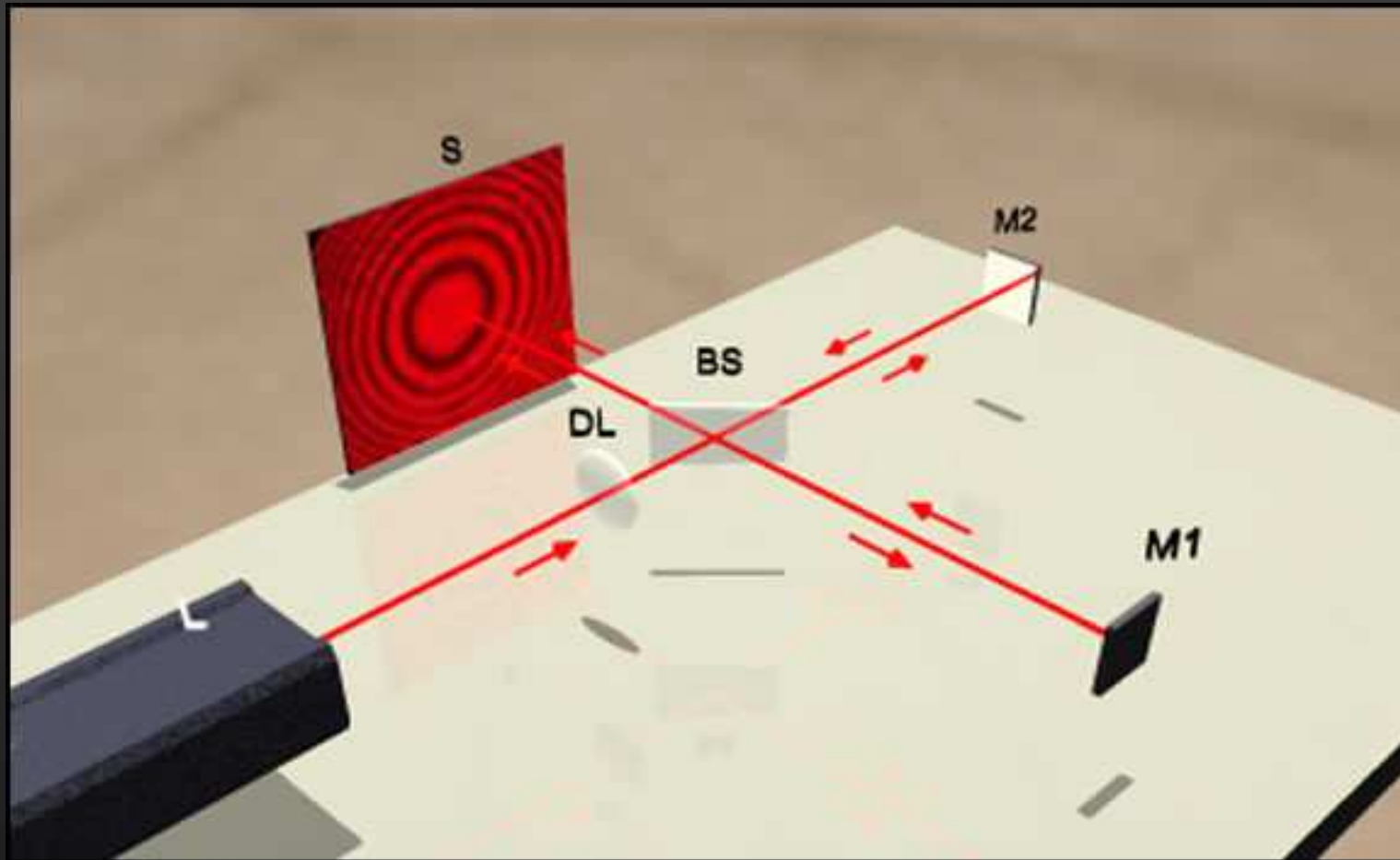
Albert Michelson (1852-1931)
- America's 1st Nobel Laureate
in physics (1907)



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

Annus Mirabilis II: Special Relativity

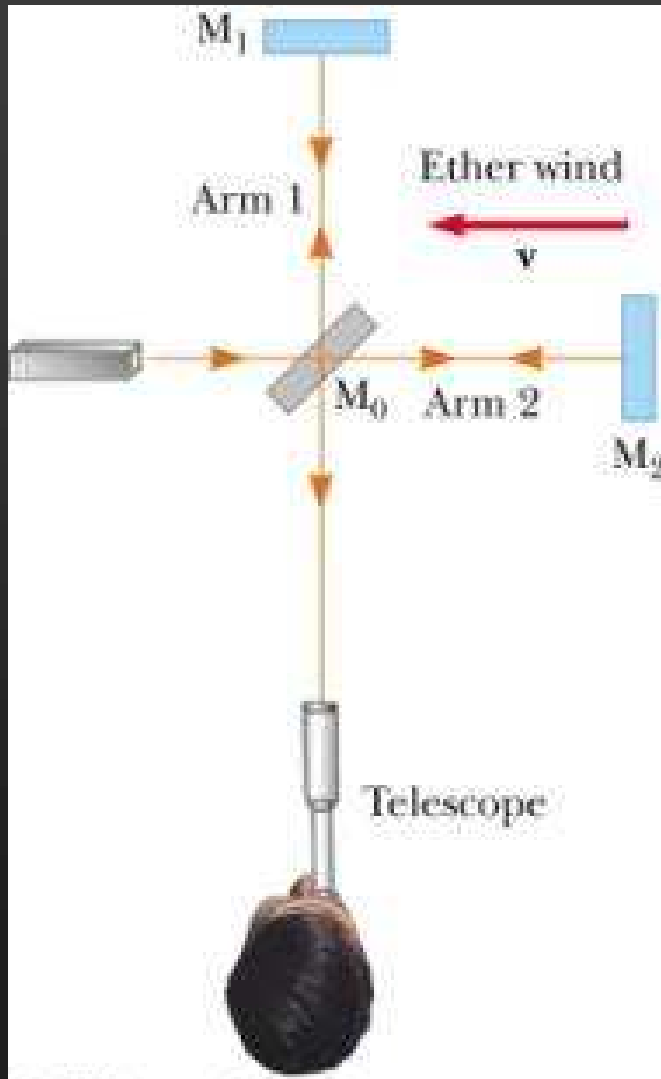
- 1887: Michelson-Morley experiment



- `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!!!

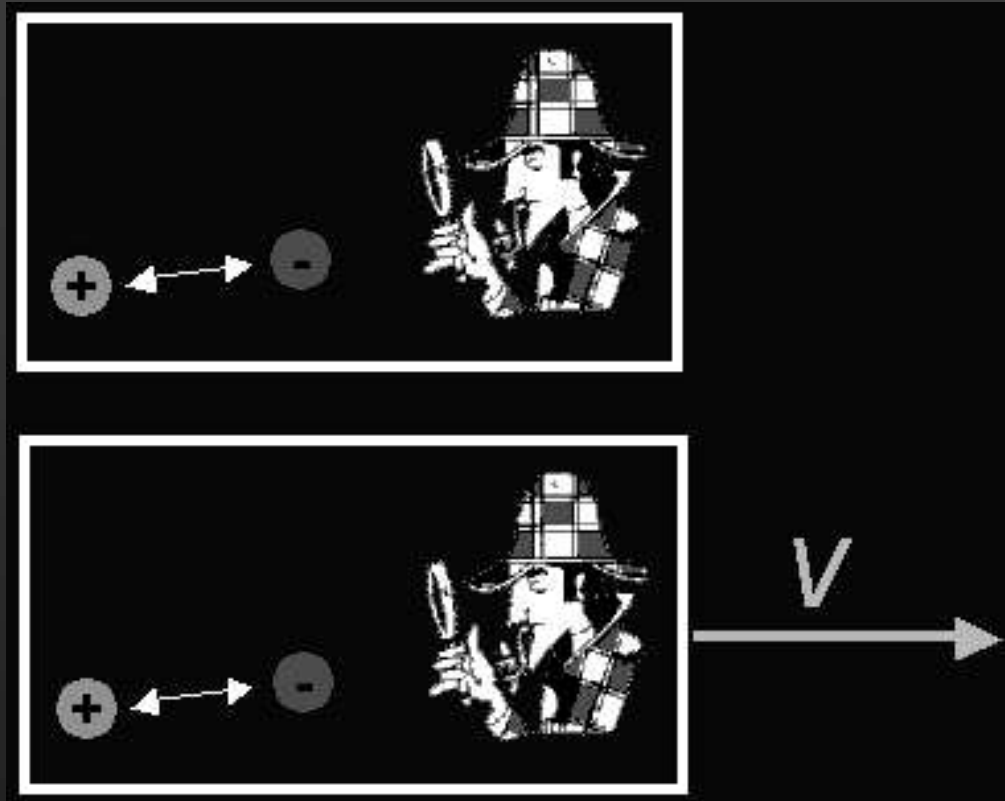
- most famous “null result” in history!

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

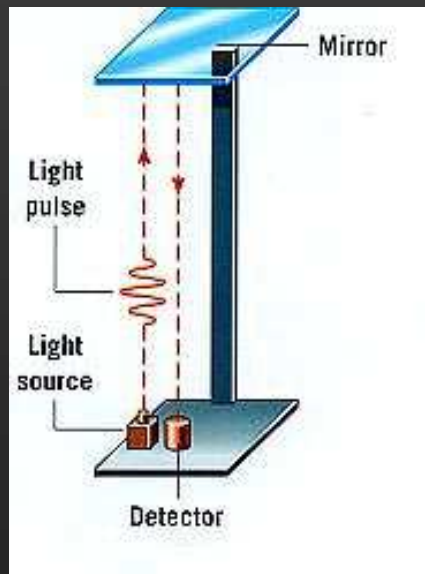
- Principle of Relativity (first proposed by Galileo)



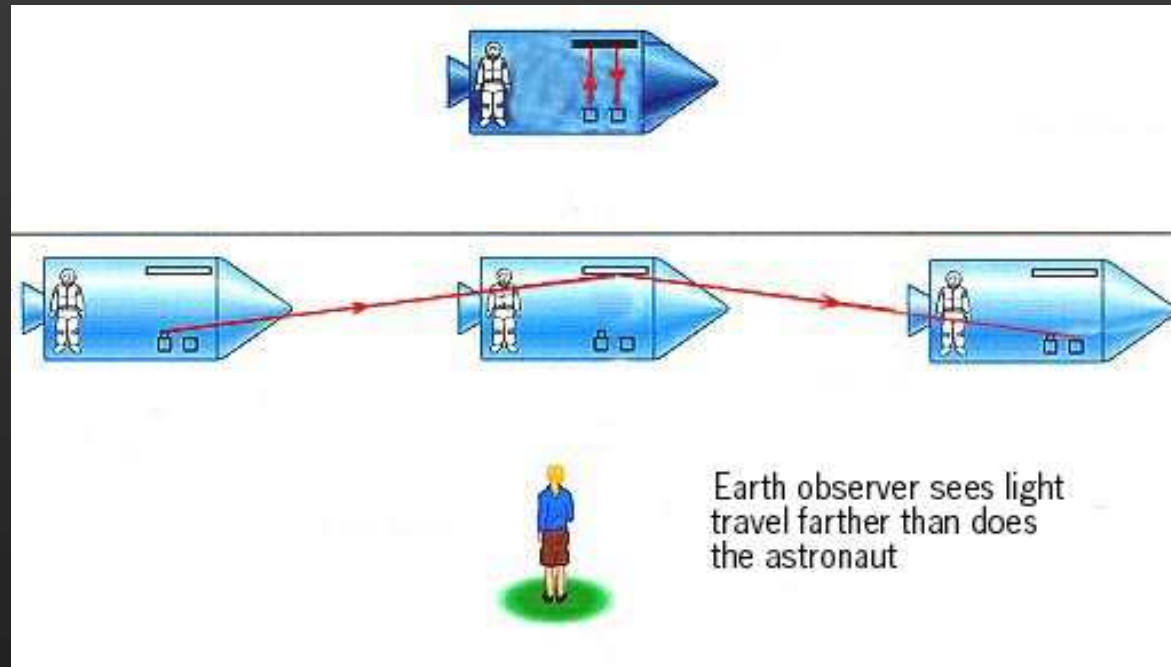
- All observers (moving at constant speed) experience same physics!

Annus Mirabilis II: Special Relativity

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



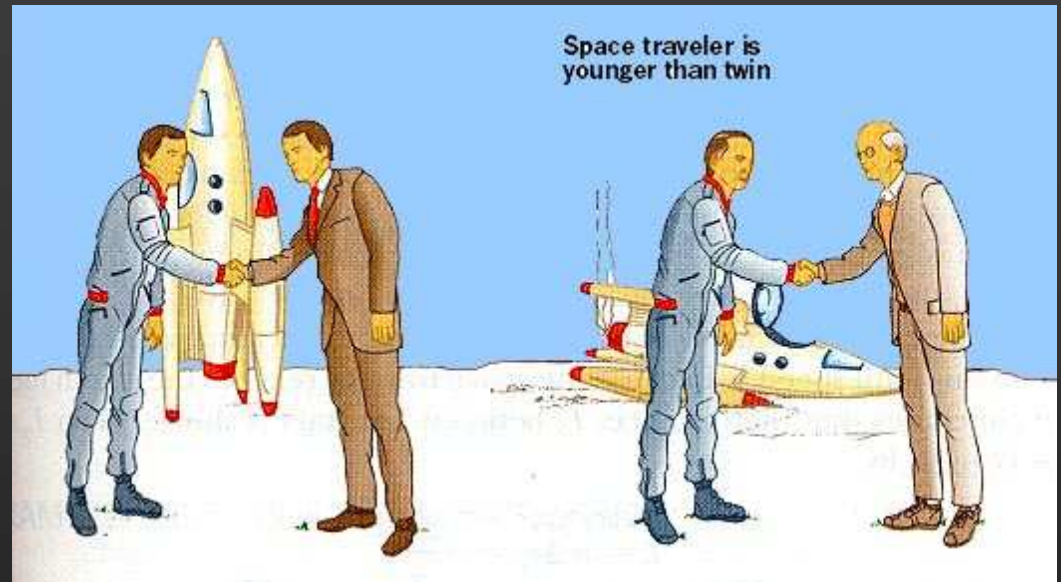
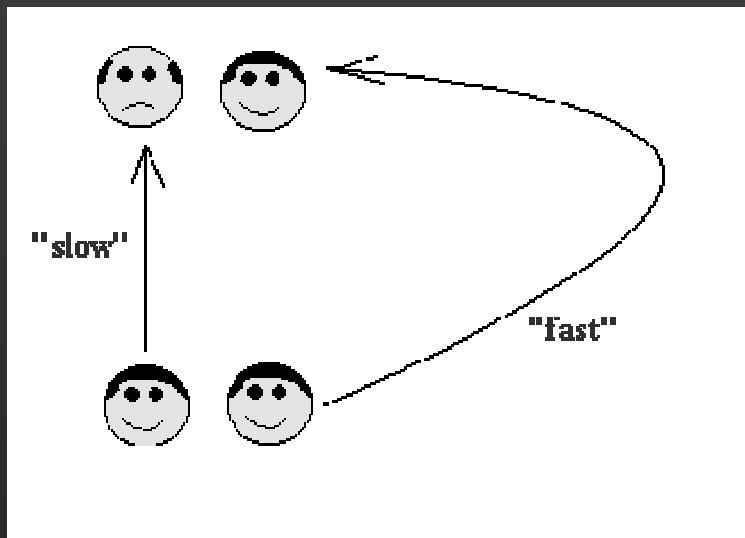
Light clock



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

Annus Mirabilis II: Special Relativity

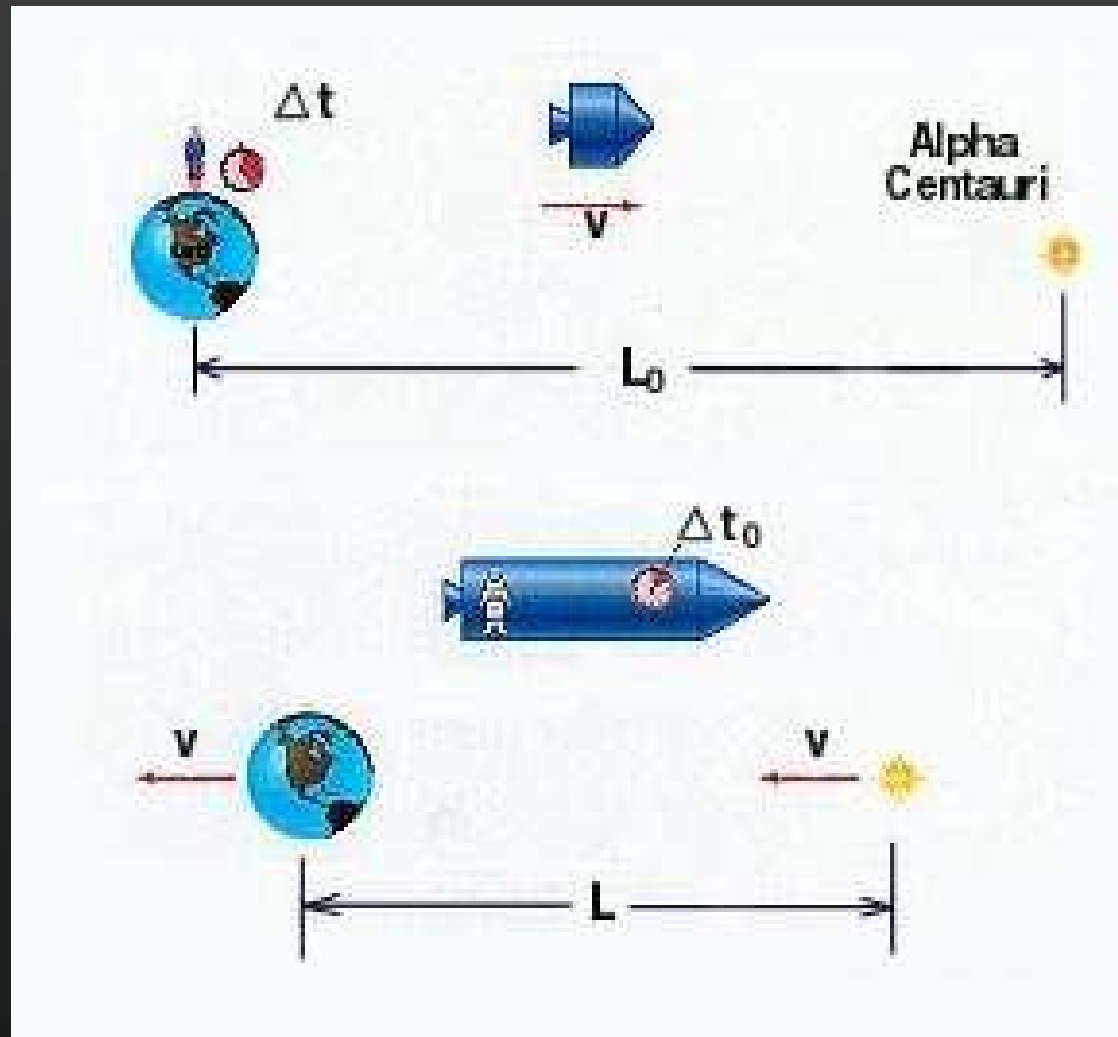
- Consequence of time dilation: **Twin Paradox**



- fast-moving twin ages less!

Annus Mirabilis II: Special Relativity

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

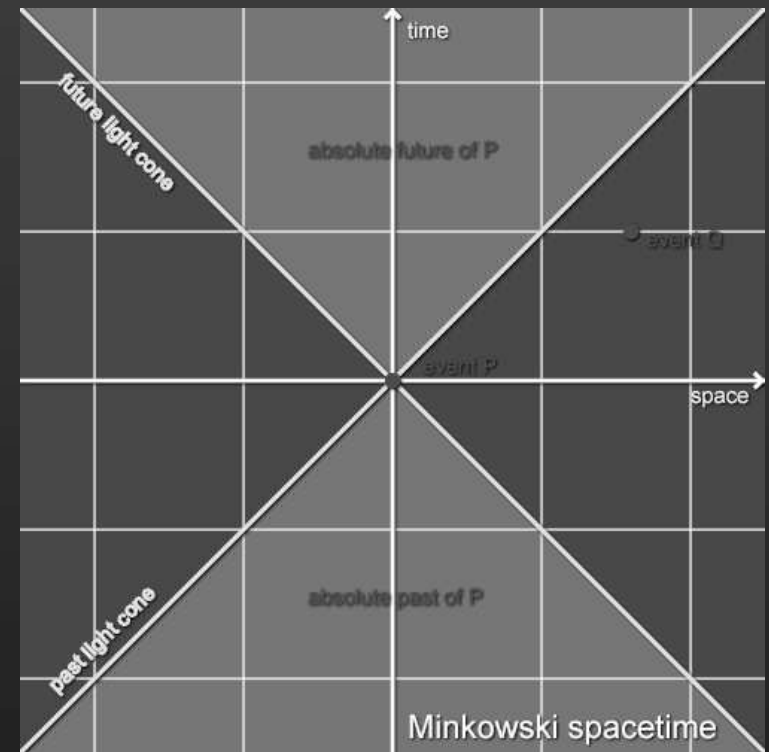


Annus Mirabilis II: Special Relativity

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

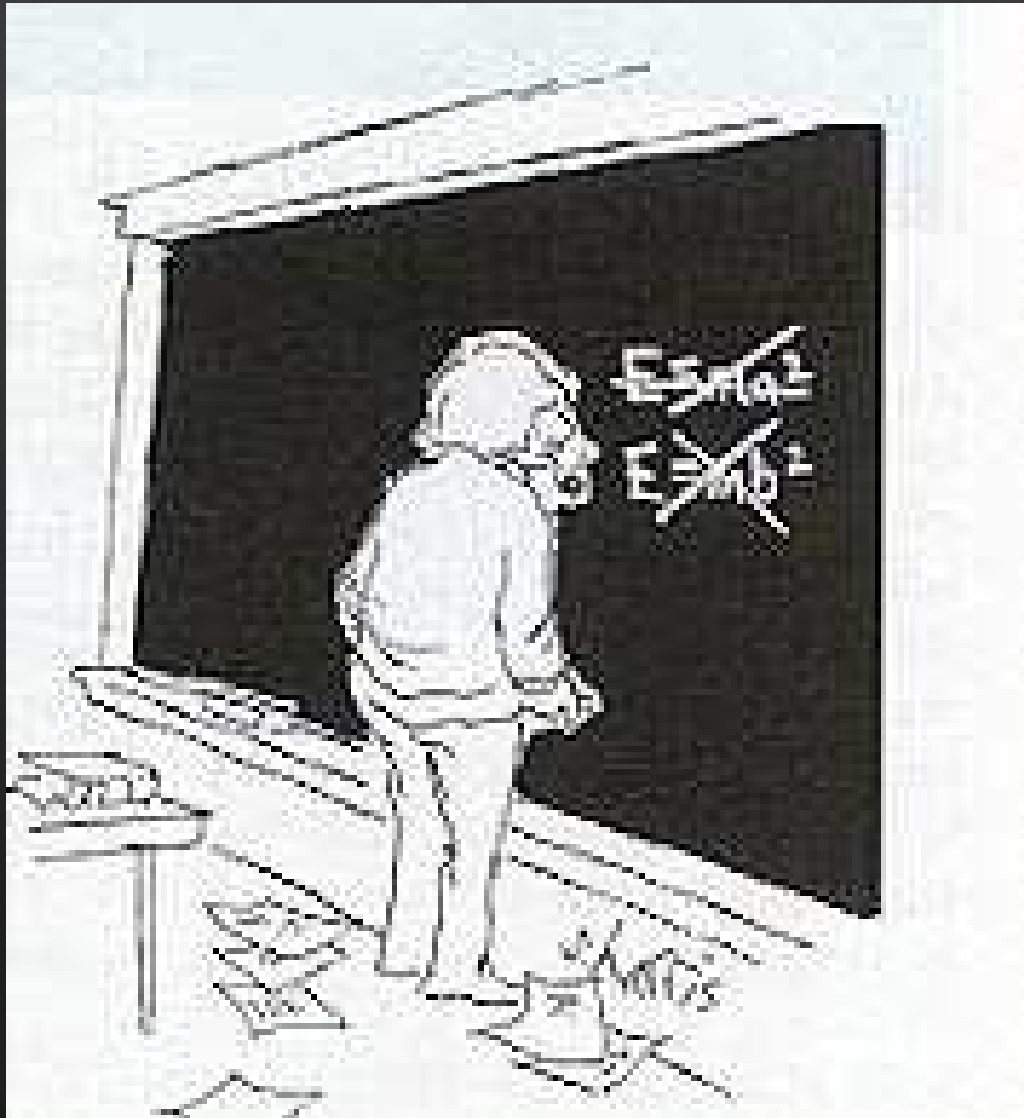


Hermann Minkowski



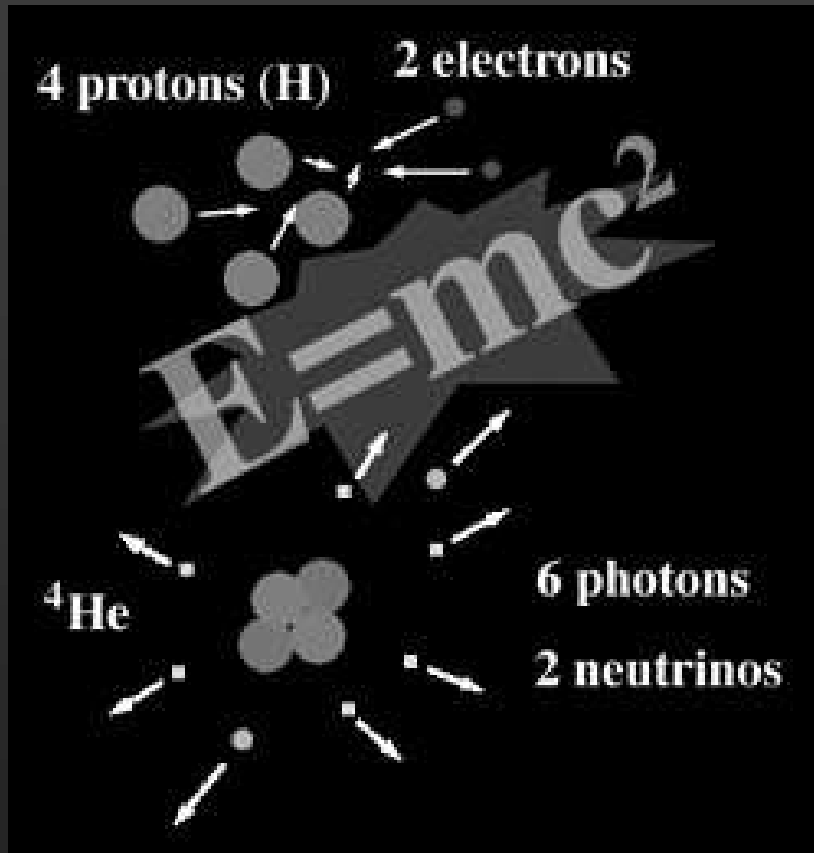
Annus Mirabilis II: Special Relativity

- equivalence of mass and energy:



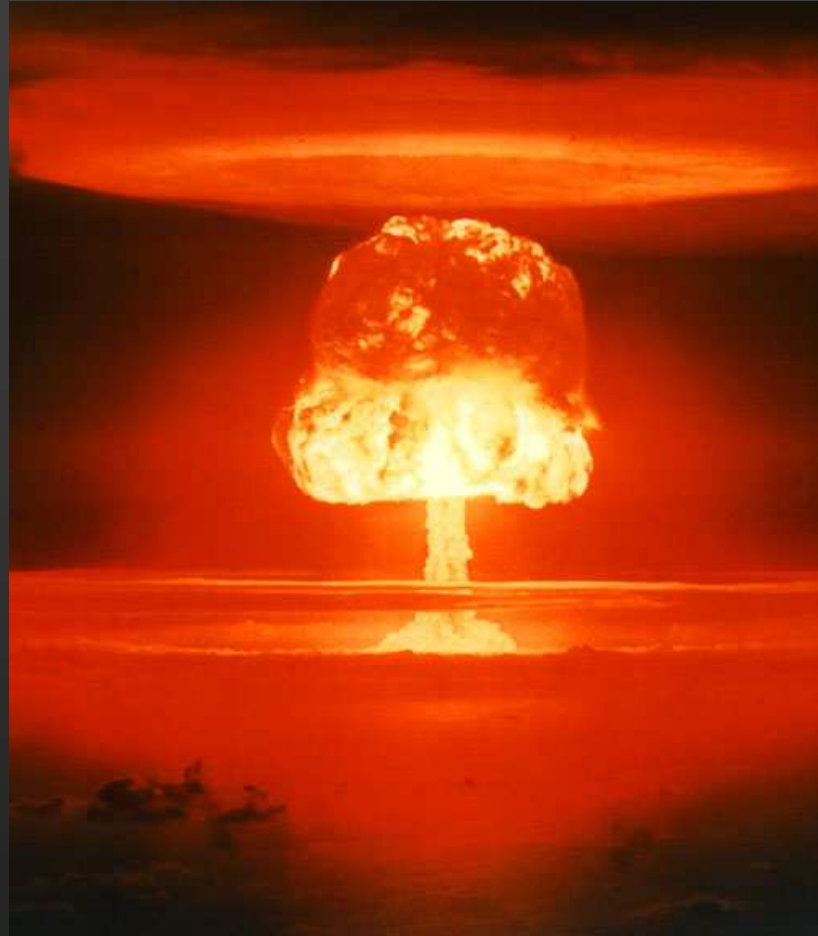
$$E = mc^2$$

Energy Source of the Stars:



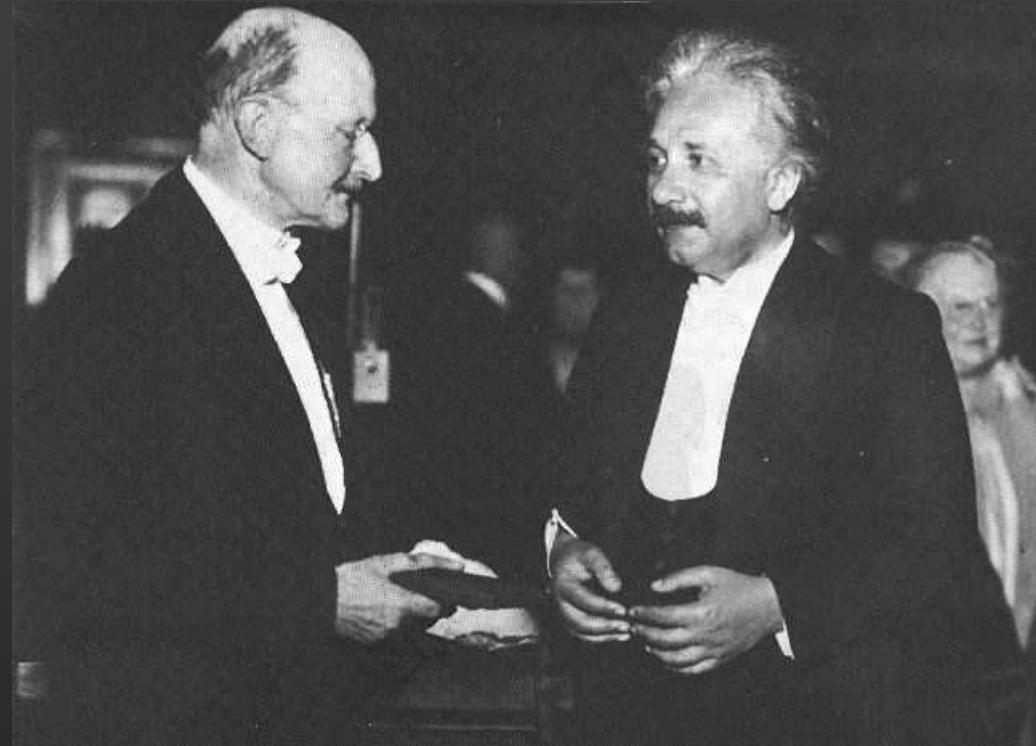
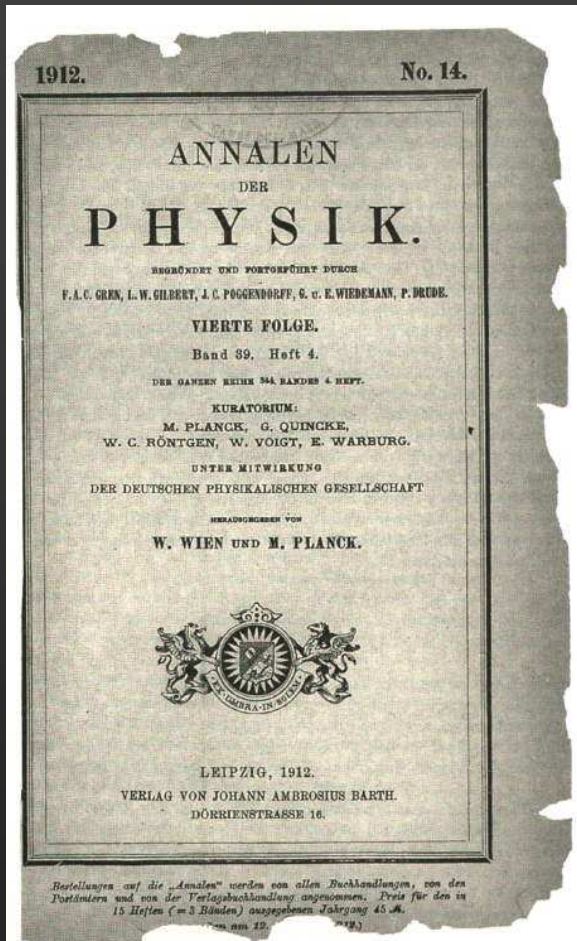
- nuclear fusion:
4 protons (H)
à 1 helium (He) nucleus
- He nucleus has a bit less mass than sum of 4 protons (mass defect)
- missing mass = energy
(Einstein's $E=mc^2$)

Astrophysics and the Bomb



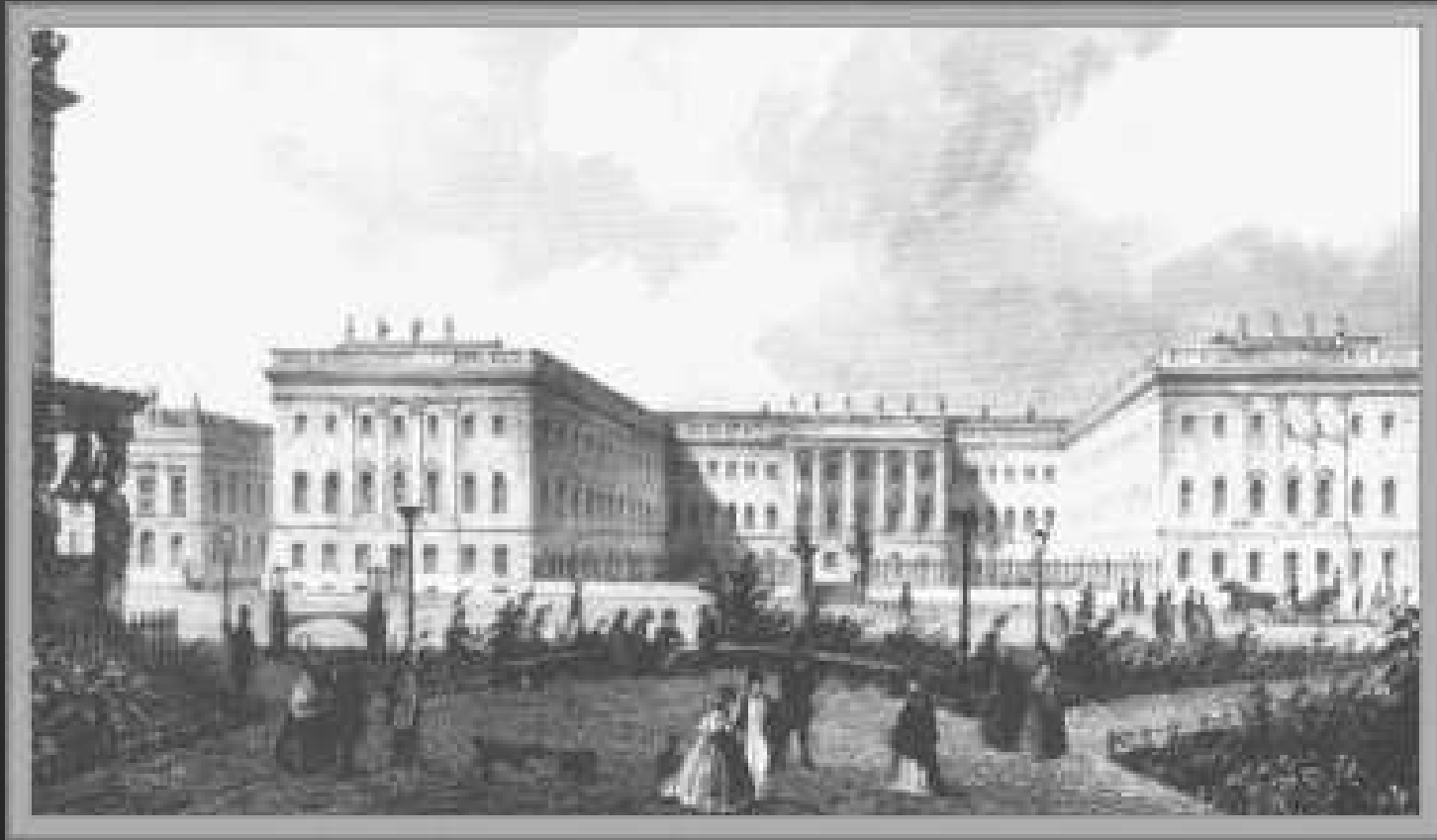
- **Hiroshima bomb: 1 gram of uranium**

Einstein's Genius Recognized



- 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)