lecture 3

EM and postulates of relativity

Announcements:

- lecture 2 is posted on the class website
- homework 1 is posted on CULearn
  - due Wed, Jan 19 in class
  - solutions will be posted on CULearn

- reading for this week is:
  - Ch 1 in TZD
  - course syllabus details

- remember to bring your clicker to every class
  - register it (once), otherwise cannot get credit
  - set it to frequency CB (once)

Last Time

recall lecture 2:

- Relativity in nature:
  - *physical phenomena are coordinate- and frame-invariant*
- Inertial reference frames:
  - *non-accelerating … constant velocity (including zero)*
- Galilean relativity:
  - *Newton's laws (mechanics, Phys 1110) are invariant*
  - *Maxwell's laws (E&M, light, Phys 1120) are not invariant*

Today

- Electromagnetic waves
- Michelson-Morley experiment
- Postulates of Einstein's special theory of relativity

Maxwell equations are *not* Galilean invariant

- Galilean relativity:
  - *satisfied* by *Newton's laws* of mechanics F = ma
  - *violated* by *Maxwell's laws* description of light (E&M)

Maxwell's equations:

$$\oint \mathbf{E}\cdot d\mathbf{A} = \frac{q_{enc}}{\varepsilon_0}$$

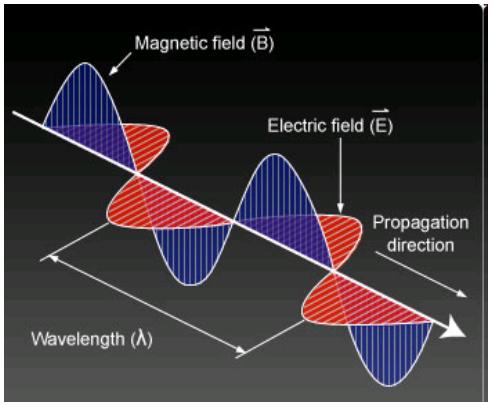
$$\oint \mathbf{B}\cdot d\mathbf{A} = 0$$

$$\oint \mathbf{E}\cdot d\mathbf{s} = -\frac{d\Phi_B}{dt}$$

$$\oint \mathbf{B}\cdot d\mathbf{s} = \mu_0\varepsilon_0\frac{d\Phi_E}{dt} + \mu_0 i_{enc}$$

E&M waves:

$$\partial_t^2\mathbf{E} - c^2\partial_x^2\mathbf{E} = 0$$



oscillating E and B fields $c = \frac{1}{\sqrt{\mu_0\varepsilon_0}} = 299792458 \text{ m/s}$

James Clerk Maxwell
1831-1879

Galileo says:

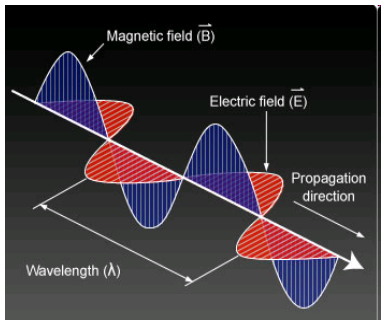
c is speed of light in frame S ⟹ c′ = c − v is speed of light in frame S′

… but c is with respect to what???

Electromagnetic radiation and speed of light

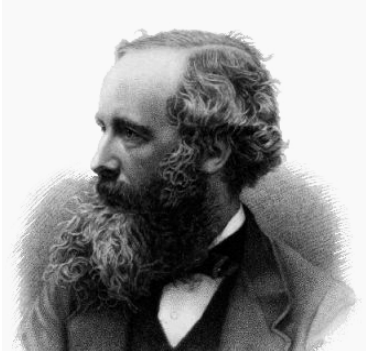
E&M waves:

$$\partial_t^2 \mathbf{E} - c^2 \partial_x^2 \mathbf{E} = 0$$

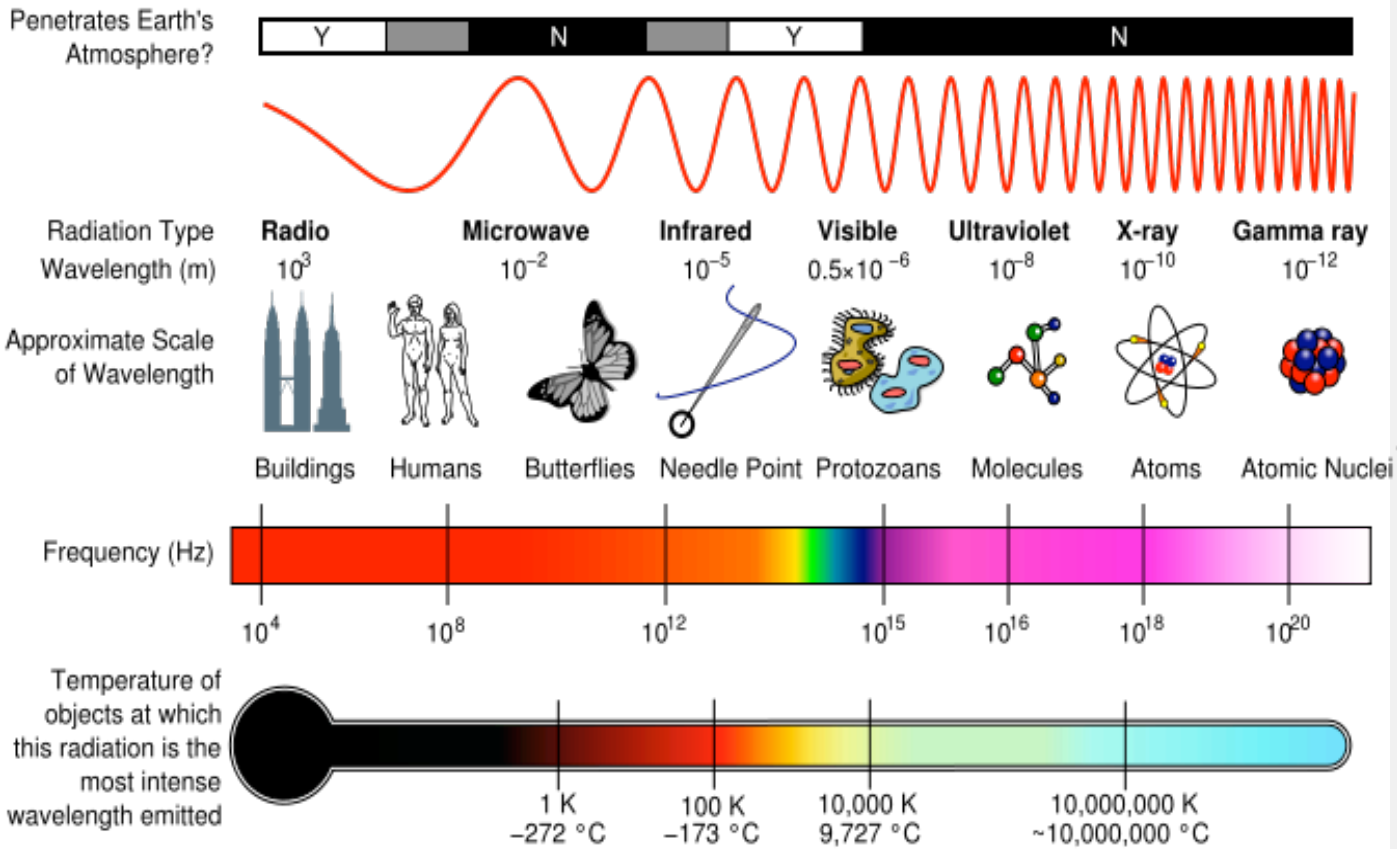


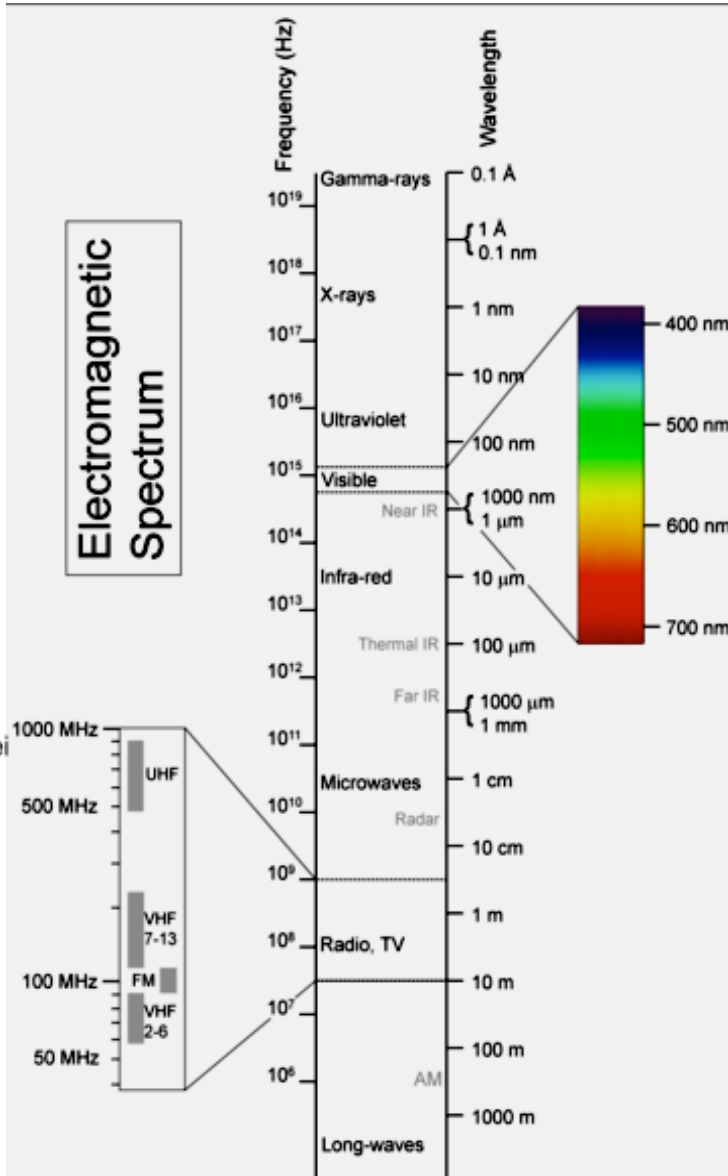
oscillating E and B fields

c = 300,000 km/s
= 186,000 mi/s
= 3 x 10^8 m/s
≈ 1 ft/nanosec



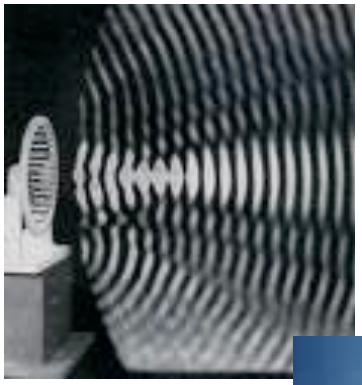
James Clerk Maxwell
1831-1879





EM-waves in what?

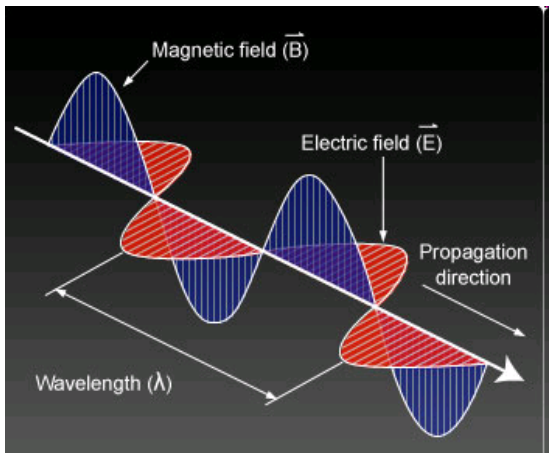
- *Sound wave* propagates through air, with velocity (330 m/sec) relative to *air*



- *Water waves* propagates through water, with velocity relative to *water*

- *"The wave"* propagates through a crowd in a stadium, with velocity relative to the *crowd*

- *Electromagnetic wave* propagates through what??? What is "moving"/oscillating?



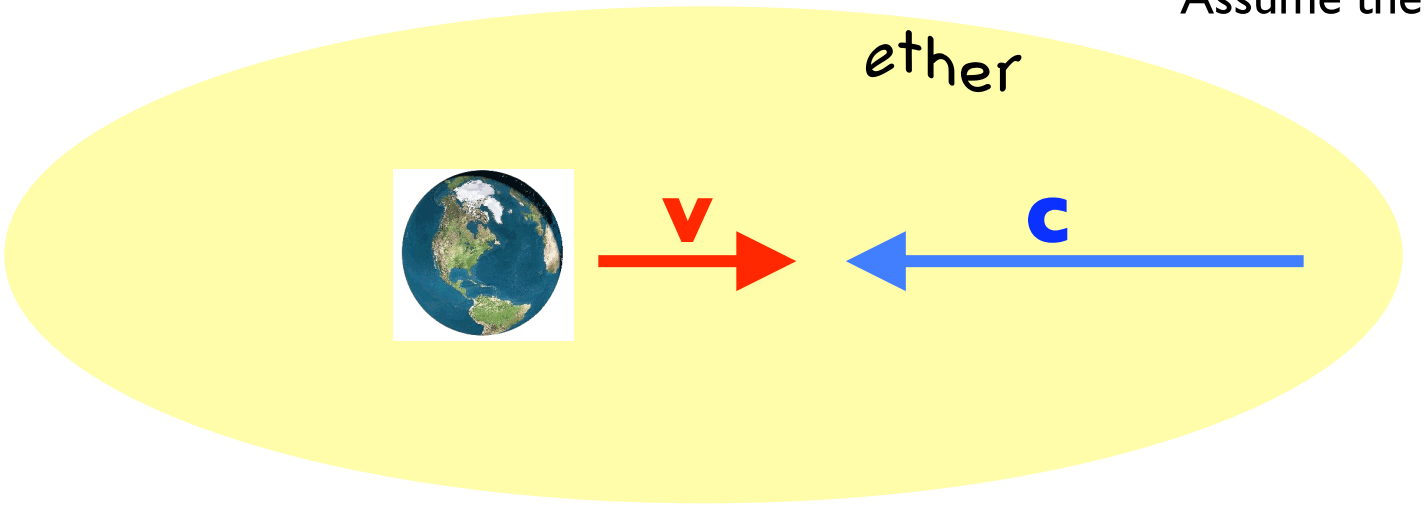
Ether...so it was (incorrectly) thought in 19th century before Einstein

clicker question

Motion through ether

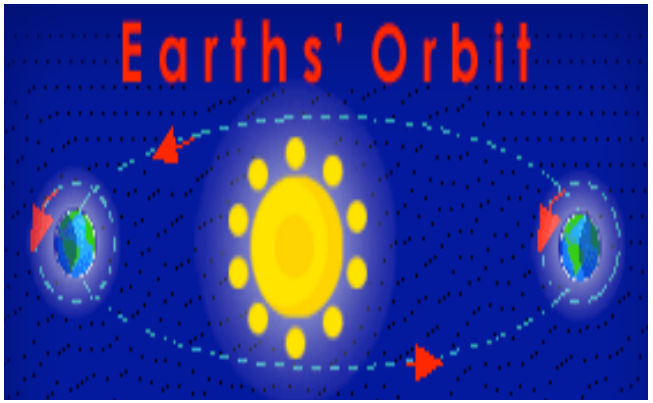
Q: *Suppose earth is moving through ether with speed v in a direction opposite to light, that moves with speed c relative to Ether. According to Galilean relativity what is speed of light relative to earth?*

* Assume the earth is not accelerating



a) c, **b) c+v,** c) c-v, d) none of the above

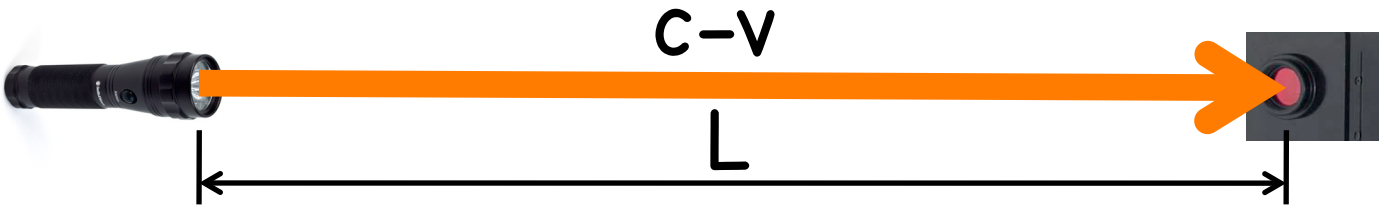
Measure earth's motion through ether



Earth goes around the sun at 30 km/s
→ must be going through ether

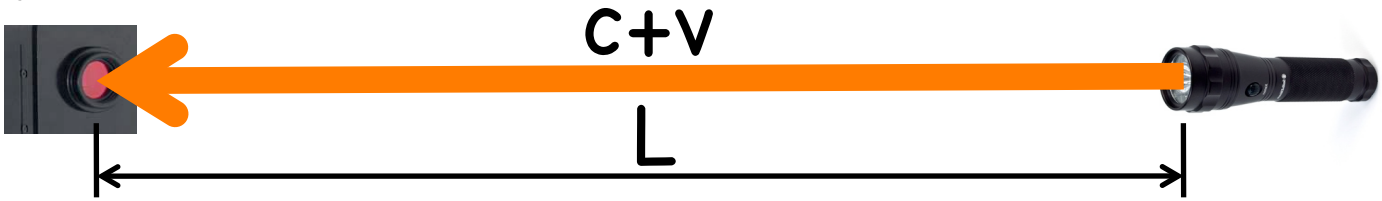
- light along earth's motion:

$$t_{\text{along}} = \frac{L}{c - v}$$



- light against earth's motion:

$$t_{\text{against}} = \frac{L}{c + v}$$



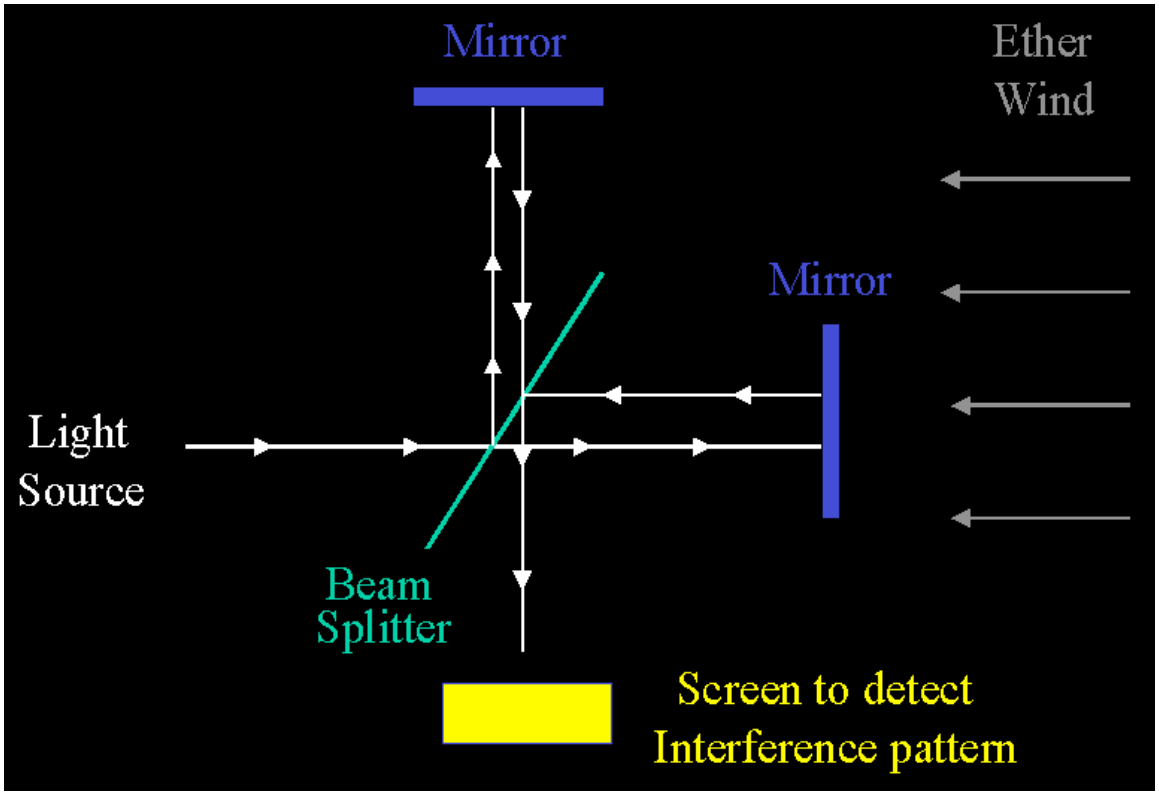
$$\Longrightarrow \quad \Delta t = t_{\text{along}} - t_{\text{against}} = \frac{L}{c - v} - \frac{L}{c + v} = \frac{2v}{c^2 - v^2} L$$

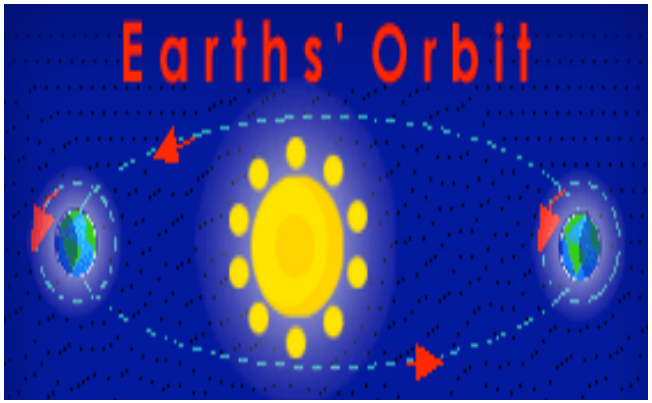
Michelson-Morley experiment, 1887

- measure speed of light in two two perpendicular directions
- interfere returned beams for higher accuracy, > 1 km/s

A.A. Michelson
1852 - 1931

E.W. Morley
1838 - 1923

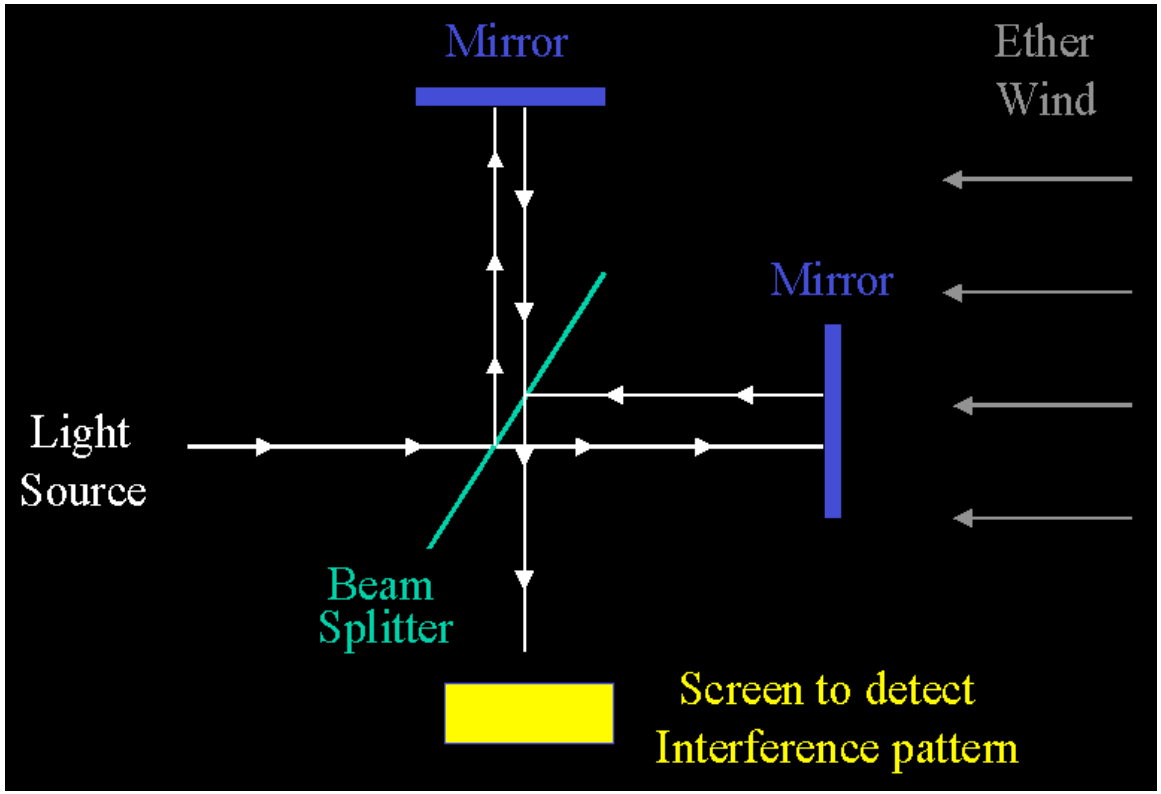


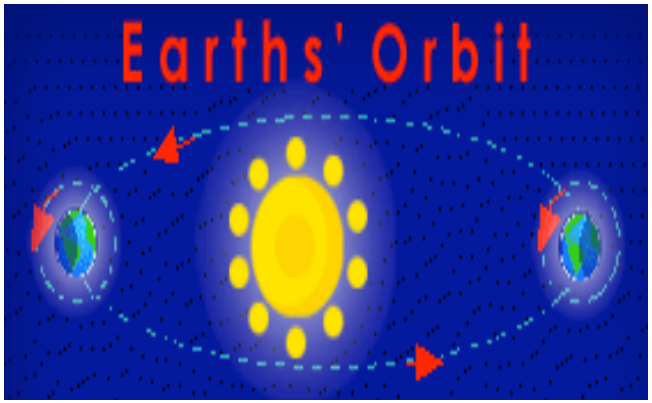


Michelson and Morley saw *nothing* !!!
i.e., no difference in time between two paths

View of experiment from Ether

- We are moving with v relative to Ether, so from Ether we look like we are moving in the opposite direction, i.e., with -v



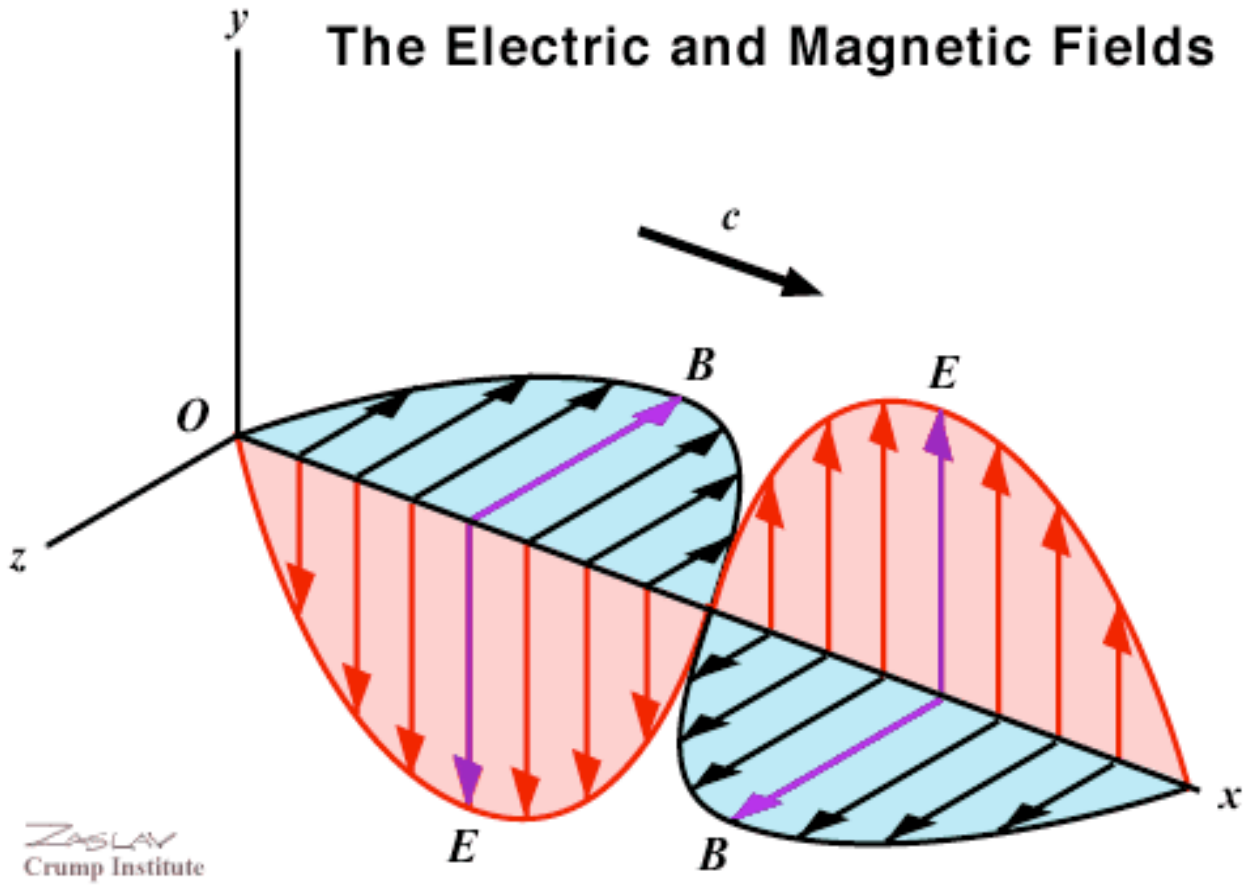


Michelson and Morley saw *nothing* !!!
i.e., no difference in time between two paths

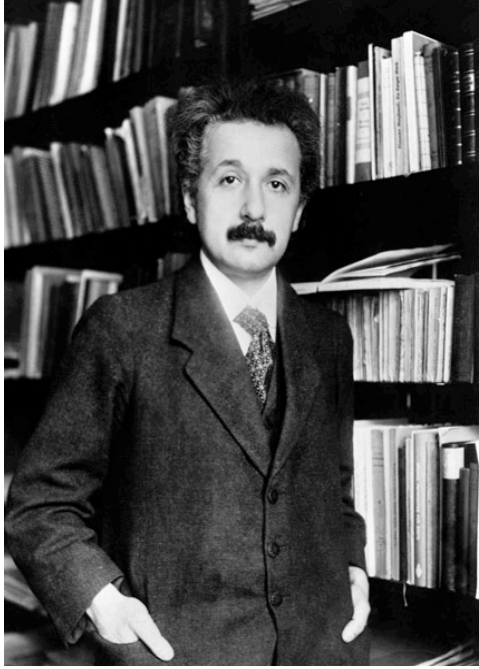
There is *no* ether

Electromagnetic waves are special:

A time-changing electric field induces a magnetic field, and vice-versa without any "ether".



Postulates of special relativity



Albert Einstein, 1879-1955

Postulates:

1.) *All laws of nature are same in all frames*

2.) *Speed of light, c is same in all all inertial frames*