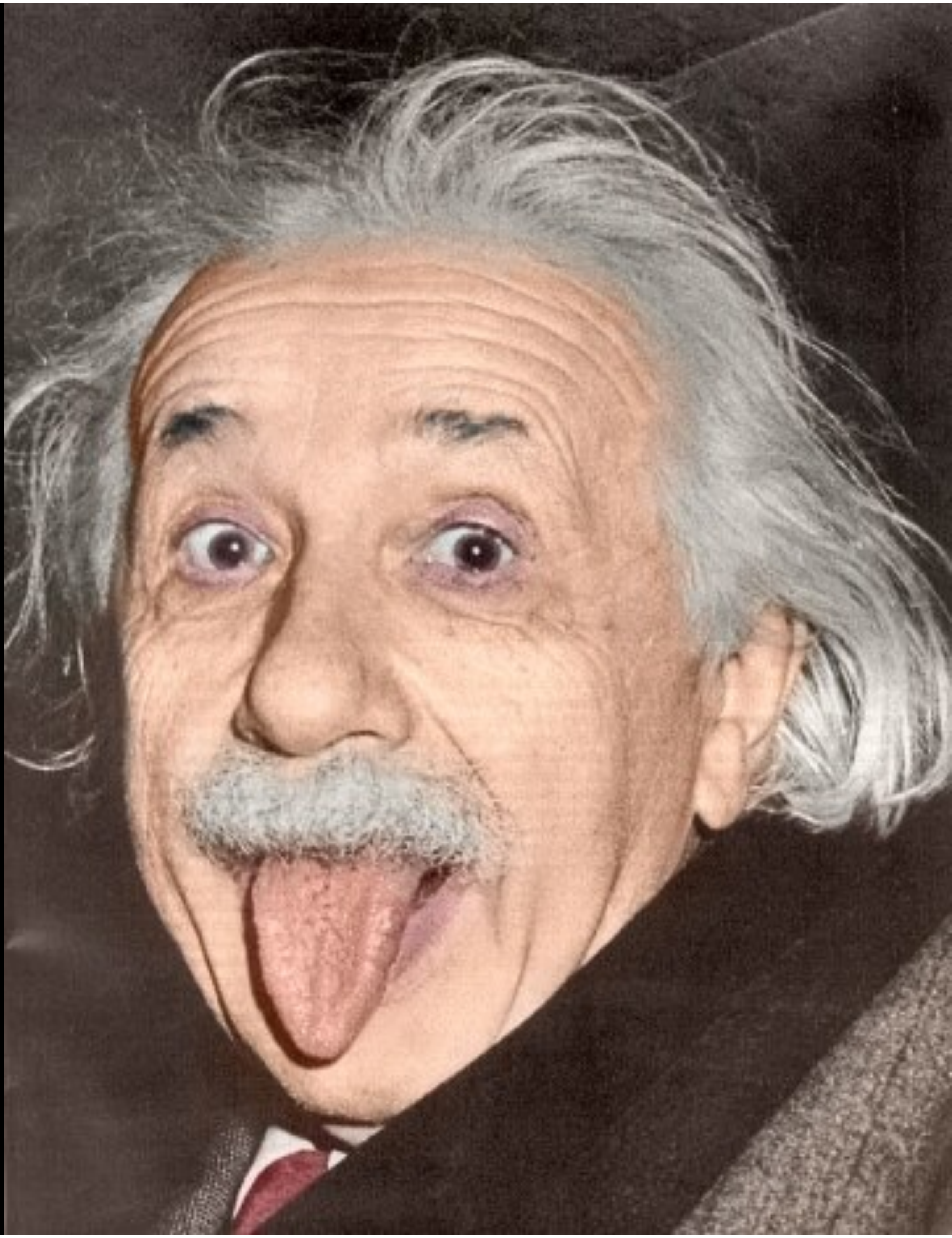
Special Theory of Relativity



The Name

"Relativity"

– Explains how observers experiencing relative motion will perceive each other.

"Special"

– Only strictly applies in situations without gravity (incorporating gravity requires General Relativity)

History

1887:

Michelson-Morley experiment

1892:

Henrik Lorentz' Equations

1905:

Einstein's Theory

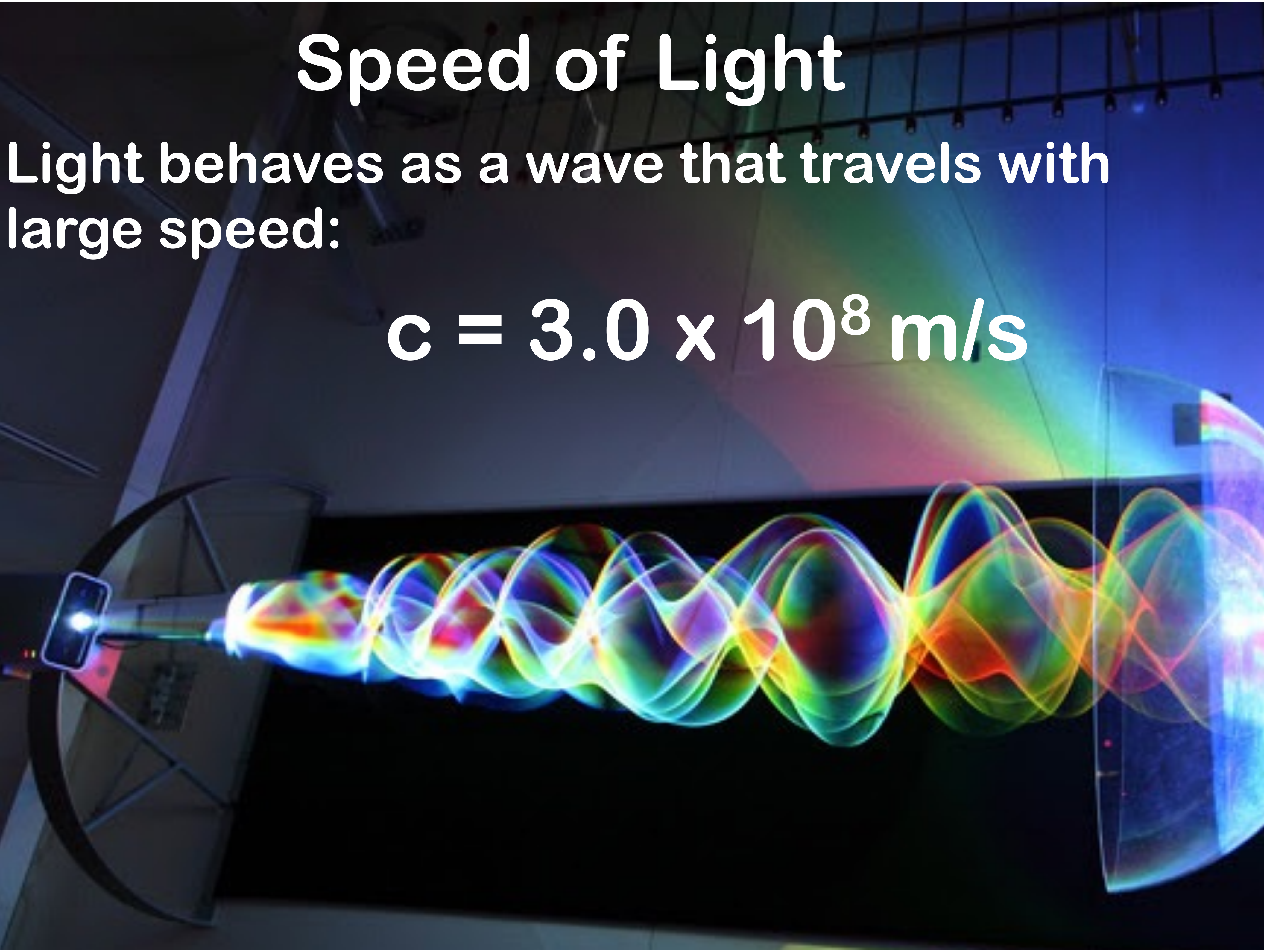
1907:

Minkowski's "Spacetime"

Speed of Light

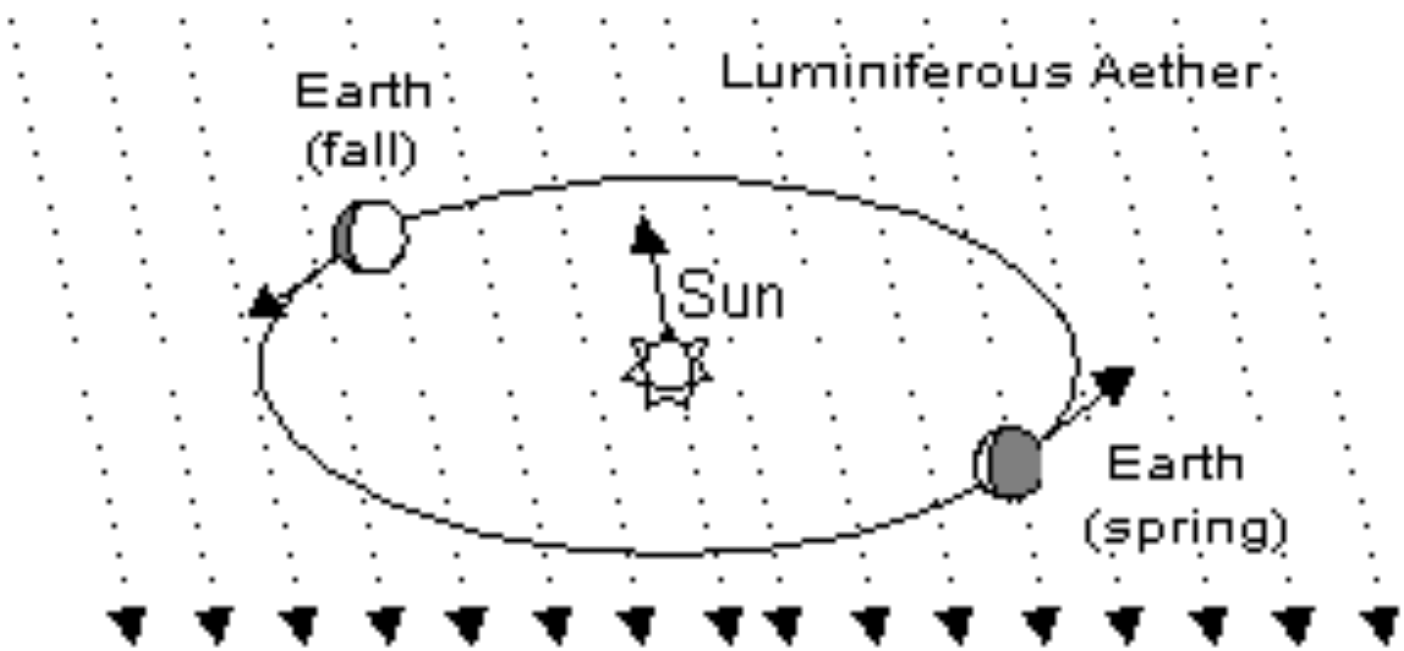
Light behaves as a wave that travels with large speed:

$$c = 3.0 \times 10^8 \text{ m/s}$$

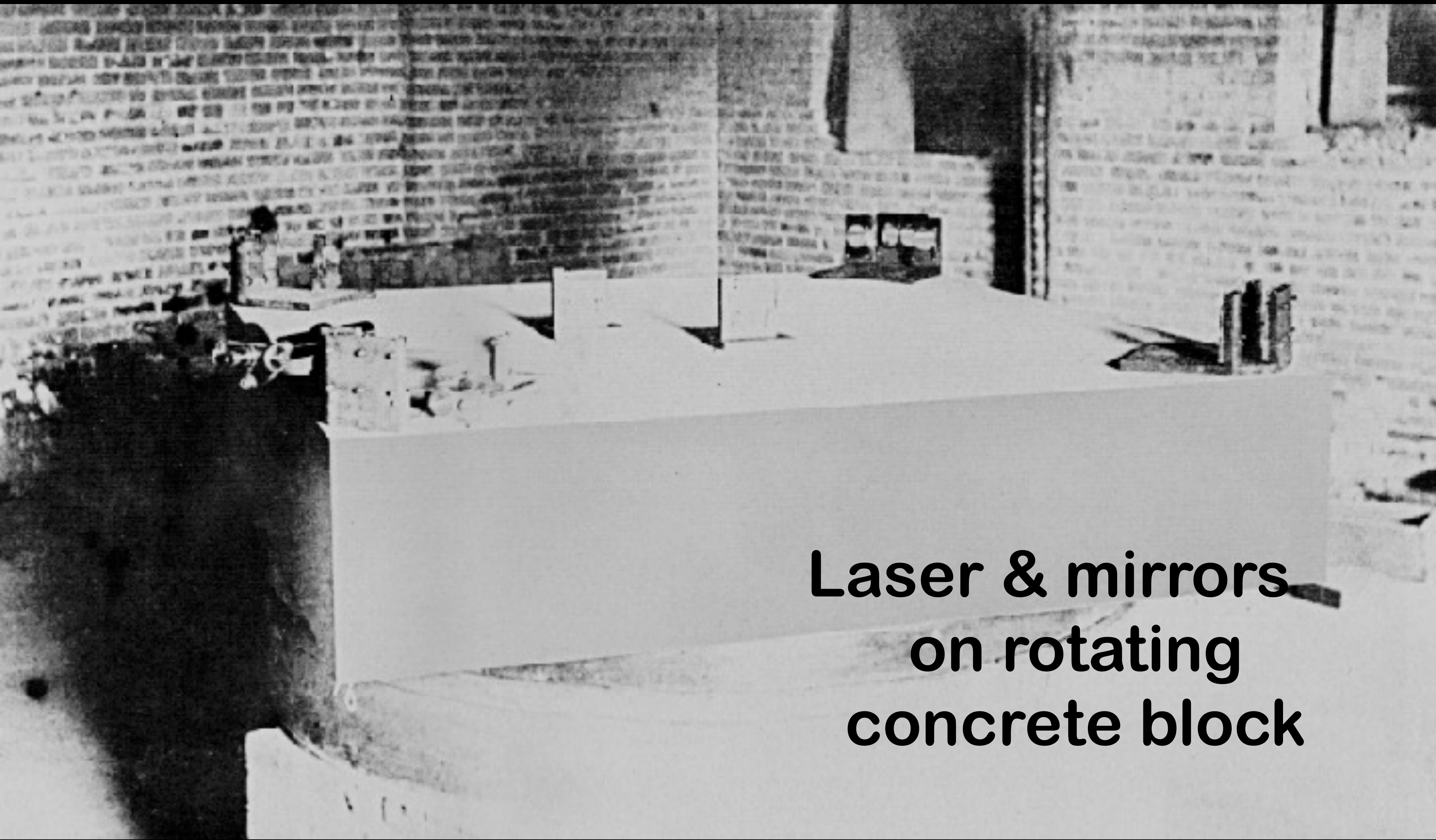


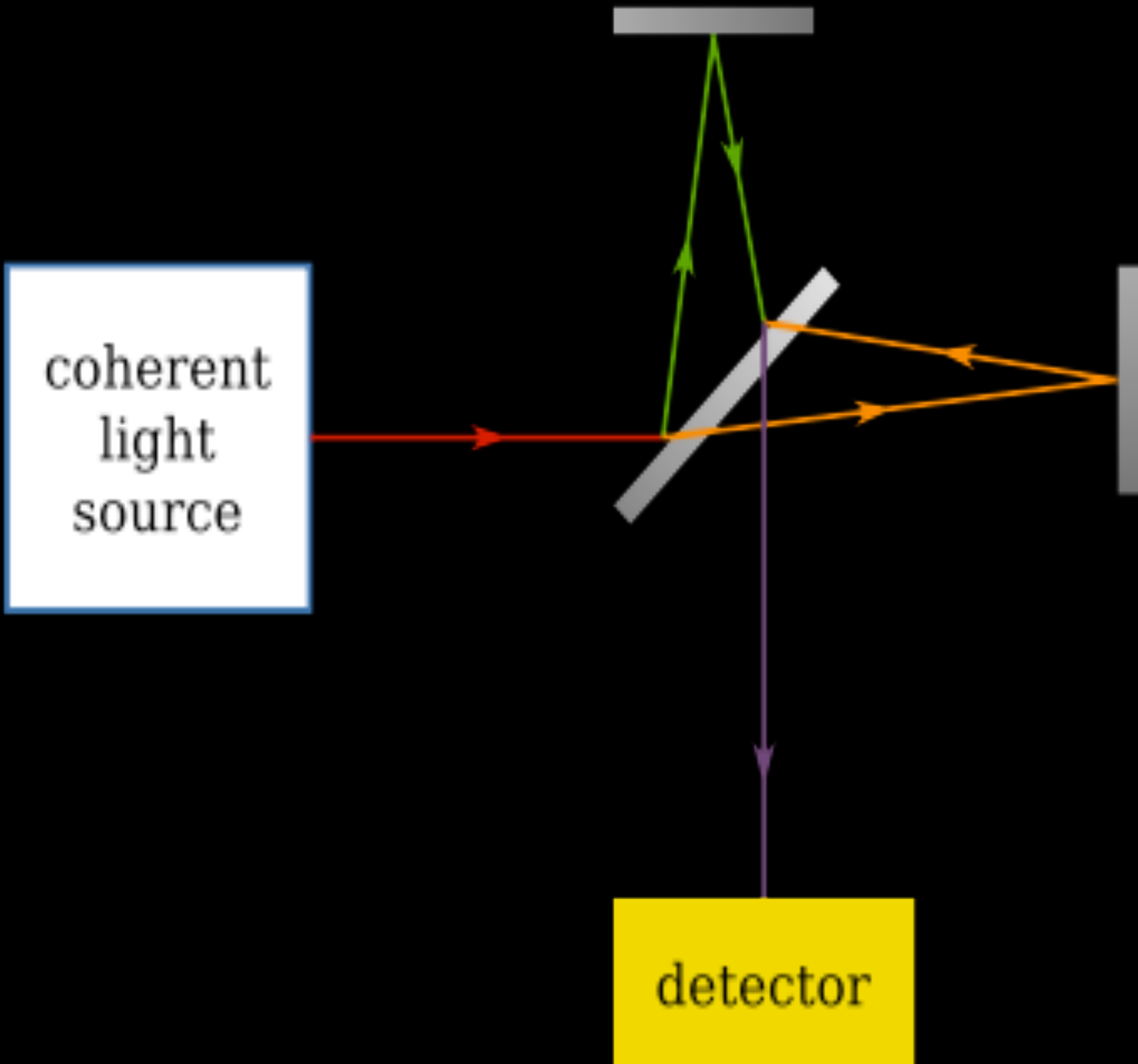
Physicists in the 1800's thought light waves needed a material to move through, like ocean waves need water.

They called this substance the "aether," and thought it filled the universe. They did experiments to detect it.



1887 Michelson-Morley Experiment





They expected the motion of Earth through "aether" to make the trip slower for one path.

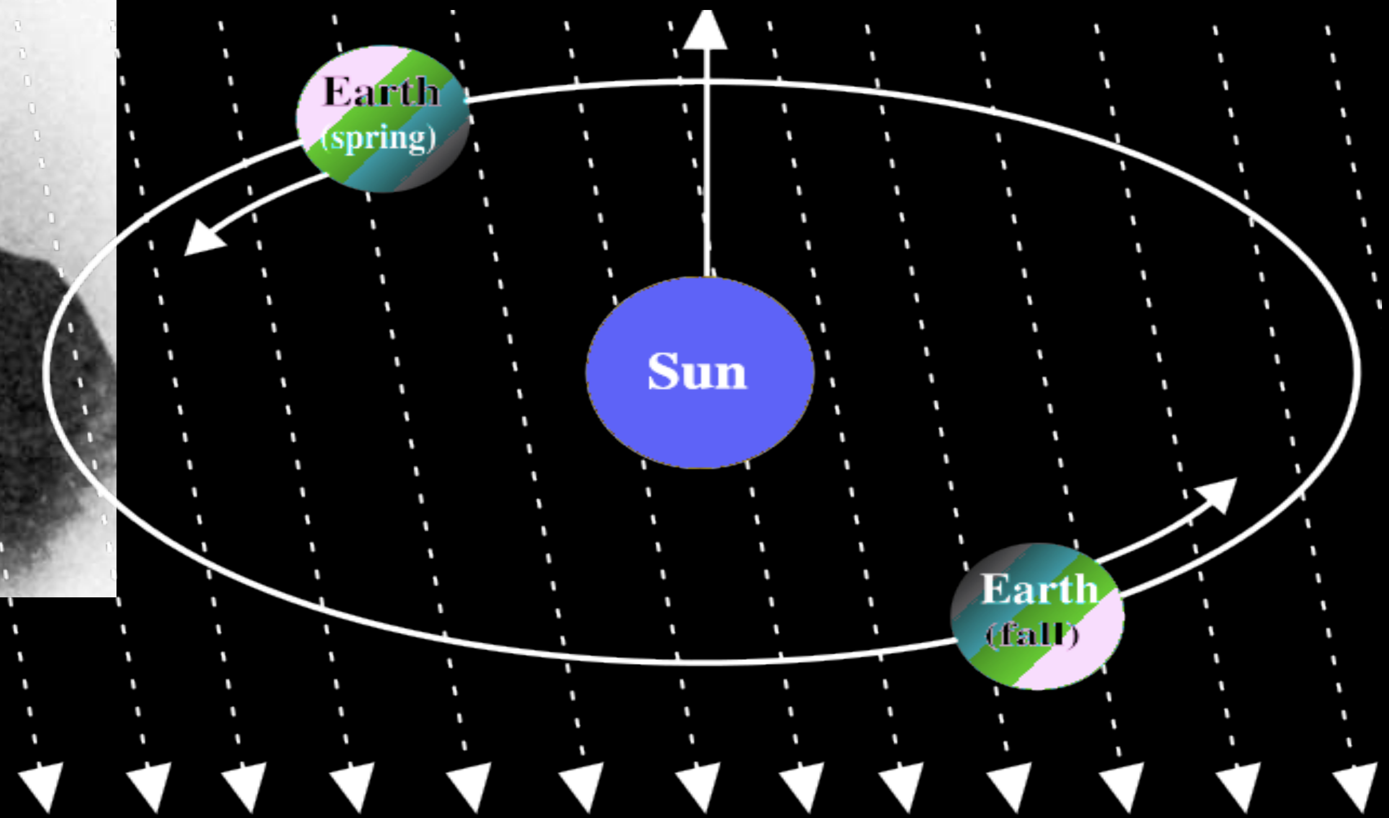
(Orange v. Green paths)

NO RESULT!!!

Repeated experiment in multiple locations – could not detect difference in speed of light under any circumstance.

1892 Lorentz Transformations

Set of math equations describing measurement in situations where speed of light is a constant.



Albert Einstein in 1905

Realized how to apply equations of Lorentz

Other stuff in 1905

Two “Postulates” (guiding principles) of Special Relativity:

1. The laws of physics are the same for anyone moving with constant velocity (“inertial frame”).
2. The speed of light is constant to all observers.

If observers are moving relative to each other, they disagree about measurements. The faster their relative motion, the bigger the effects. The Lorentz transformations describe their disagreeing measurements.

For motion in +x direction:

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

$$y' = y$$

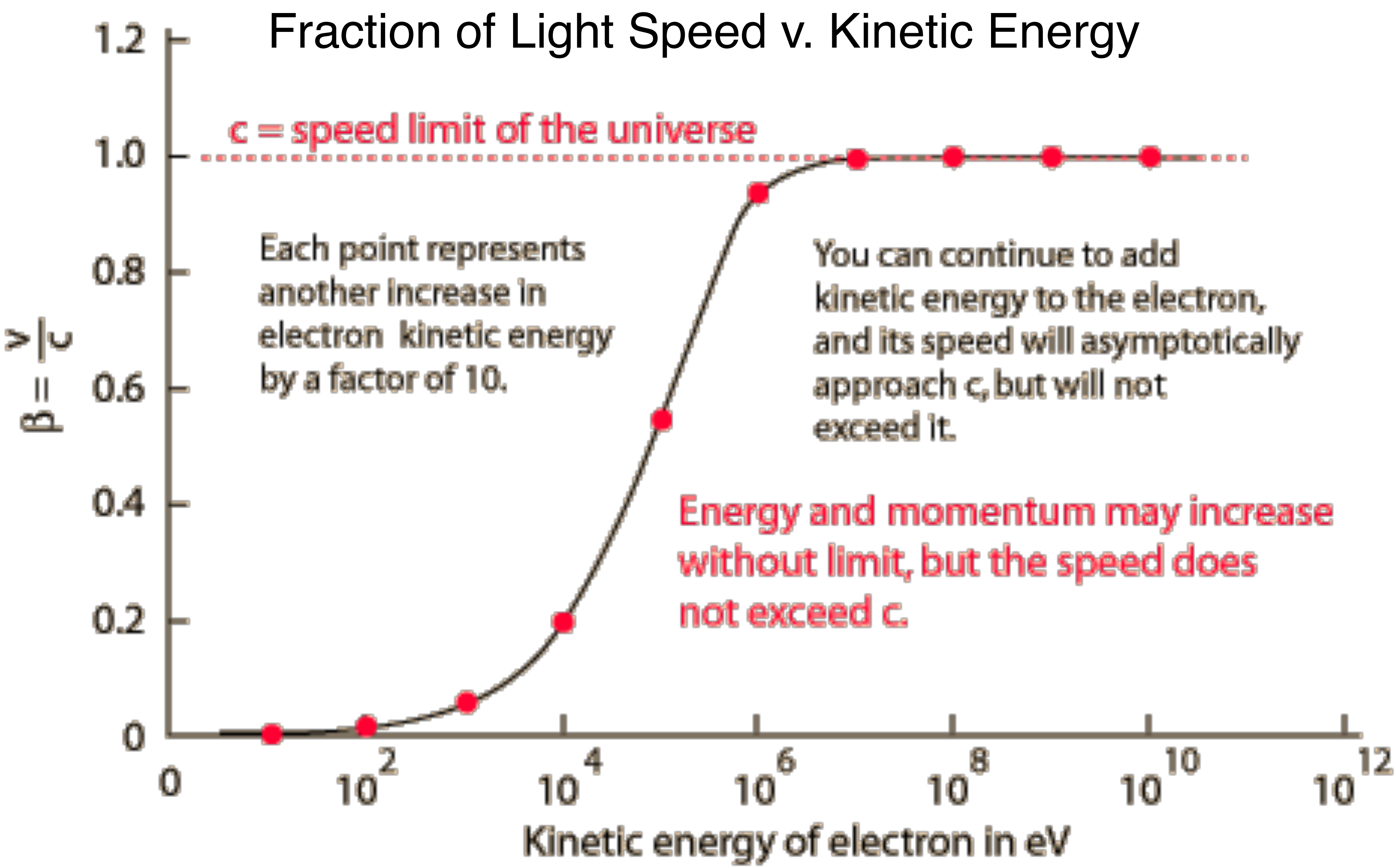
$$z' = z$$

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

Outcomes:

1. Speed of light = Speed Limit
2. Time dilation
3. Length contraction
4. Relativity of simultaneity
5. Non-Galilean velocity addition

1. Speed of Light = Speed Limit



2. Time Dilation — Muons

$v = 0$

$\tau_0 = 2.2\ \mu s$

$v = 0.995c$

$\tau = 22\ \mu s = 10\tau_0$

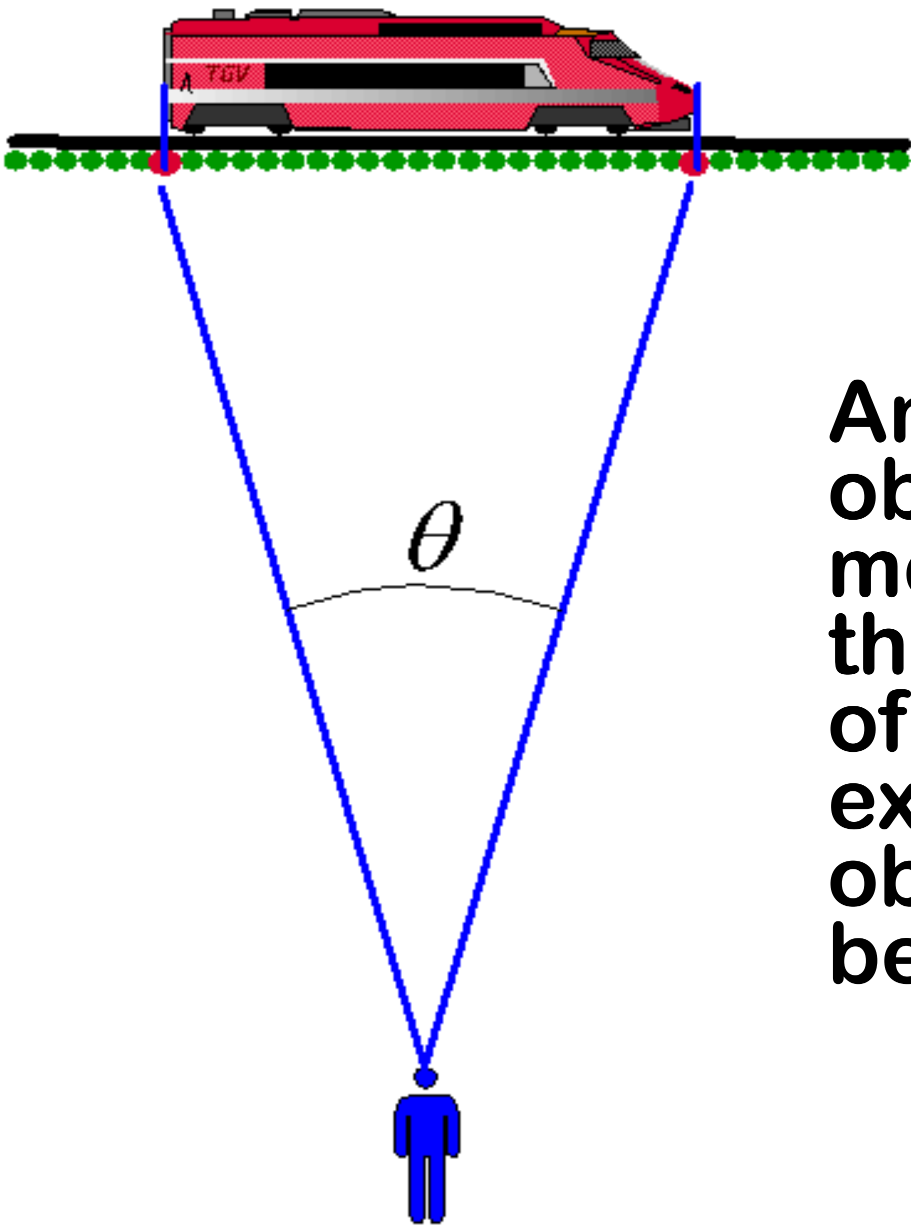
$v = 0.99995c$

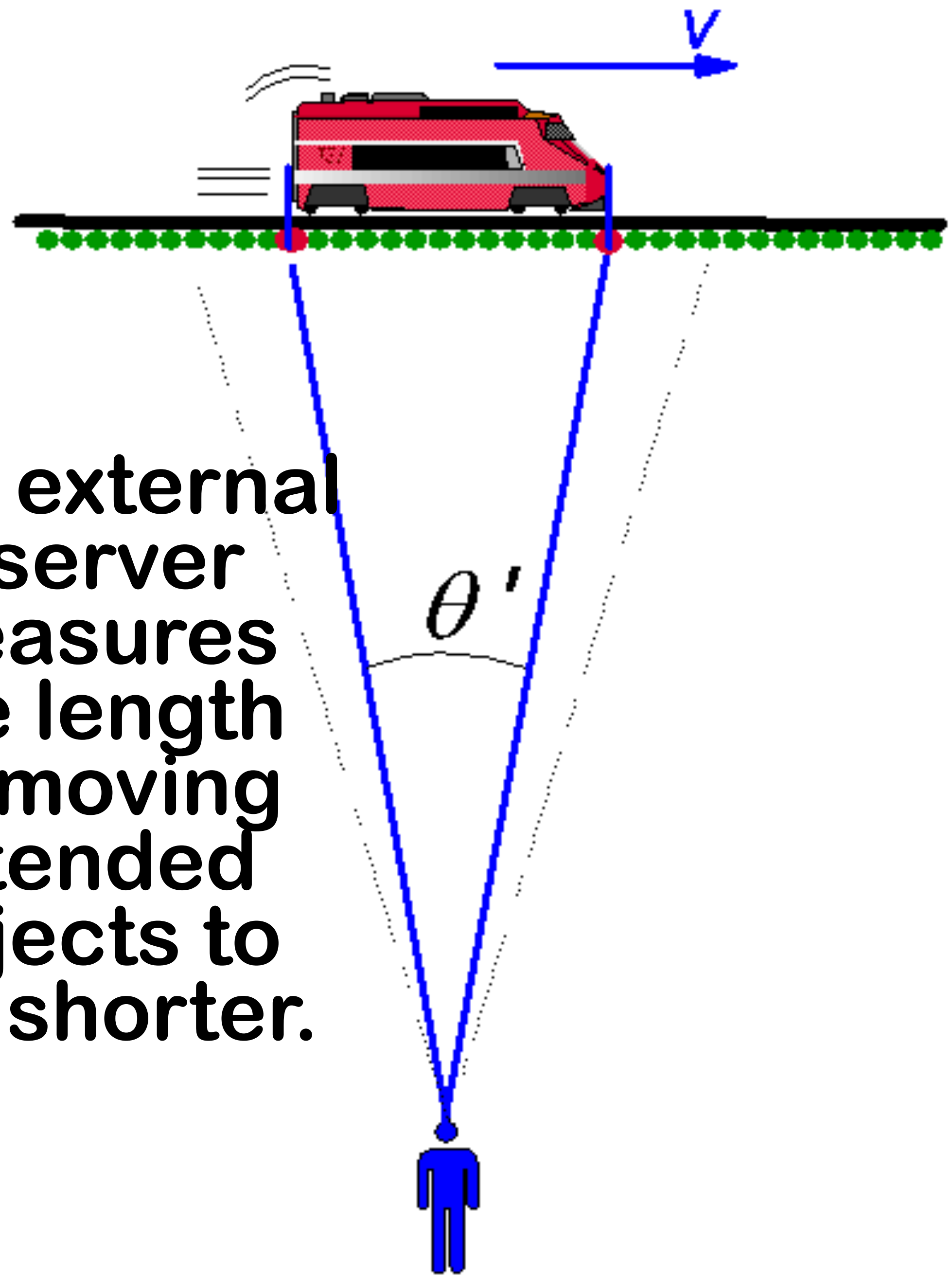
$\tau = 220\ \mu s = 100\tau_0$

Mean lifetime τ as measured in laboratory frame

The mean lifetime of a muon in its own reference frame, called the proper lifetime, is $\tau_0 = 2.2\ \mu s$. In a frame moving at velocity v with respect to that proper frame, the lifetime is $\tau = \gamma\tau_0$, where γ is the time dilation factor.

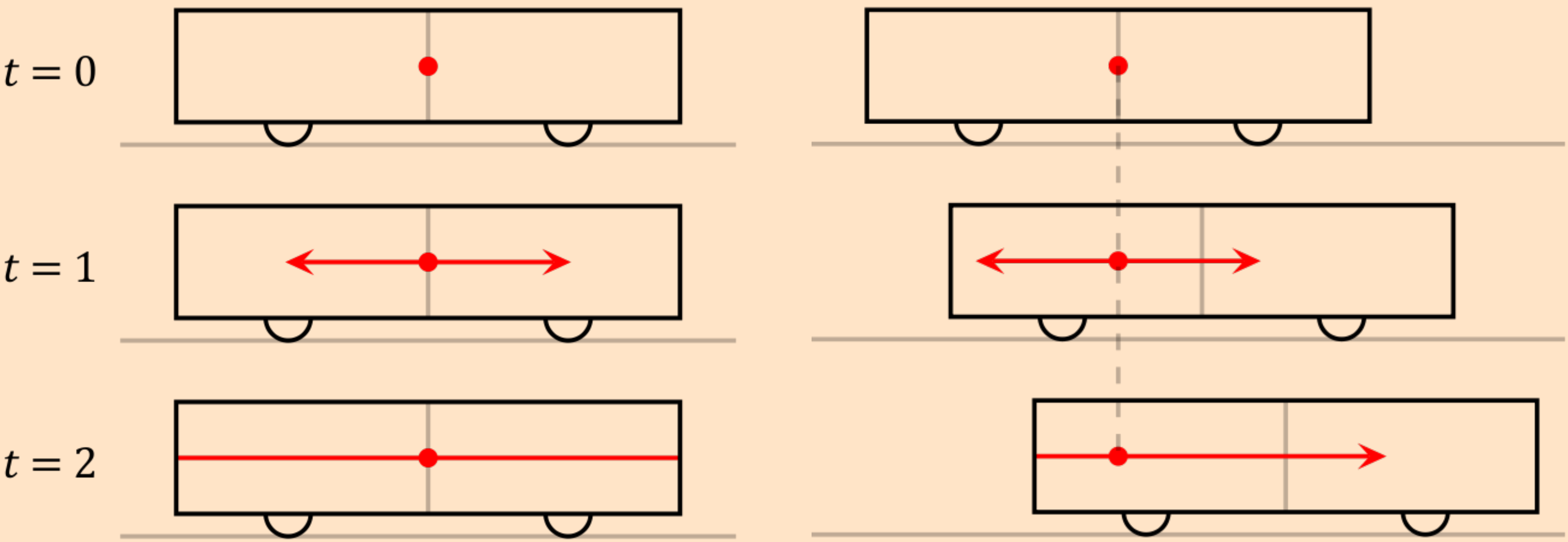
3. Length Contraction





An external observer measures the length of moving extended objects to be shorter.

4. Relativity of Simultaneity



On Board Observer:

Light Hits Walls Same Time

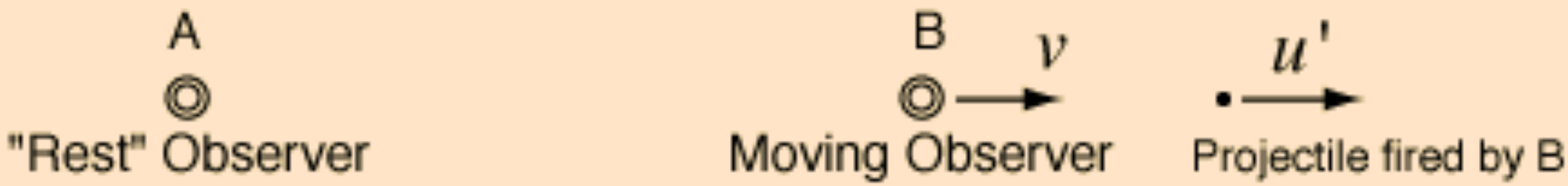
External Observer:

Light Hits Back Wall First

5. Relativistic Velocity Addition

Ship flying over half of c fires torpedoes that can move over half of c…

What does observer at rest see?



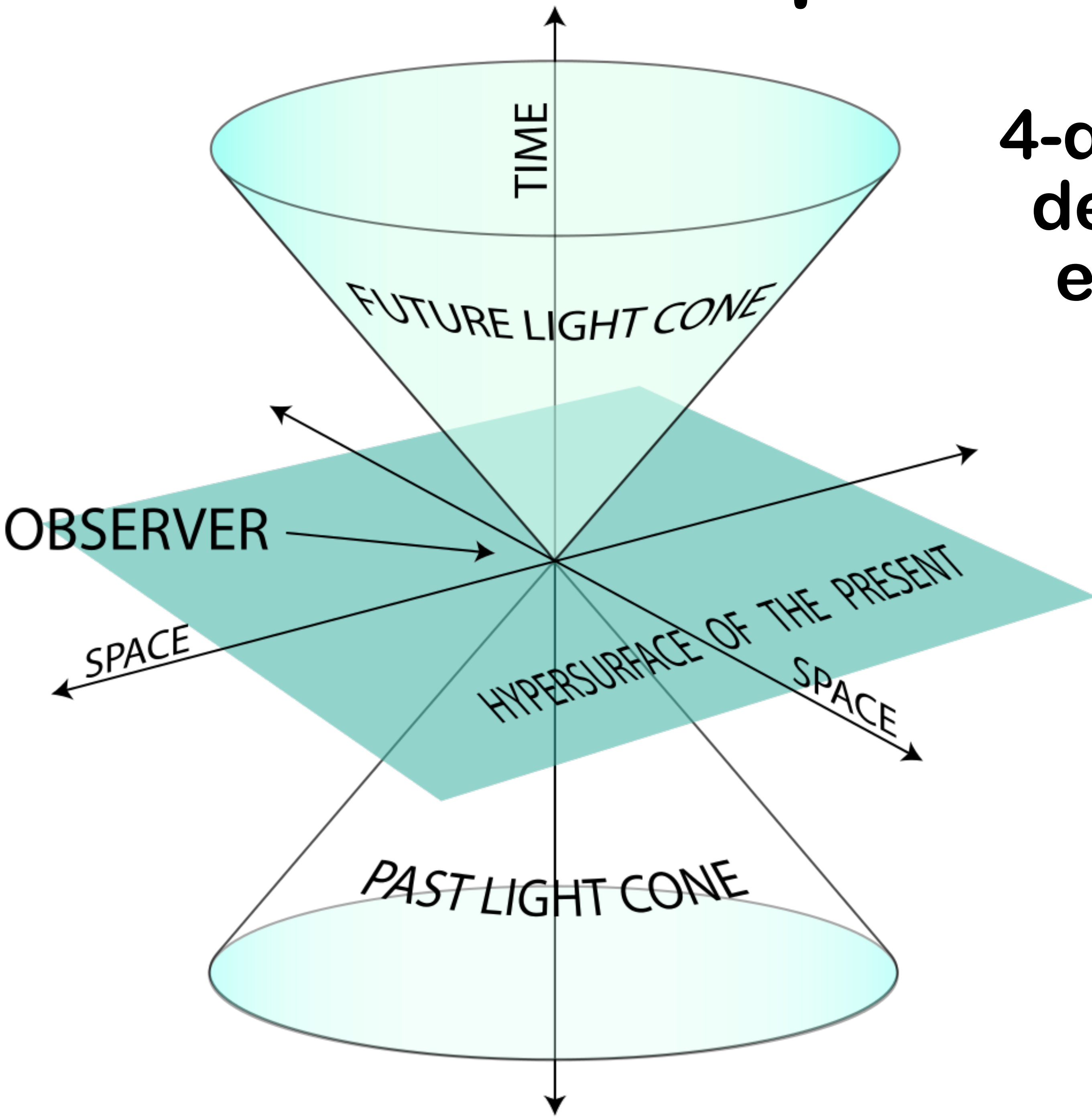
$$u = \frac{v + u'}{1 + \frac{vu'}{c^2}}$$

u' = velocity of projectile as seen by B

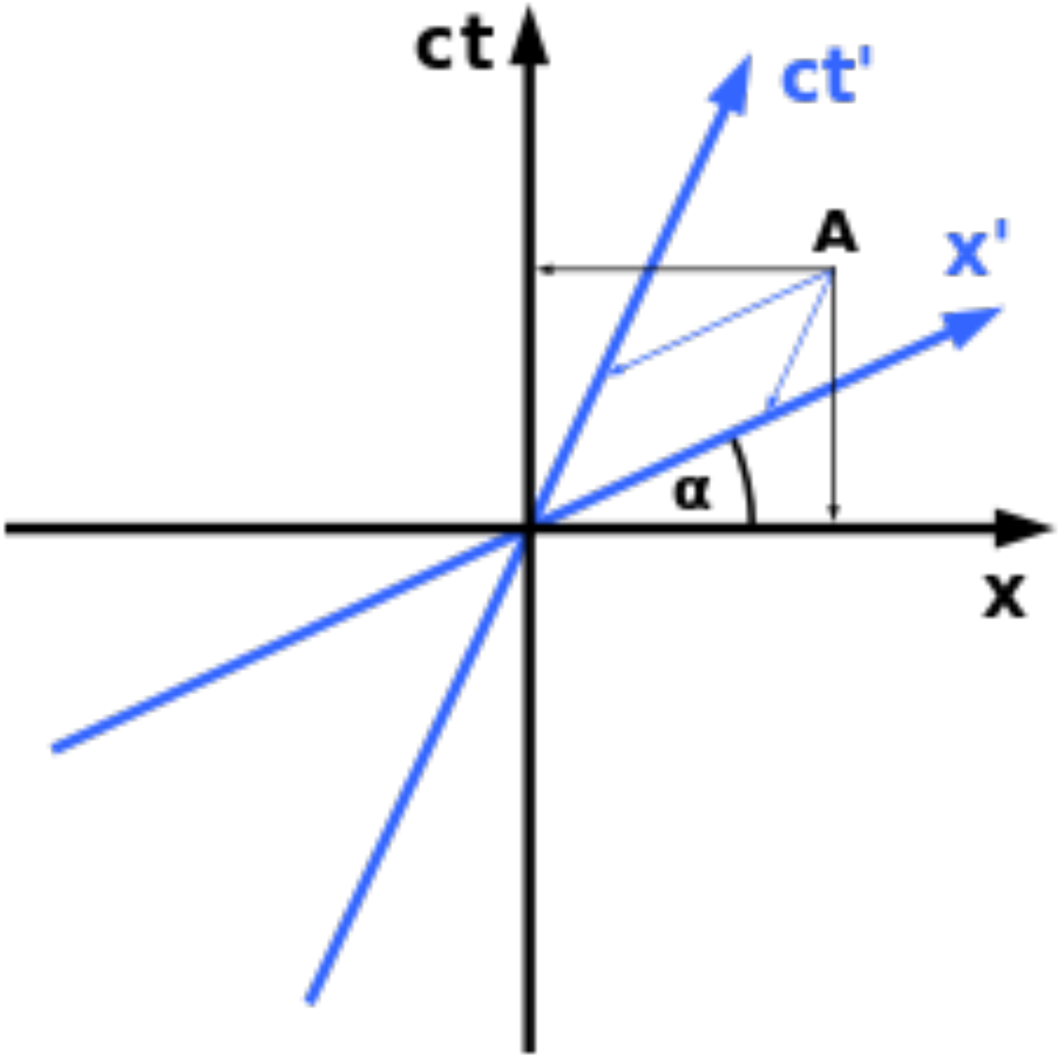
u = velocity of projectile as seen by A

$$u' = \frac{u - v}{1 - \frac{uv}{c^2}}$$

1907 Minkowski Spacetime



4-dimensional description of events in the universe.



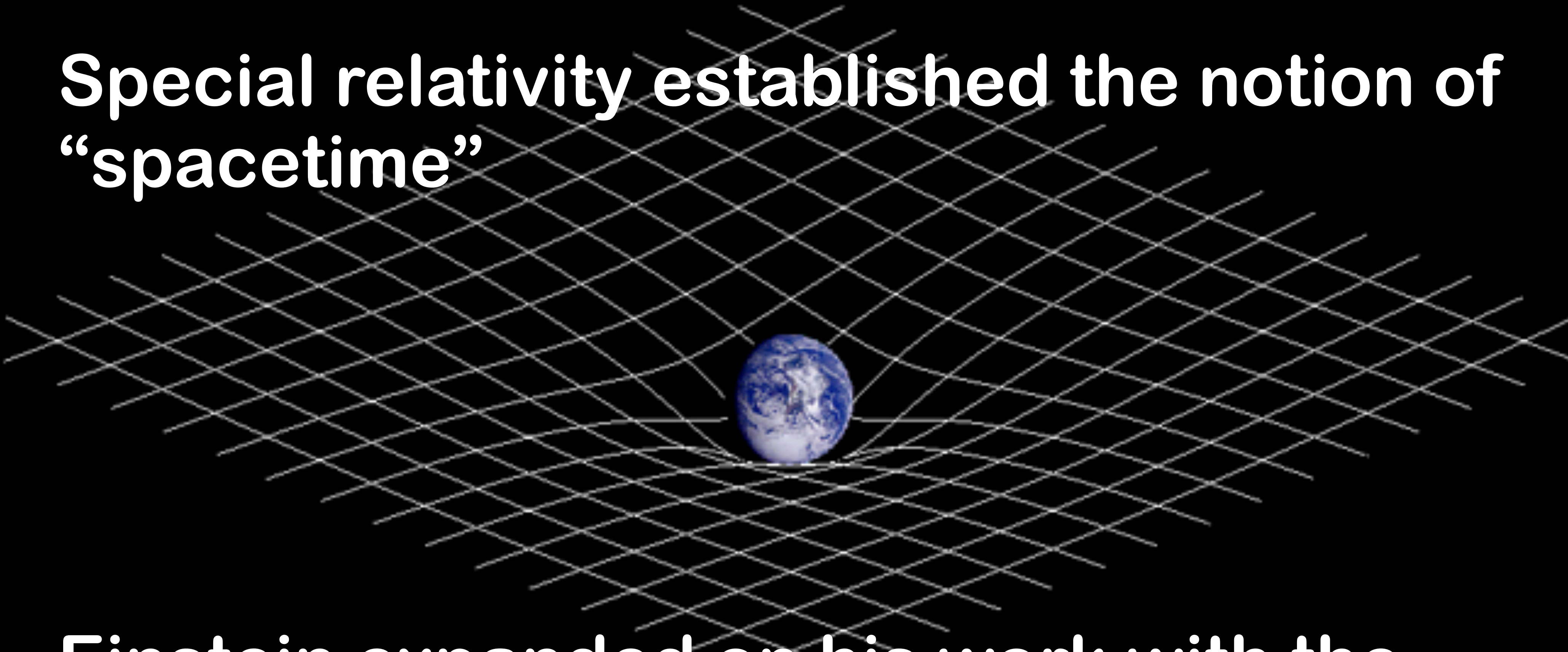
Blue frame in relative motion compared to rest frame.

Observers in the two frames disagree about timing and placement of event A

$$\tan(\alpha) = \frac{v}{c} = \beta$$

1908 and beyond…

Special relativity established the notion of "spacetime"



Einstein expanded on his work with the theory of General Relativity in 1915, which can also describe accelerating objects and gravitational fields.

SUMMARY

Einstein's Special Theory of Relativity is built on the idea that all observers measure the speed of light as a constant. As a result, observers disagree about their measurements; all descriptions of the universe are relative.

Philosophical Musings:

- All measurement and experience is relative; we can only describe the world with respect to our own viewpoint.
- There is no “absolutely true” frame of reference better than any other.