# Announcements

- Problem 2 is now available!
  - due 02/02 @ 11:59pm
- Exploration paper 1 is also now available!

# Today:

- Einstein, special relativity, general relativity
- Time dilation

# Newton’s concept of time

Time moves forward *continuously from past to future*

Time is completely *independent* from 3d space

*Everyone* experiences time the same way

Doctor Who
"Blink"

Written:
Steven Moffat

BBC (2007)

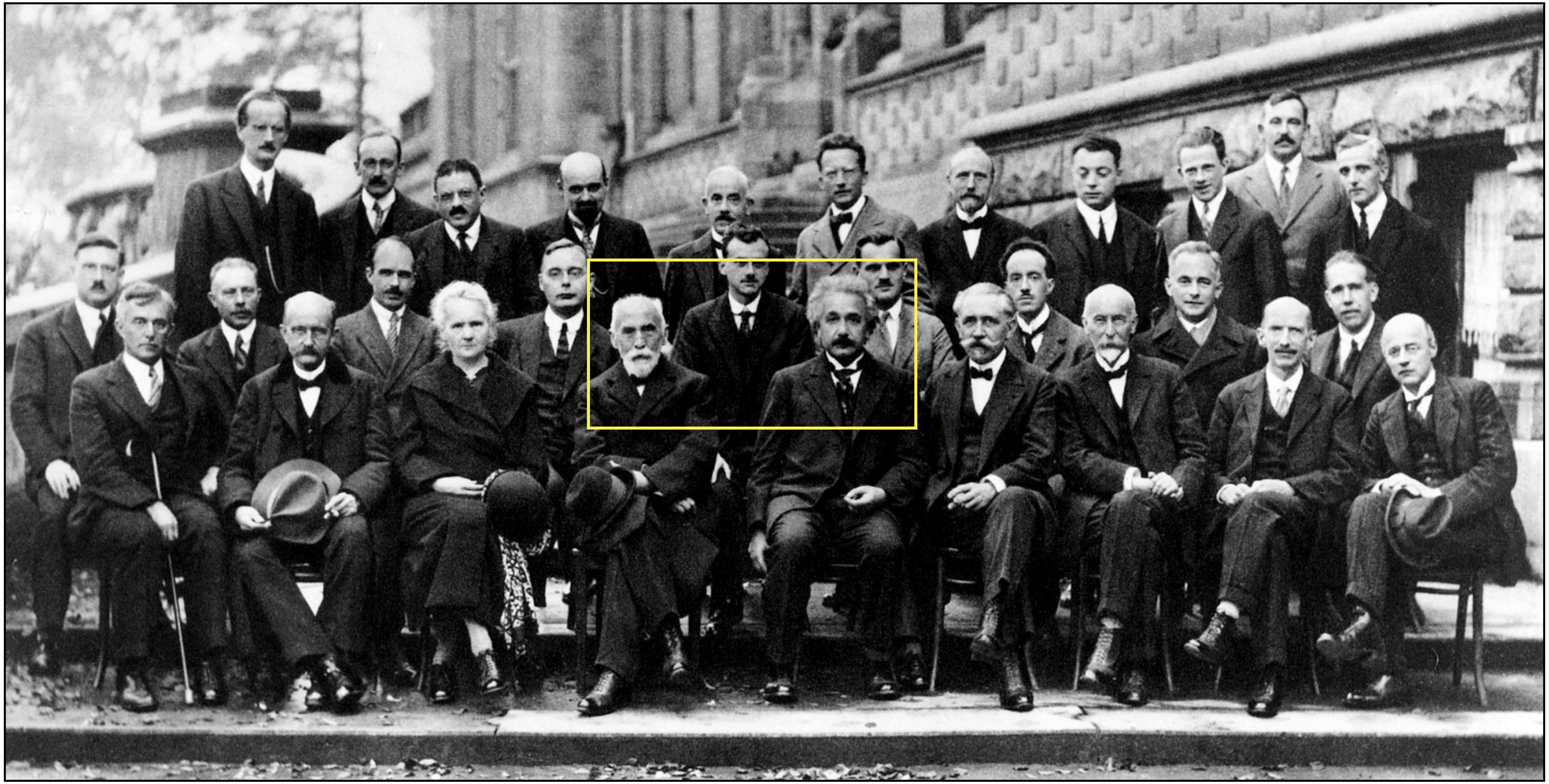
“It’s bigger on the inside”


# The T.A.R.D.I.S.

Time
And
Relative
Dimension
In
Space

Doctor Who explores the concepts of time & time travel

~ wibbly, wobbly, timey, wimey ~



Top row: A. Piccard, E. Henriot, P. Ehrenfest, E. Herzen, Th. De Donder, E. Schrödinger, J.E. Verschaffelt, W. Pauli, W. Heisenberg, R.H. Fowler, L. Brillouin;
Middle row: P. Debye, M. Knudsen, W.L. Bragg, H.A. Kramers, P.A.M. Dirac, A.H. Compton, L. de Broglie, M. Born, N. Bohr;
Bottom row: I. Langmuir, M. Planck, M. Curie, H.A. Lorentz, A. Einstein, P. Langevin, Ch. E. Guye, C.T.R. Wilson, O.W. Richardson

# Special relativity: 1905

The speed of light is constant in
*all reference frames*

Time and space are described as a single 4-dimensional spacetime

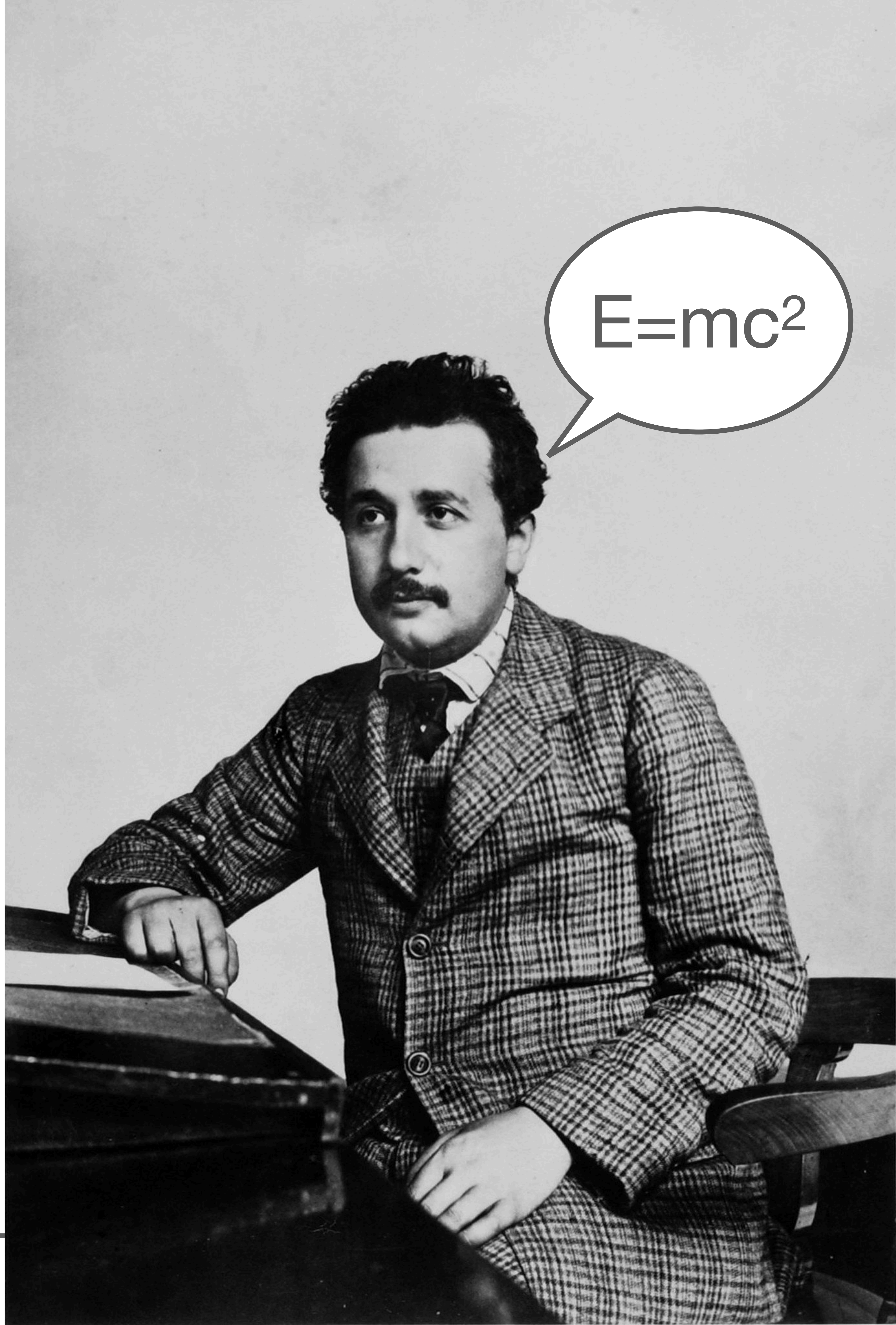
spacetime = (x, y, z, c * t)

# Special relativity: 1905

The speed of light is constant in *all reference frames*

Time and space are described as a single 4-dimensional spacetime

Perception of space and time depends on relative motion

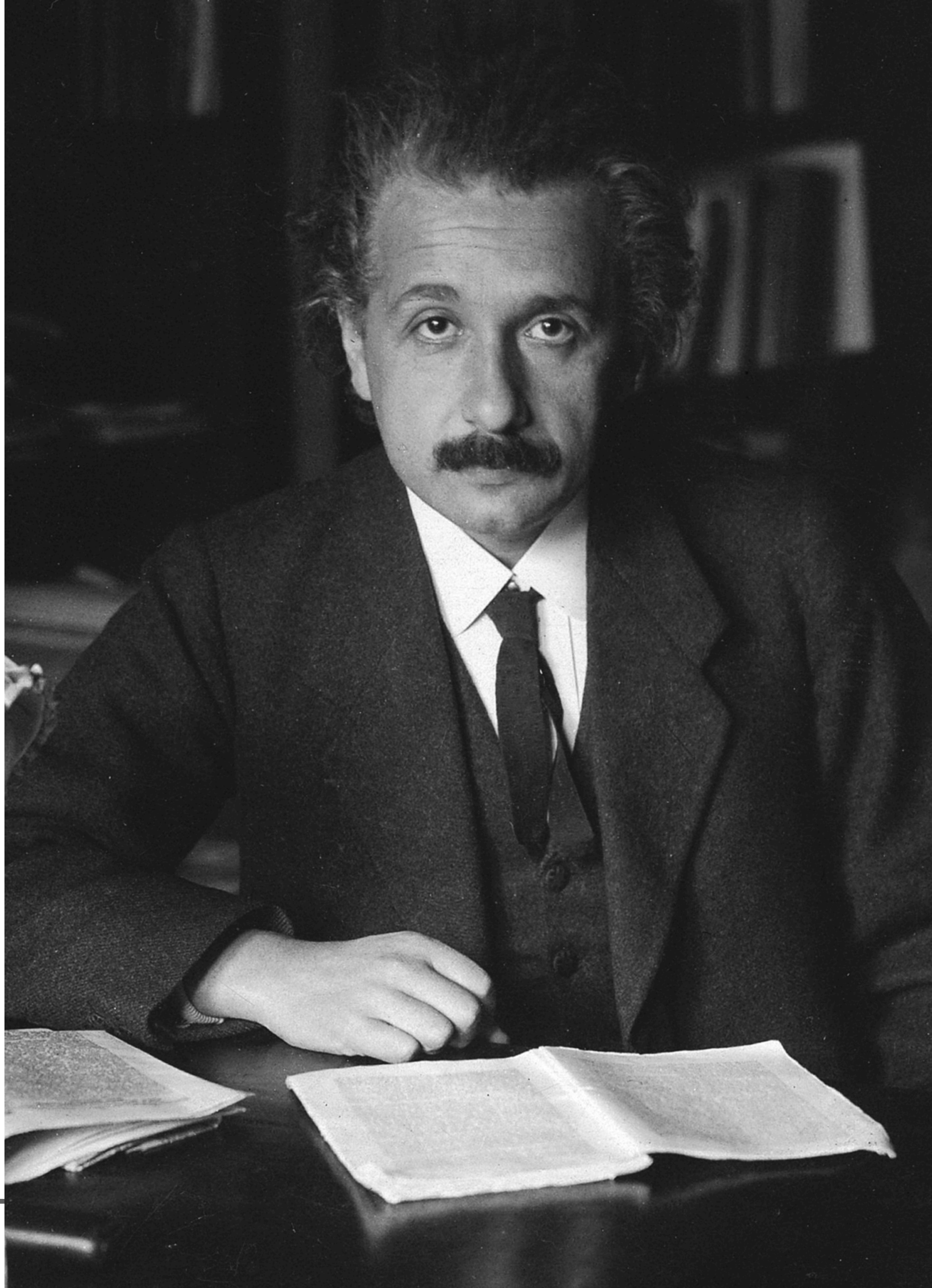


# General relativity: 1915

The speed of light is constant in *all reference frames*

Time and space are described as a single 4-dimensional spacetime **that move at the speed of light**

Gravity is the manifestation of mass distorting spacetime




# The Time Machine

H.G. Wells

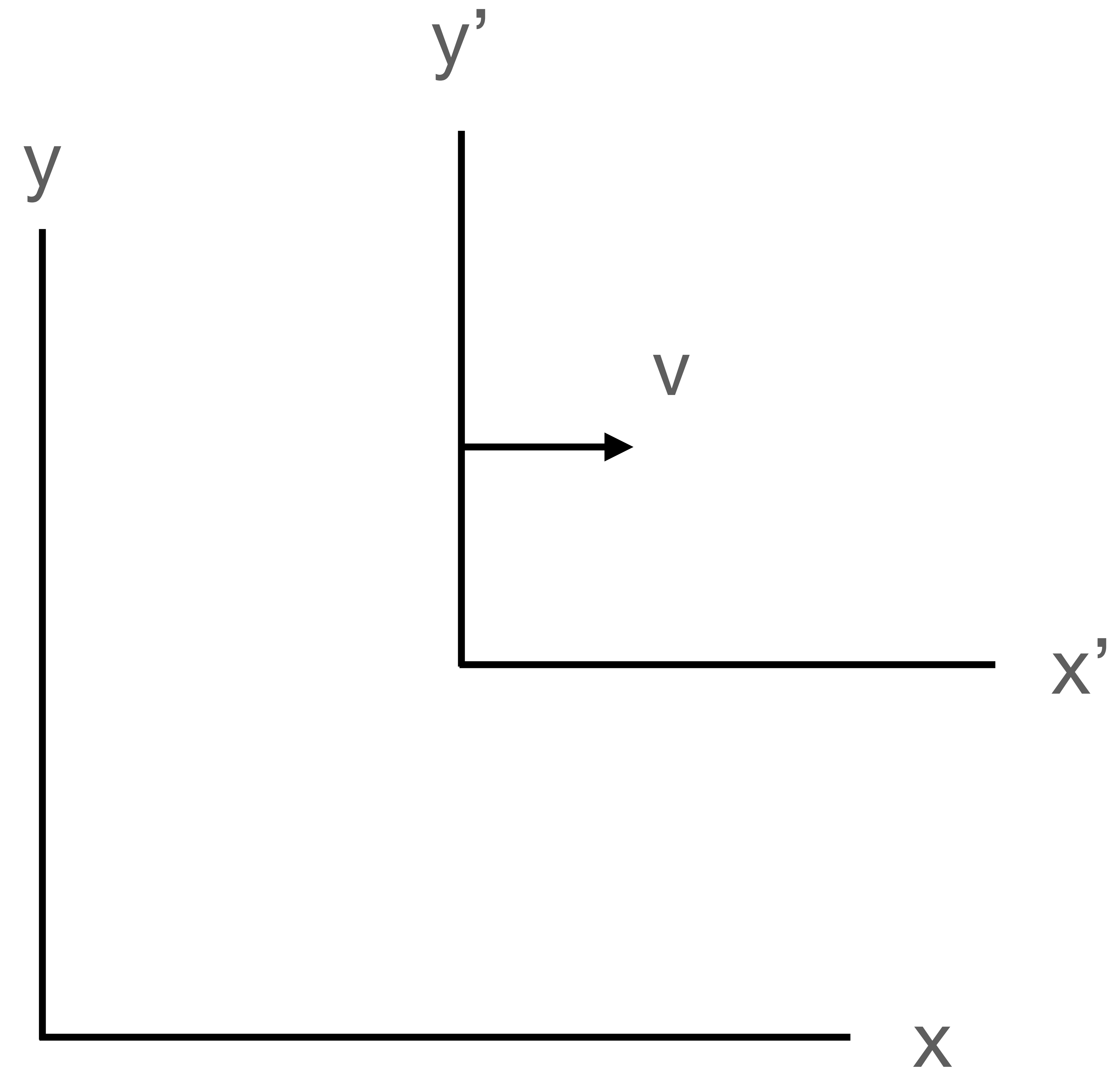
—

published in **1895!**

See page 26 in chapter 2 of the textbook for an excerpt!

# Special relativity:

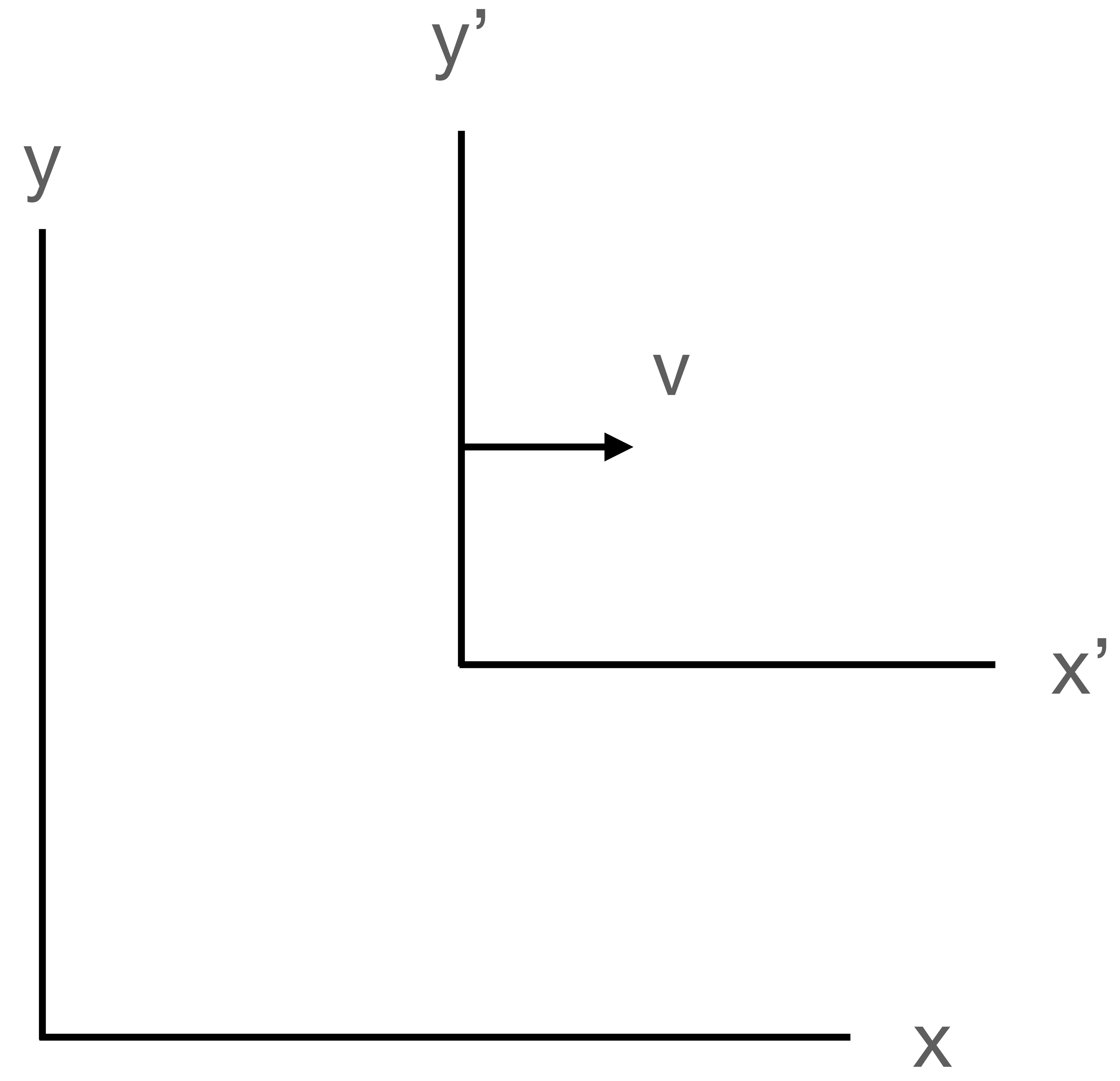
relative motion between reference frames introduces differences in how quickly time passes according to observers in each reference frame



Time dilation

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

What can we say about time in each frame?



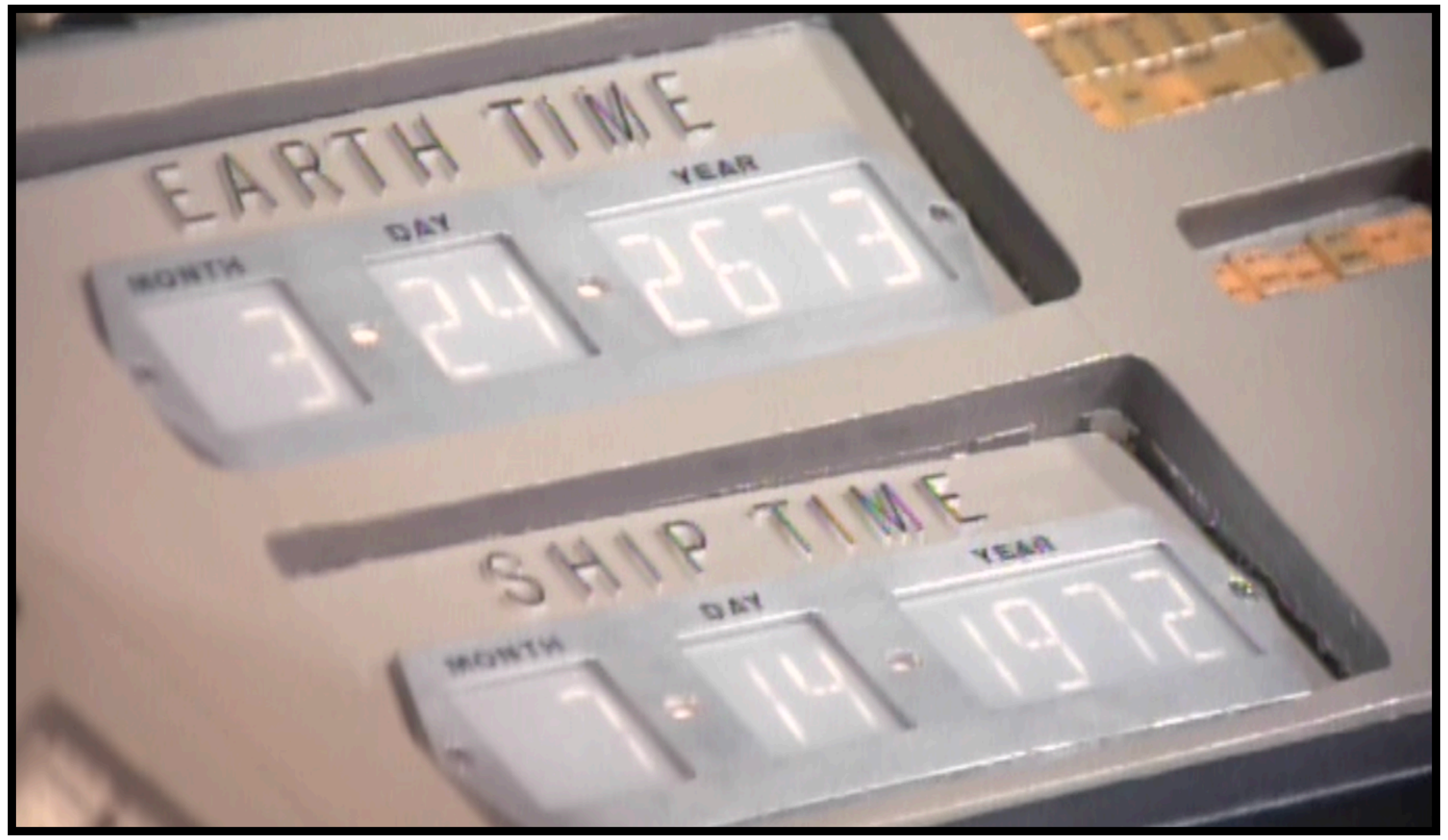

Time moves **faster** in rest frame; **slower** in moving frame

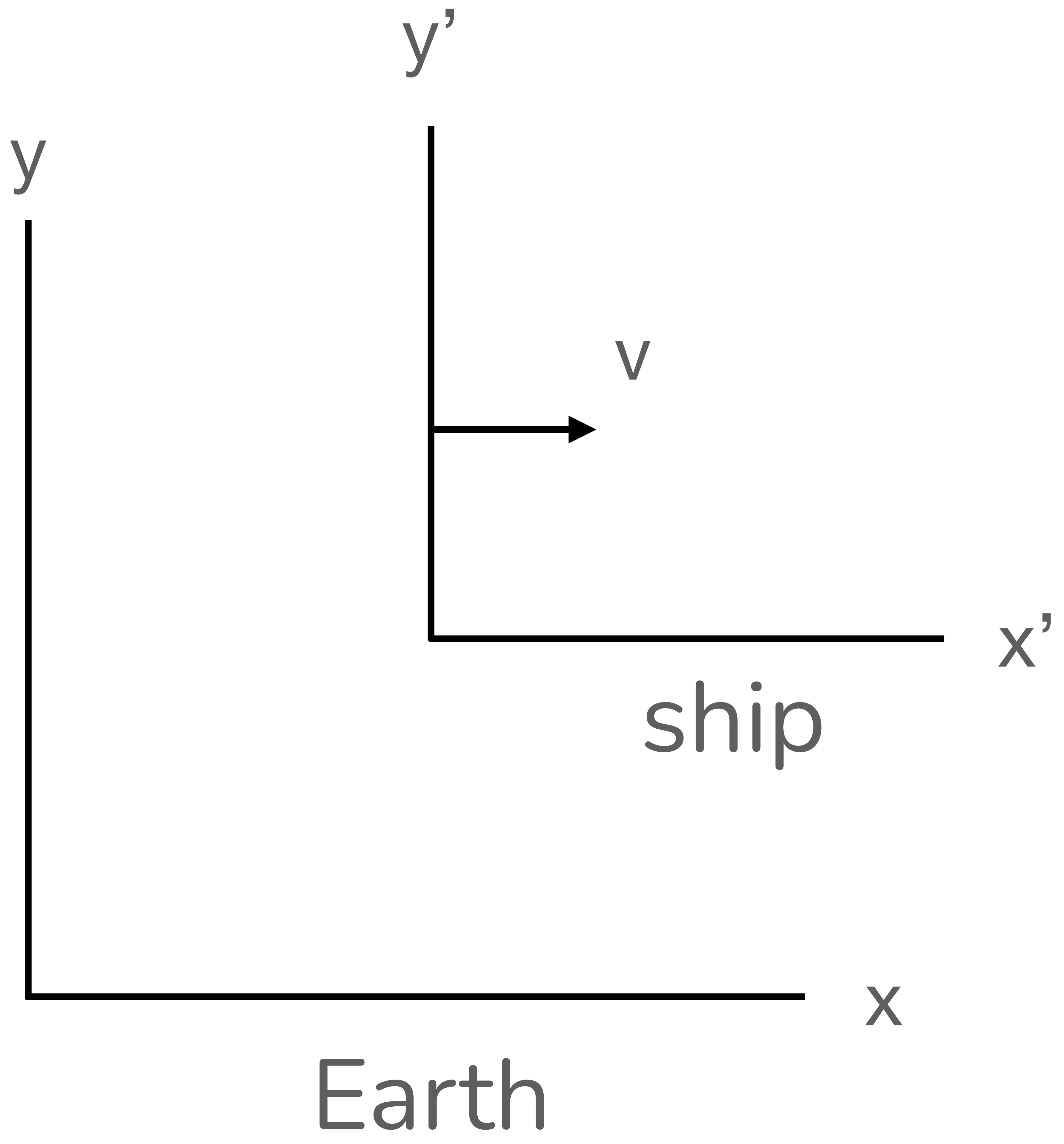
# Planet of the Apes

Directed: Franklin J. Schaffner

20th Century Fox (1968)

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



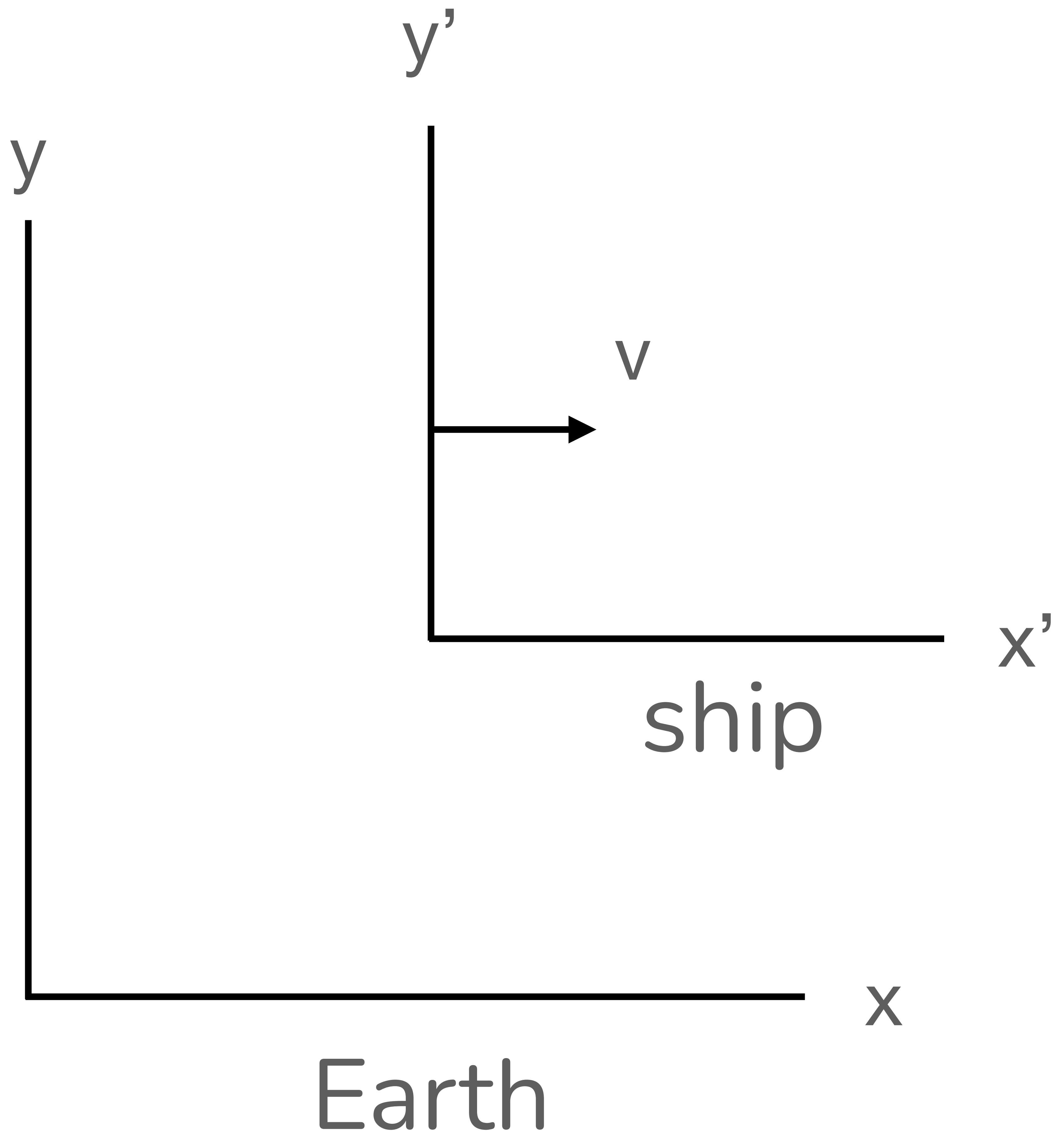



$$t = \frac{t'}{\sqrt{1 - \frac{v^2}{c^2}}}$$

ship date: 07/14/1972

launch date: 01/14/1972

earth date: 03/24/2673

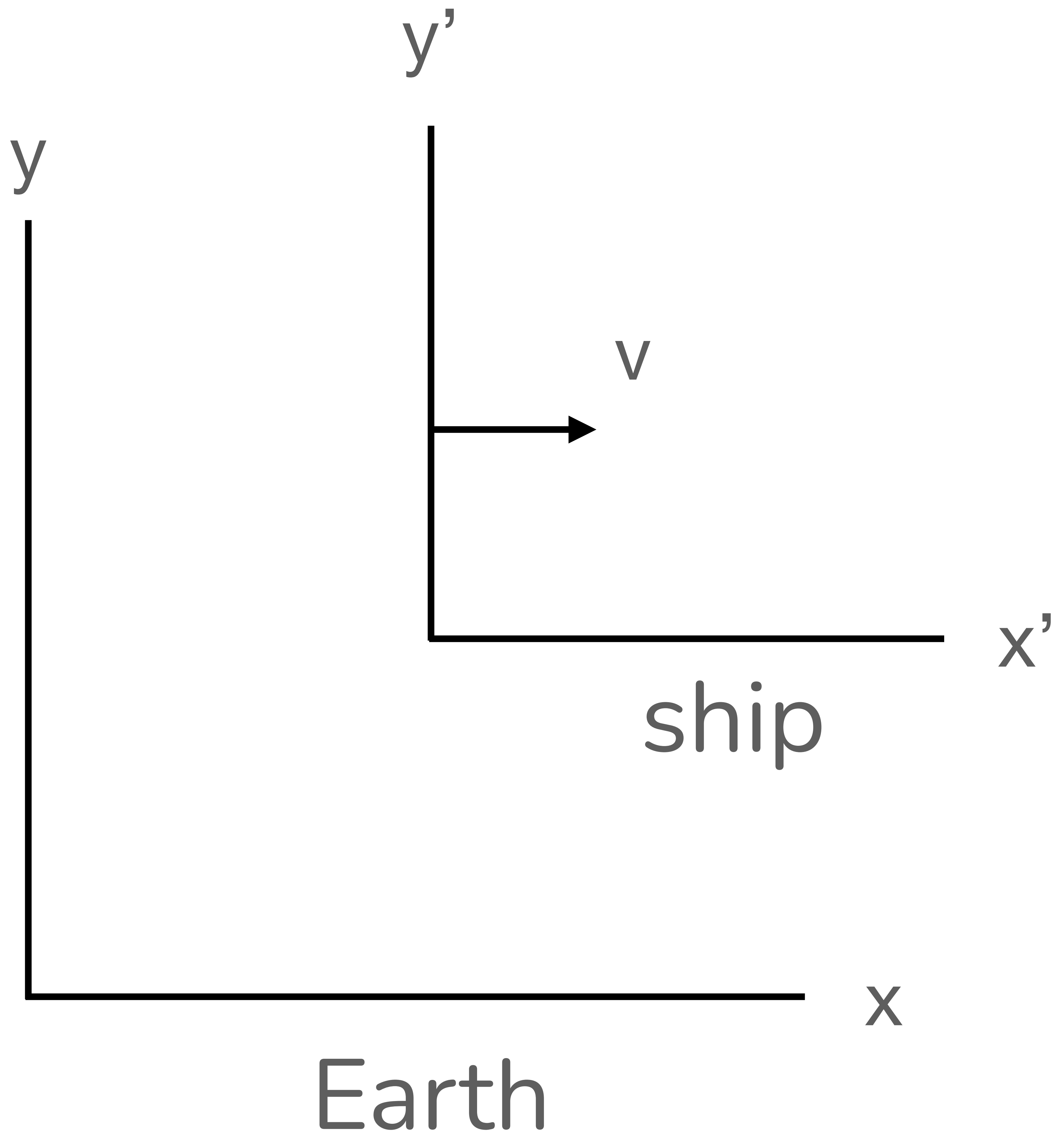


$$t = \frac{t'}{\sqrt{1 - \frac{v^2}{c^2}}}$$

t = 6 months = 0.5 yr

t’ = 702 yr

So how fast was the ship traveling?



So how fast was the ship traveling?

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

$$1 - \frac{v^2}{c^2} = \left(\frac{t'}{t}\right)^2$$

$$\frac{v}{c} = \sqrt{1 - \left(\frac{t'}{t}\right)^2}$$

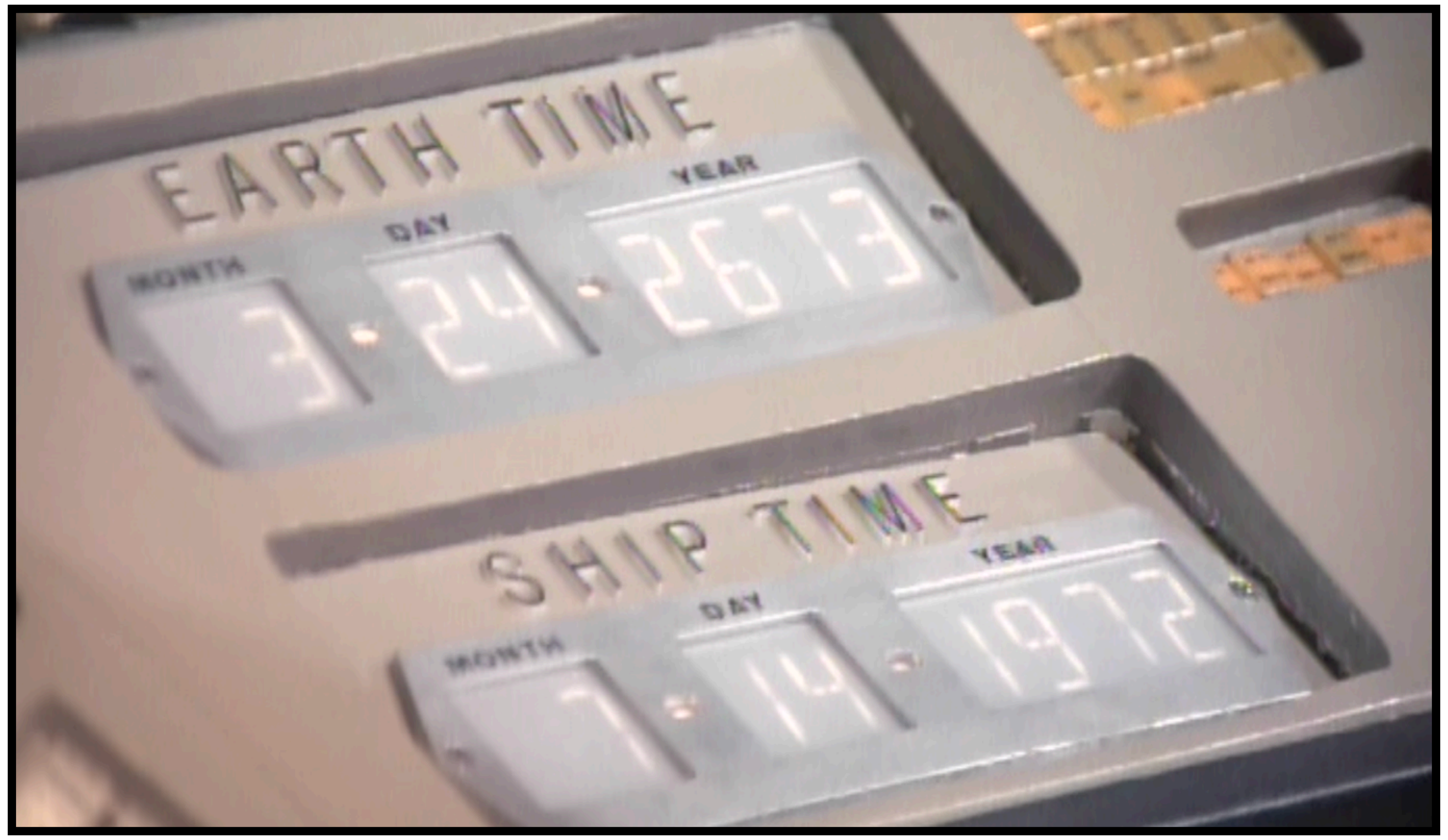
$$\sqrt{1 - \frac{v^2}{c^2}} = \frac{t'}{t}$$

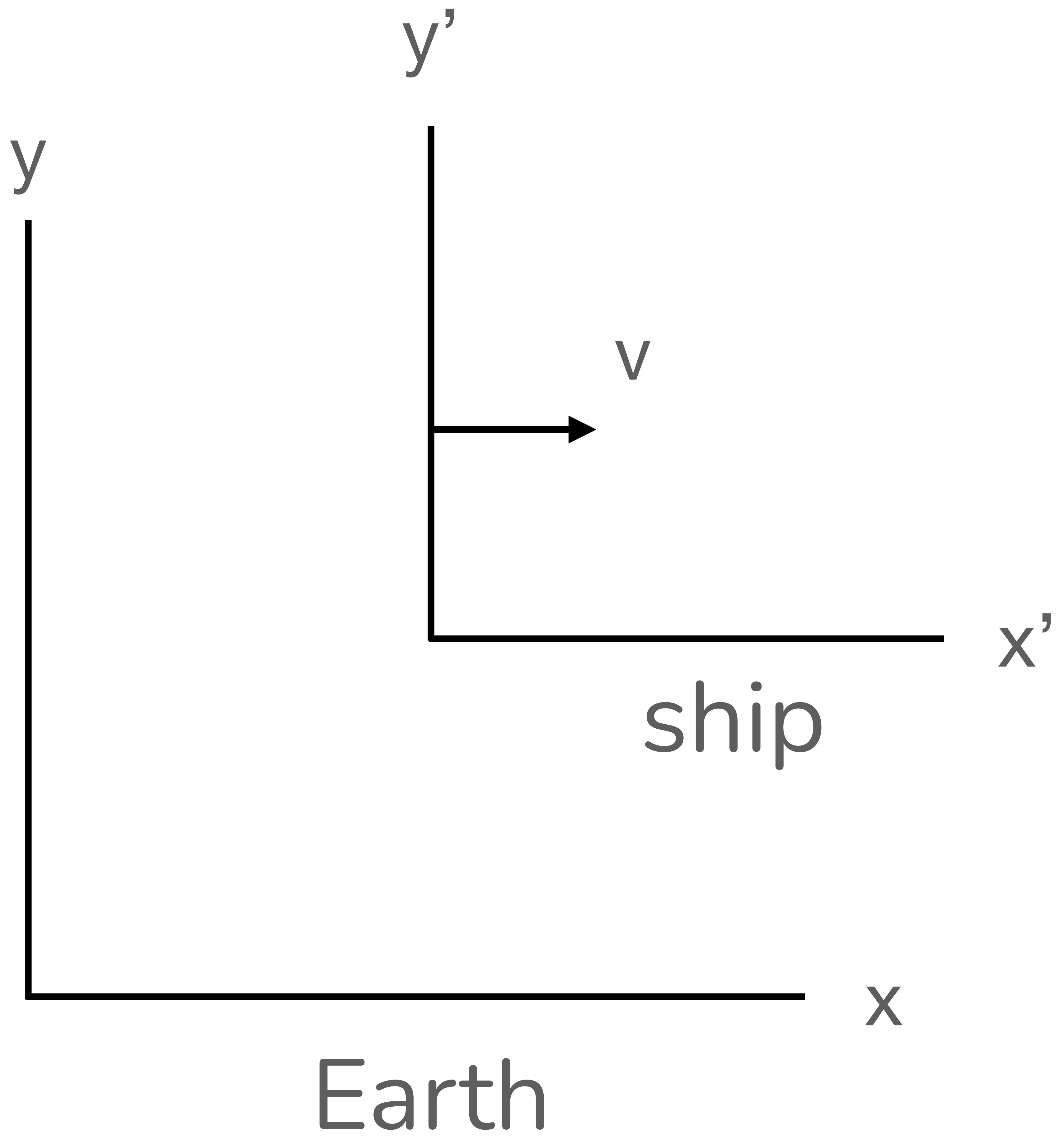
$$\frac{v^2}{c^2} = 1 - \left(\frac{t'}{t}\right)^2$$

$$\frac{v}{c} = \sqrt{1 - \left(\frac{0.5\,\mathrm{yr}}{702\,\mathrm{yr}}\right)^2}$$

$$\frac{v}{c} = 0.999999746349$$

But wait! There was another time scaling shown in the film!



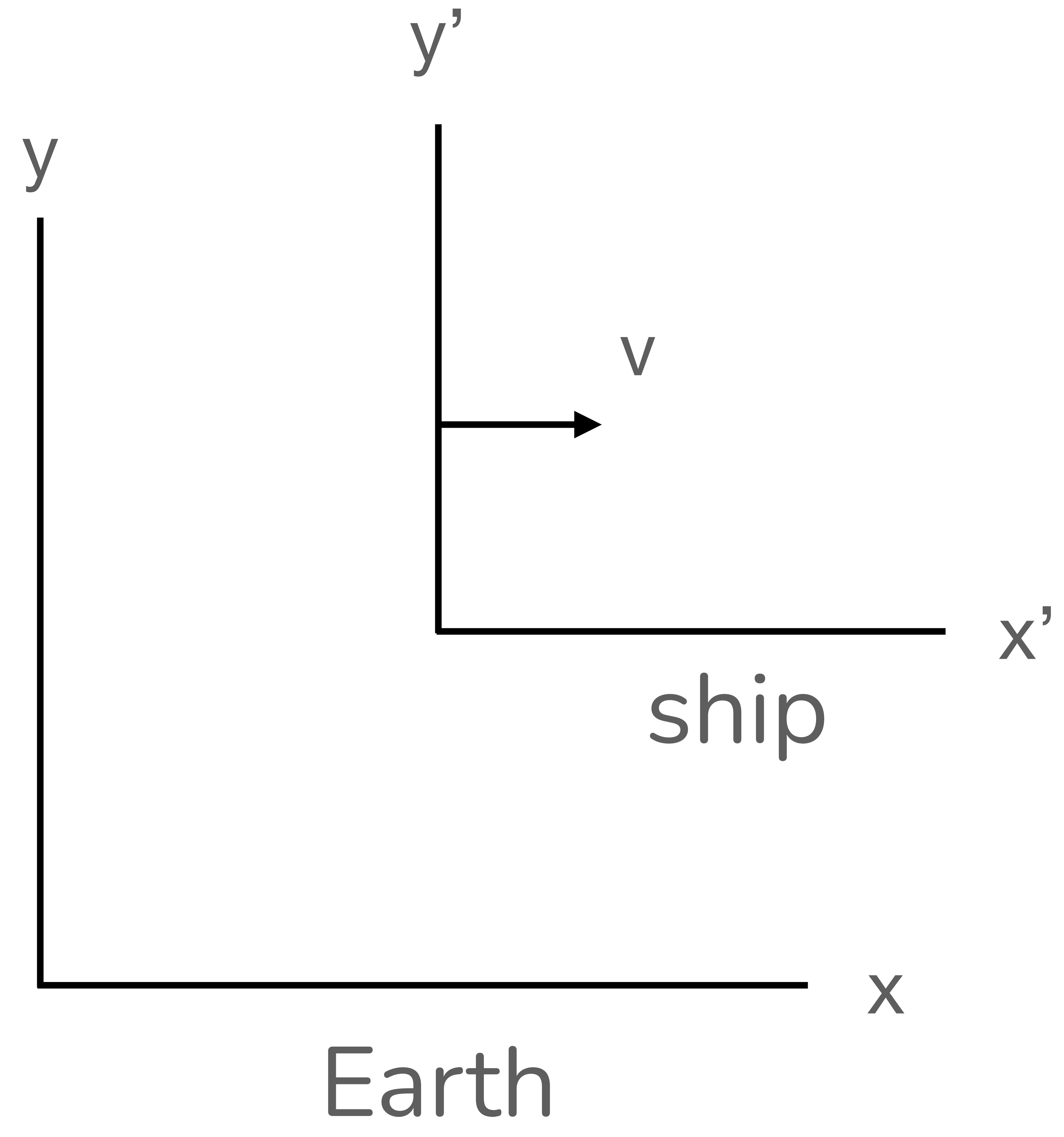



$$t = \frac{t'}{\sqrt{1 - \frac{v^2}{c^2}}}$$

t = 3 days = 259200 s

t’ = 90 s

So how fast was the ship traveling?



So how fast was the ship traveling?

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

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

$$1 - \frac{v^2}{c^2} = \left(\frac{t'}{t}\right)^2$$

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$$\frac{v}{c} = \sqrt{1 - \left(\frac{t'}{t}\right)^2}$$

$$\frac{v}{c} = \sqrt{1 - \left(\frac{0.5\,\text{yr}}{702\,\text{yr}}\right)^2}$$

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So how fast was the ship traveling?

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$$\frac{v^2}{c^2} = 1 - \left(\frac{t'}{t}\right)^2$$

$$\frac{v}{c} = \sqrt{1 - \left(\frac{t'}{t}\right)^2}$$

$$\frac{v}{c} = \sqrt{1 - \left(\frac{90\ \mathrm{s}}{259{,}200\ \mathrm{s}}\right)^2}$$

$$\frac{v}{c} = 0.99999993972$$

$$\frac{v}{c} = 0.99999993972$$ speed during the clip

$$\frac{v}{c} = 0.999999746349$$ average ship speed

So what's the deal here??

$\Longrightarrow$ There must have been acceleration!

Problem 2 is similar to this process but applied to the space station!

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

$$1 - \frac{v^2}{c^2} = \left(\frac{t'}{t}\right)^2$$

$$\frac{v}{c} = \sqrt{1 - \left(\frac{t'}{t}\right)^2}$$

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

$$\frac{v^2}{c^2} = 1 - \left(\frac{t'}{t}\right)^2$$

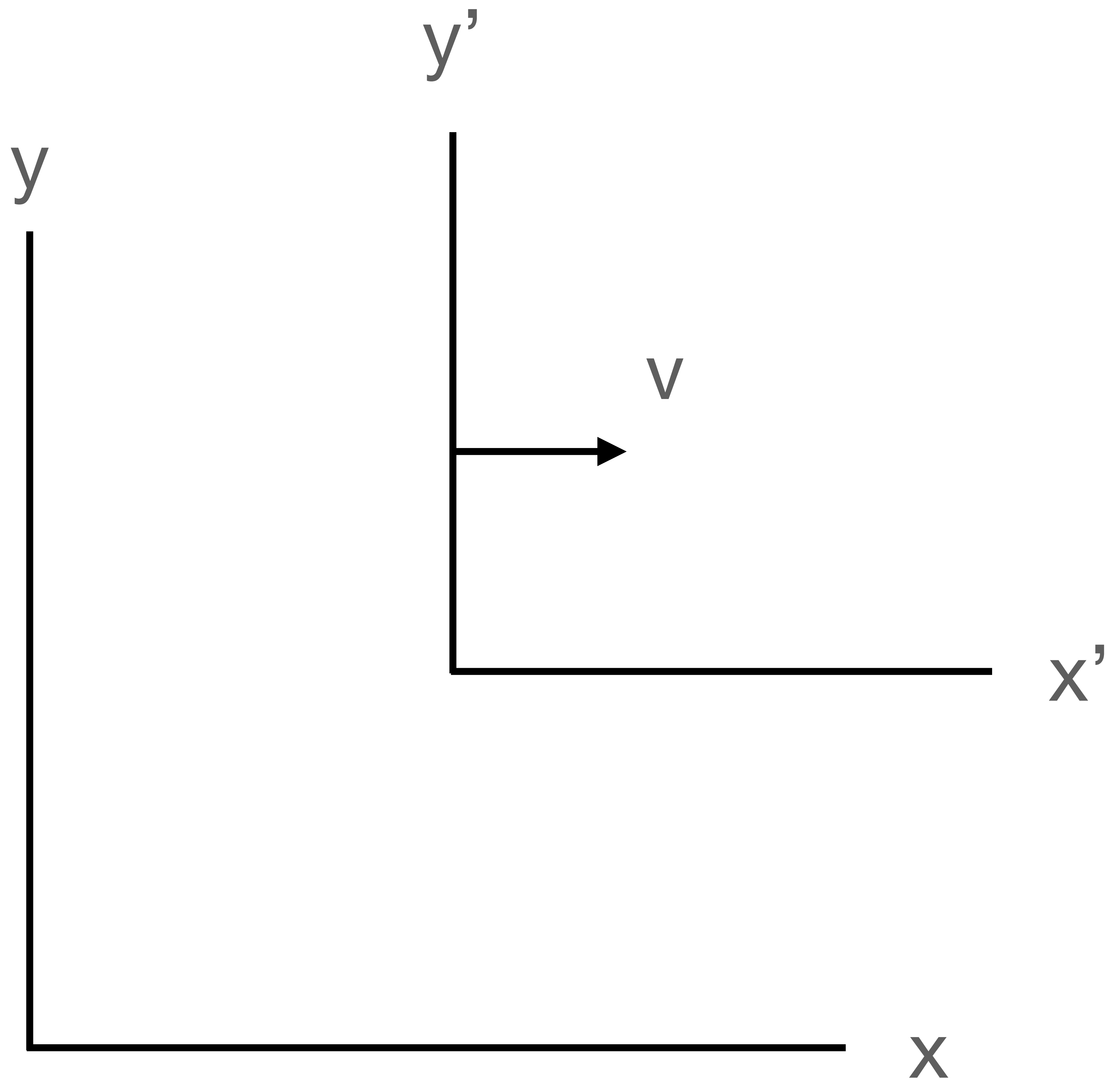
$$\frac{v}{c} = \sqrt{1 - \left(\frac{90\ \mathrm{s}}{259{,}200\ \mathrm{s}}\right)^2}$$

$$\frac{v}{c} = 0.99999993972$$

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

What is the limiting speed
in the moving frame?

What happens if v=c?




**imaginary** time is not negative time $\longrightarrow$ no going back in time

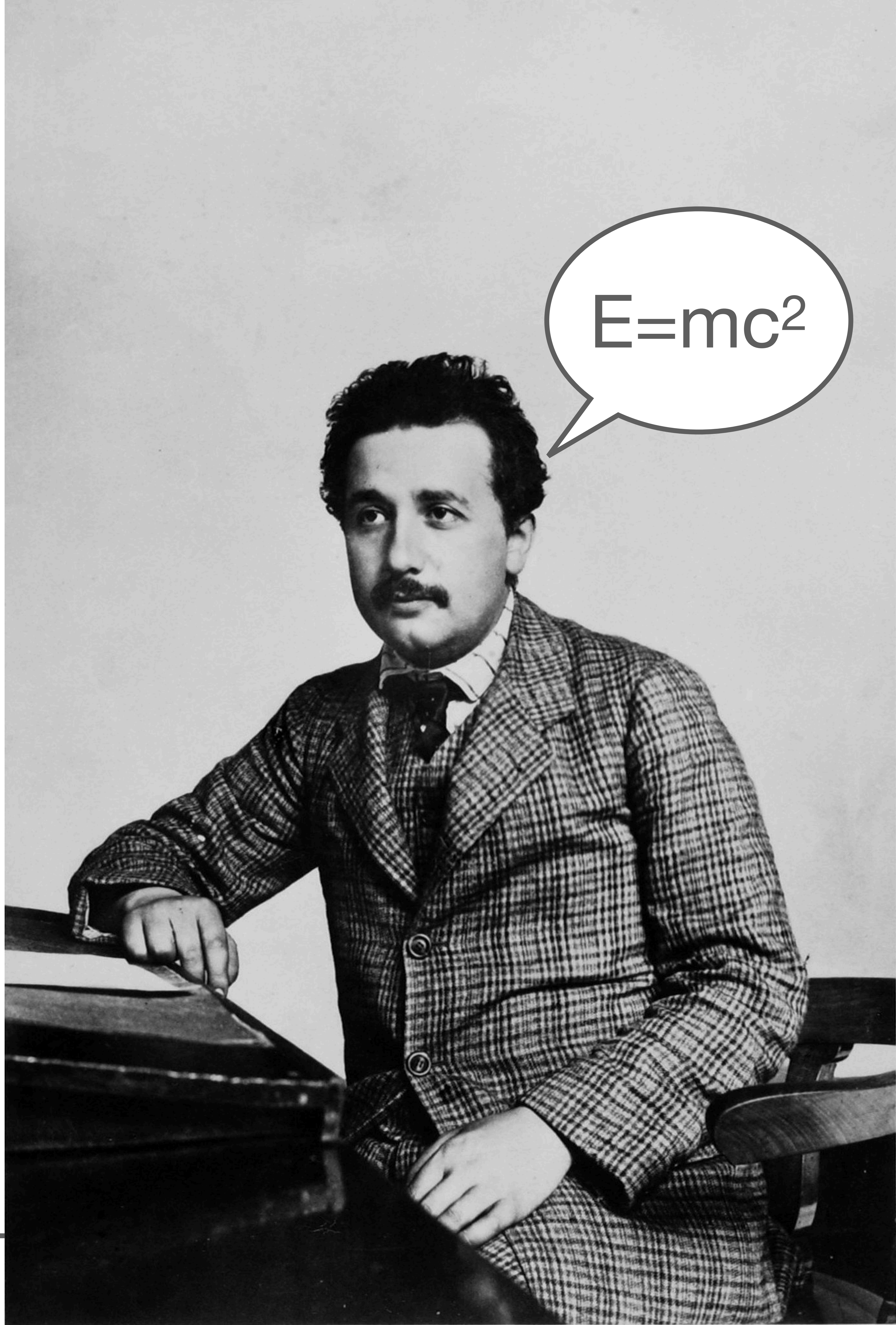
# Special relativity: 1905

*Nothing* travels faster than the speed of light

Time and space are described as a single 4-dimensional spacetime

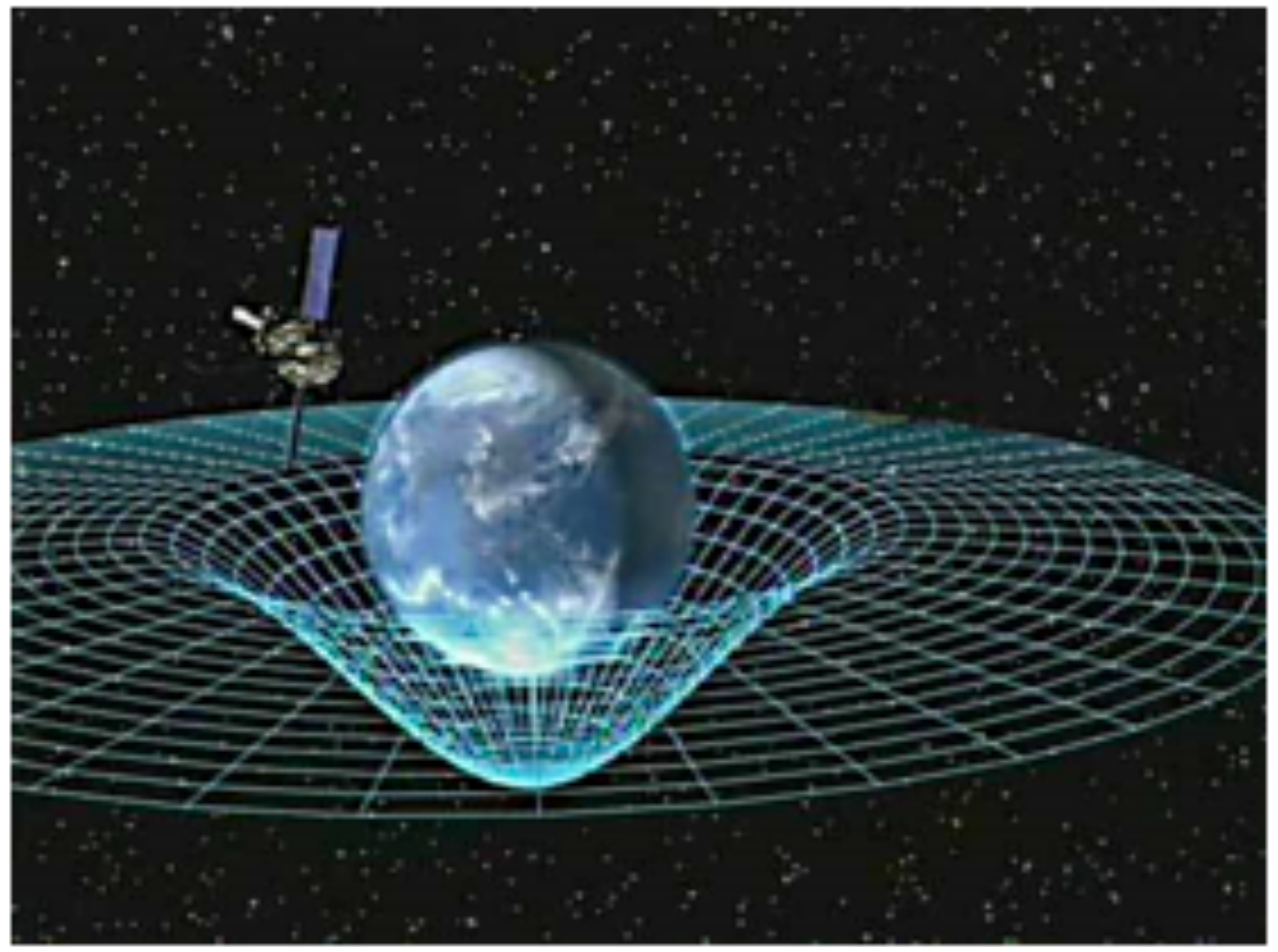
Perception of space and time depends on relative motion

Time moves slower in moving frames



# Next time:

- Continue relativity!
  - Dive into general relativity
  - Gravitational time dilation & GPS
  - Gravitational waves & black holes



What is the nature of space and time?

# Reminder:

- Problem 2: now available and due Feb 2
- Exploration paper 1: now available and due Feb 7