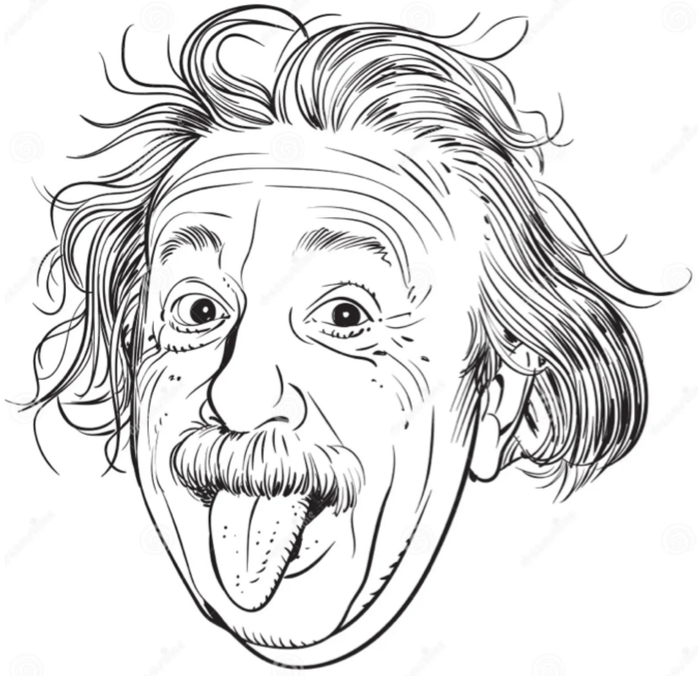
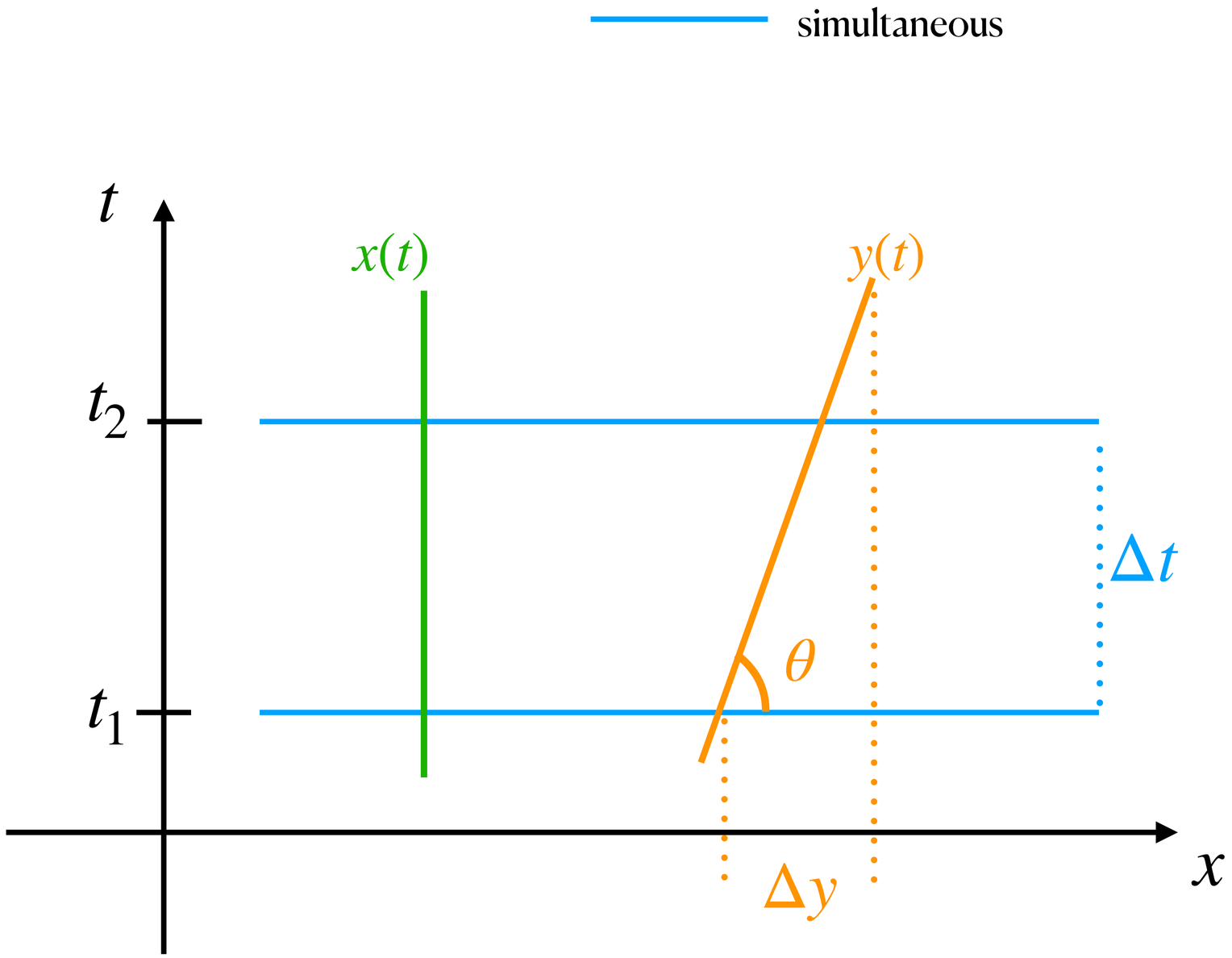
Philosophy of Physics

-

Lec. 4 - Special Relativity

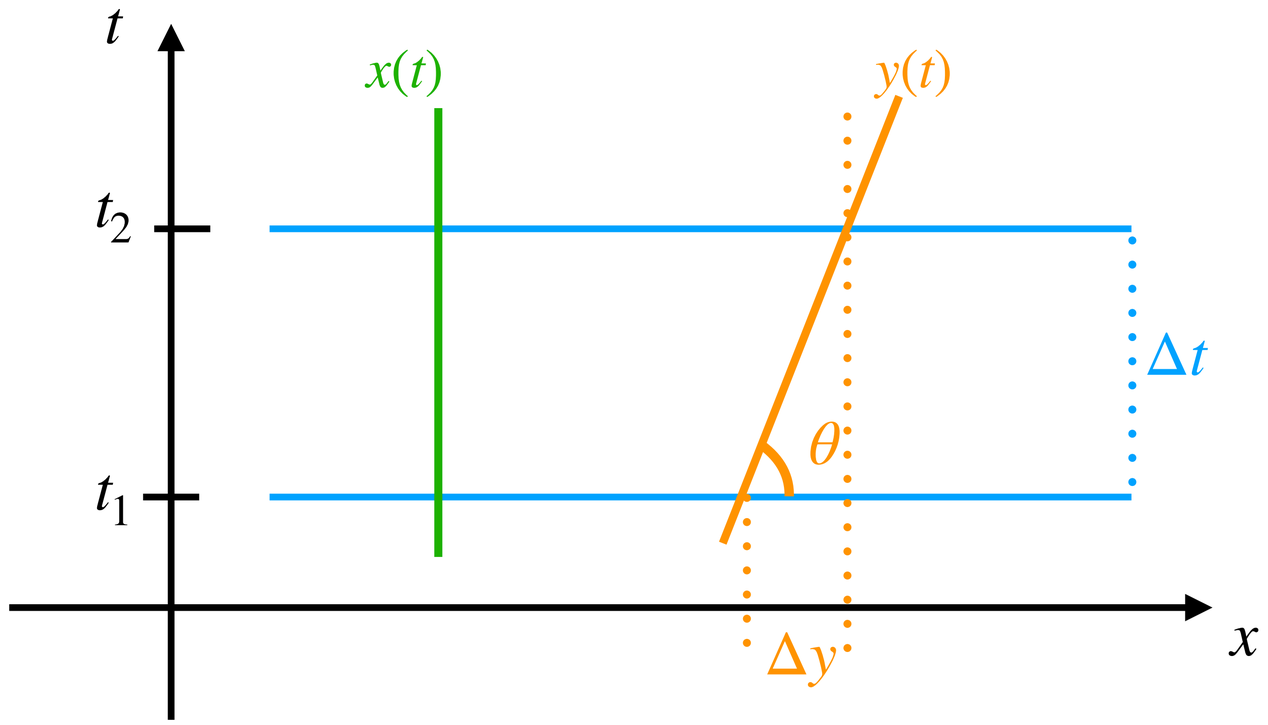


Newtonian Spacetime



Newtonian Spacetime

- time is absolute: stack infinitely many copies of space
- space is absolute: absolute rest frame



$$x(t_1) = x(t_2), \quad \Delta x = 0$$

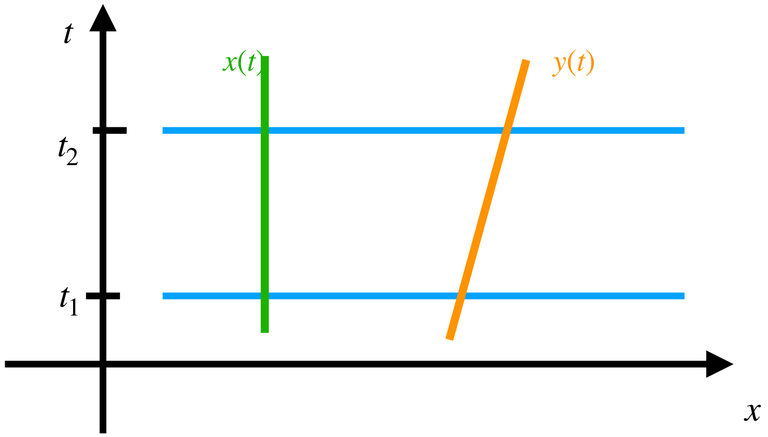
$$v = \frac{\Delta x}{\Delta t} = 0$$

$$y(t_1) \neq y(t_2), \quad \Delta y \neq 0$$

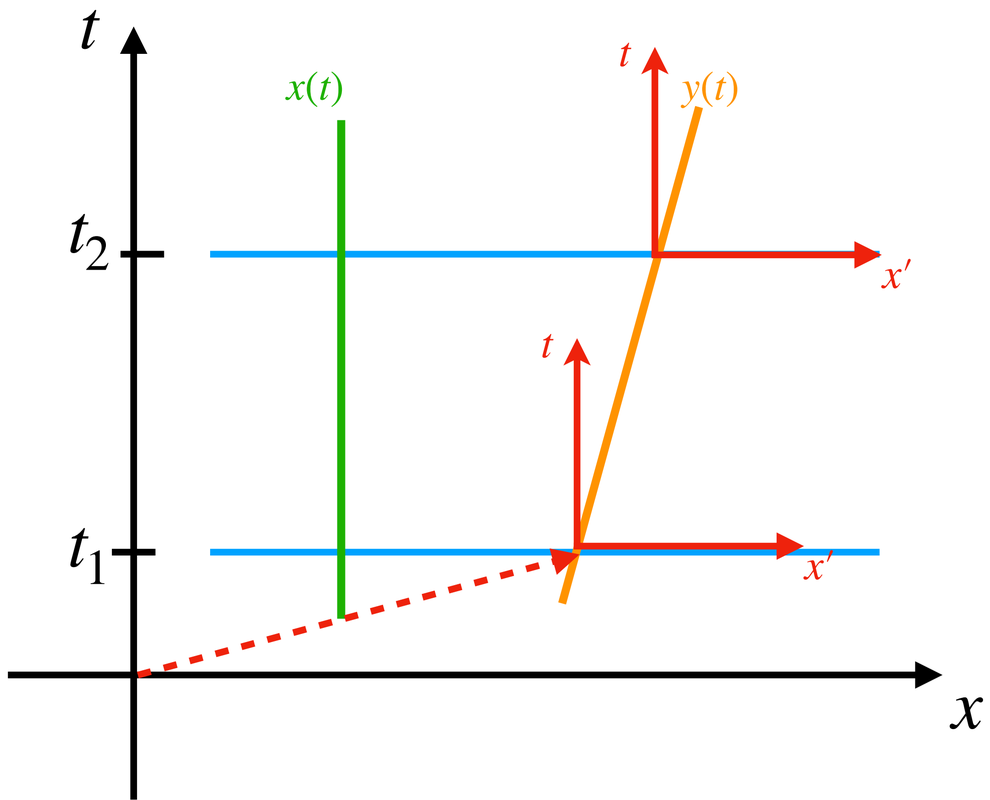
$$u = \frac{\Delta y}{\Delta t} = \cot\theta$$

- the set of trajectories that $\Delta x = 0$ for any t_i, t_f, which represents particles at rest, **define** the rest frame structure

Galilean Spacetime

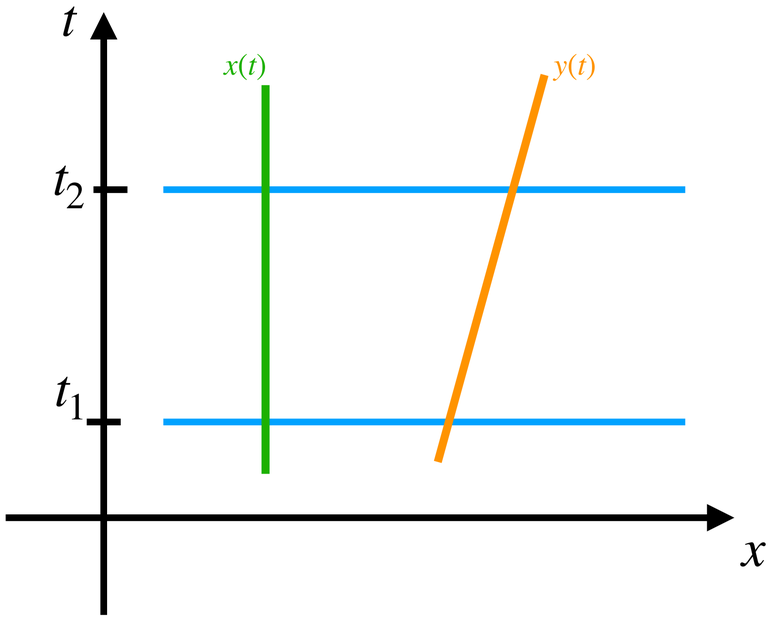


$$x' = x - u \times t$$

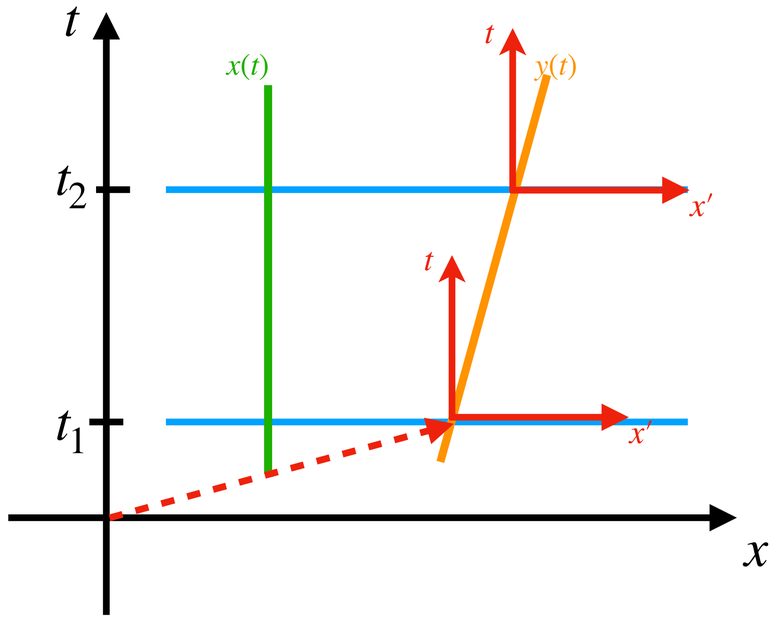


Galilean Spacetime

- principle of relativity (17th century!): laws of physics unchangeable for boosted reference frames



$x' = x - u \times t$



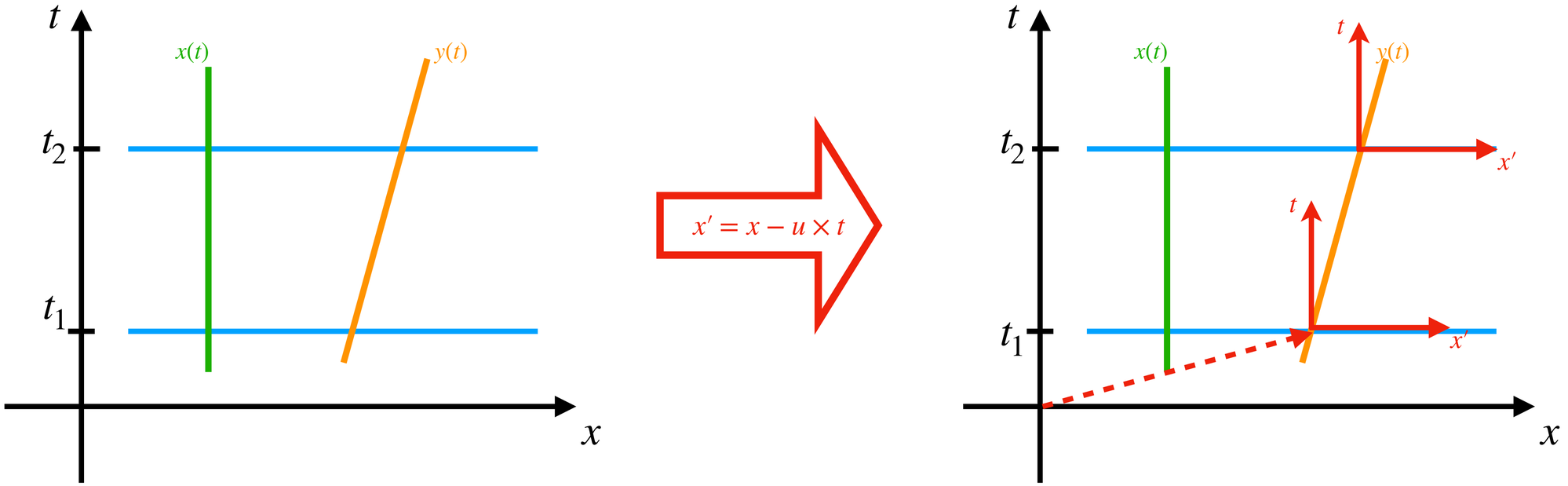
- absolute rest frame structure gone!
- **acceleration:** $x = a \times t^2$

5 min!

- how does it look like?
- what happens with the velocity?

Galilean Spacetime

- principle of relativity (17th century!): laws of physics unchangeable for boosted reference frames



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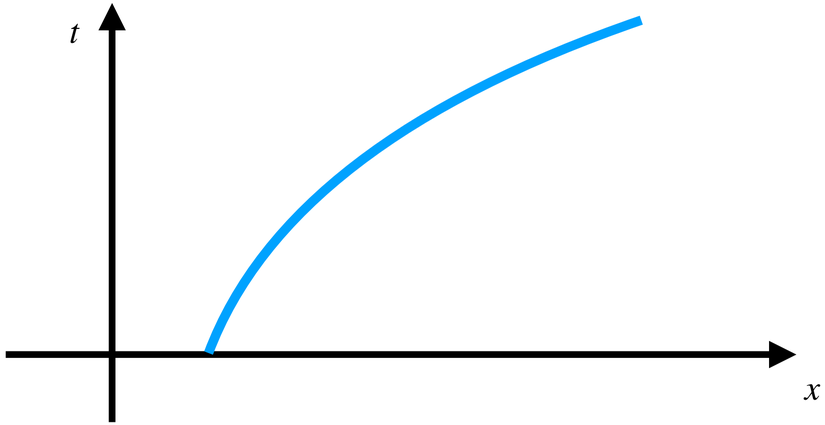
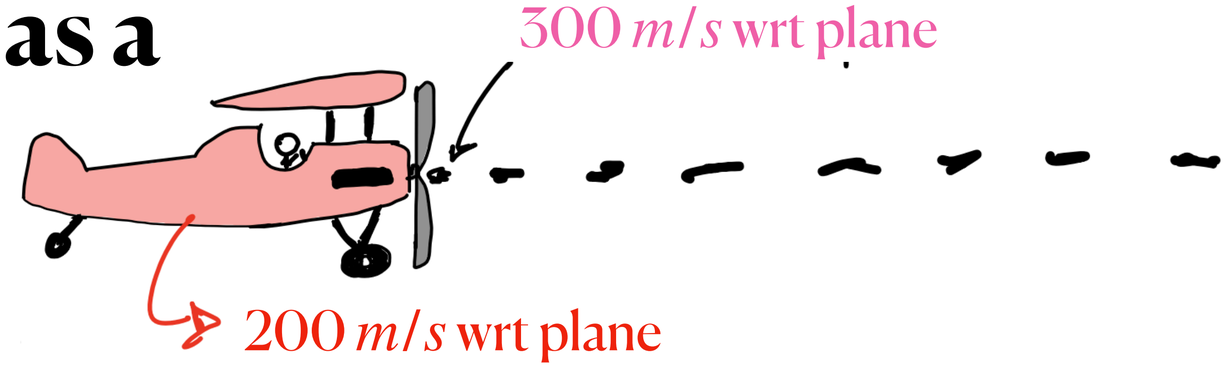


Sound as a Wave



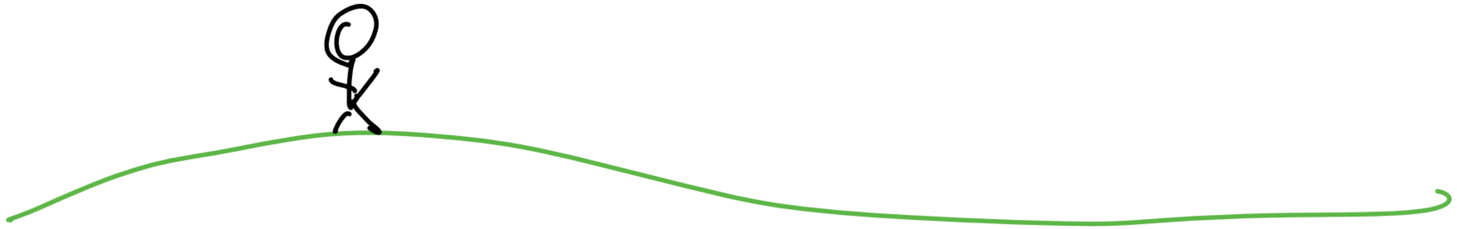
- bullets travel at

  300 m/s wrt plane

  500 m/s wrt us

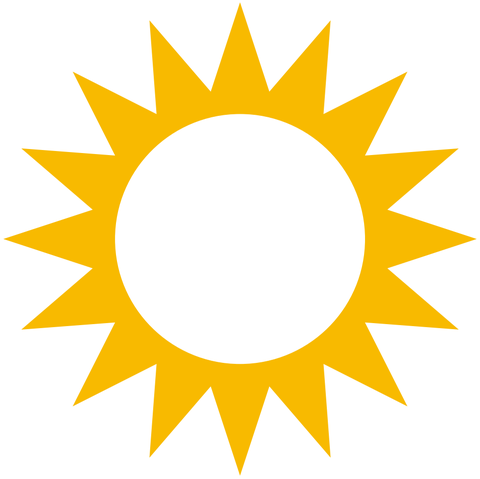
- engine sound

  340 m/s wrt air!



- waves typically propagate in a **medium**
- the speed of the wave depends on how fast you move wrt to the medium, not the source [supersonic?]
- the medium provides a local preferred inertial frame (like using the ground)

Light as a Wave

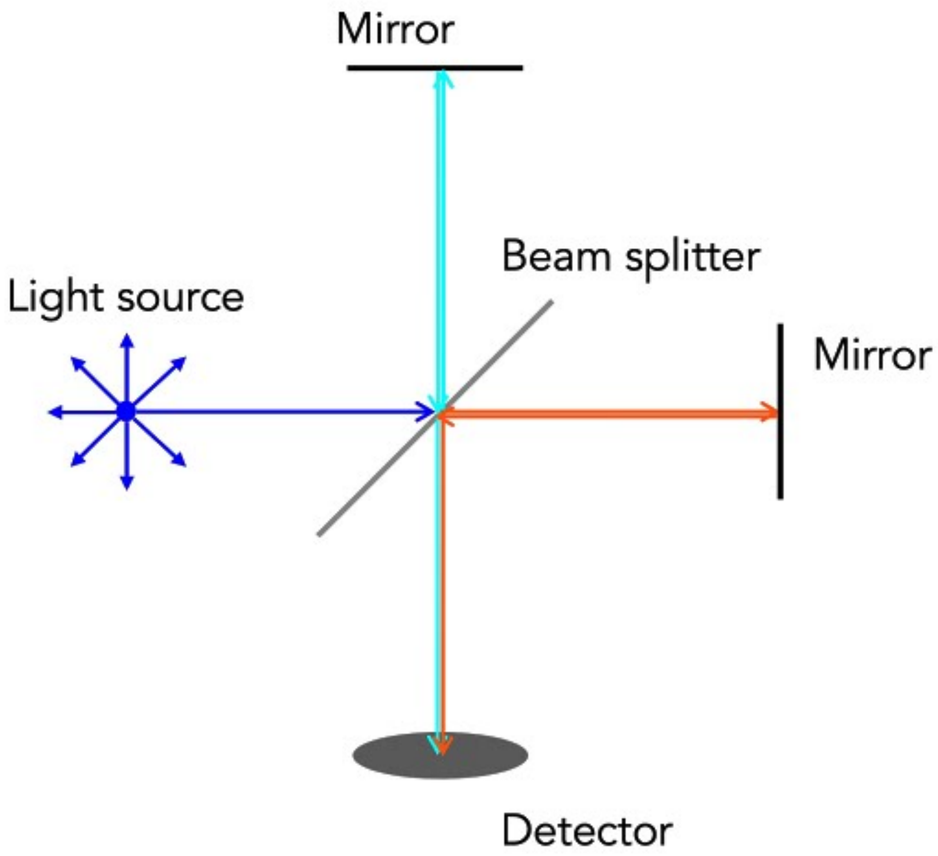


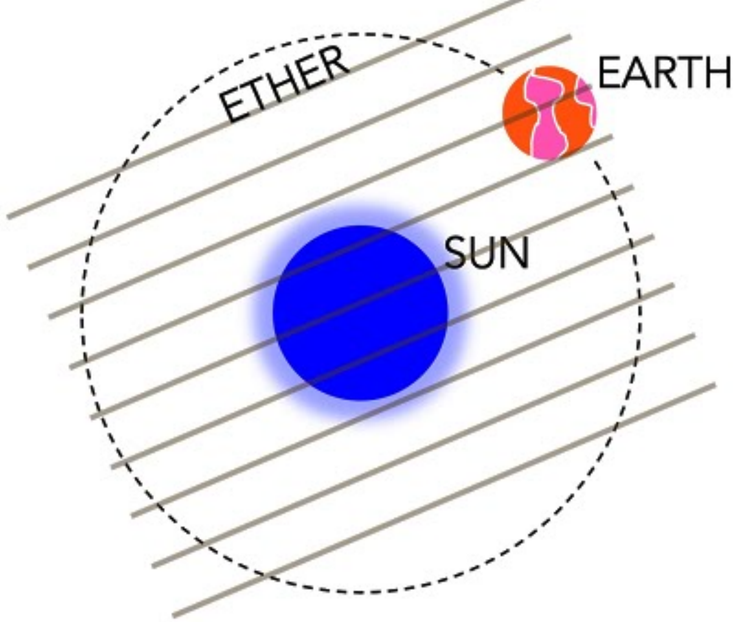
- light is a wave, so it needs a medium: aether
    - light propagates with **constant** speed wrt it!

HOWEVER!

- no friction or viscosity was to be found
- polarization indicated transversal oscillation, diffcult to understand in a medium that did not look like a solid body at all!
- light is everywhere, so **universal** preferred inertial frame?
    - And how fast are we moving wrt it?

1887





The Michelson-Morley Experiment

No speed difference found! if there is an aether, we are not moving in relation to it!

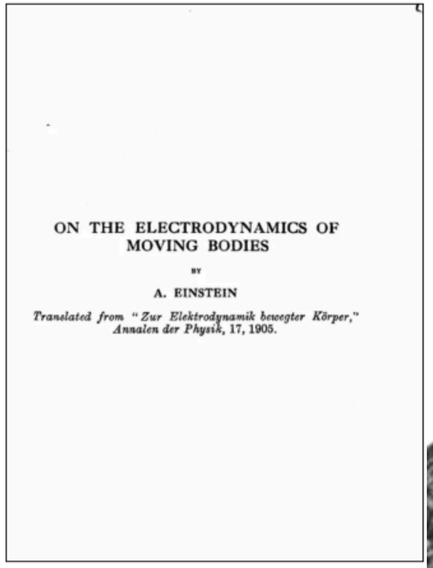
The Rise of Relativity

- light is a wave → needs a medium → is universal → speed of light is measured as always constant wrt medium → breaks principle of relativity!

What do we give up?

Exercise:

10 min reading Einstein's paper + group discussion


ON THE ELECTRODYNAMICS OF MOVING BODIES

BY

A. EINSTEIN

Translated from "Zur Elektrodynamik bewegter Körper," Annalen der Physik, 17, 1905.

Special Relativity

- the laws of physics remain the same under boosts, i.e., for any inertial frame

- the speed of light is constant

Special Relativity

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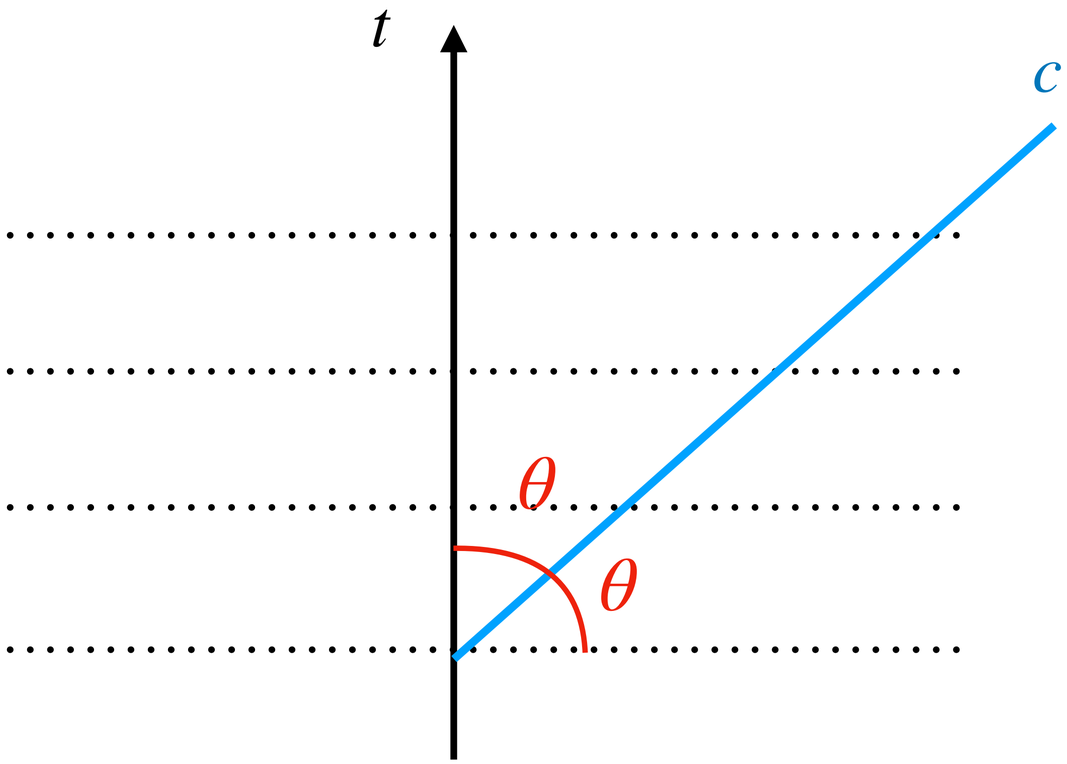
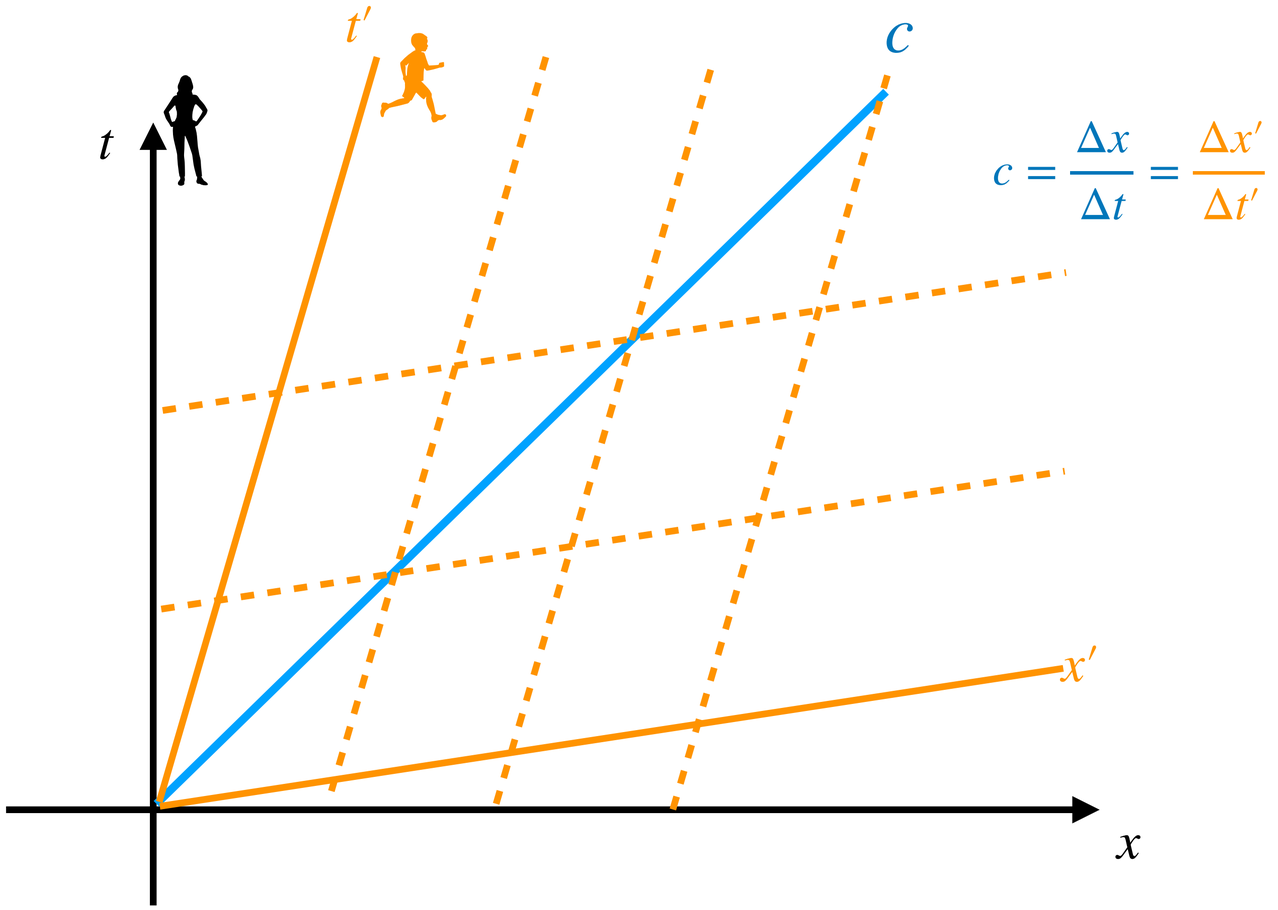
- the speed of light is constant for inertial observers

Special Relativity

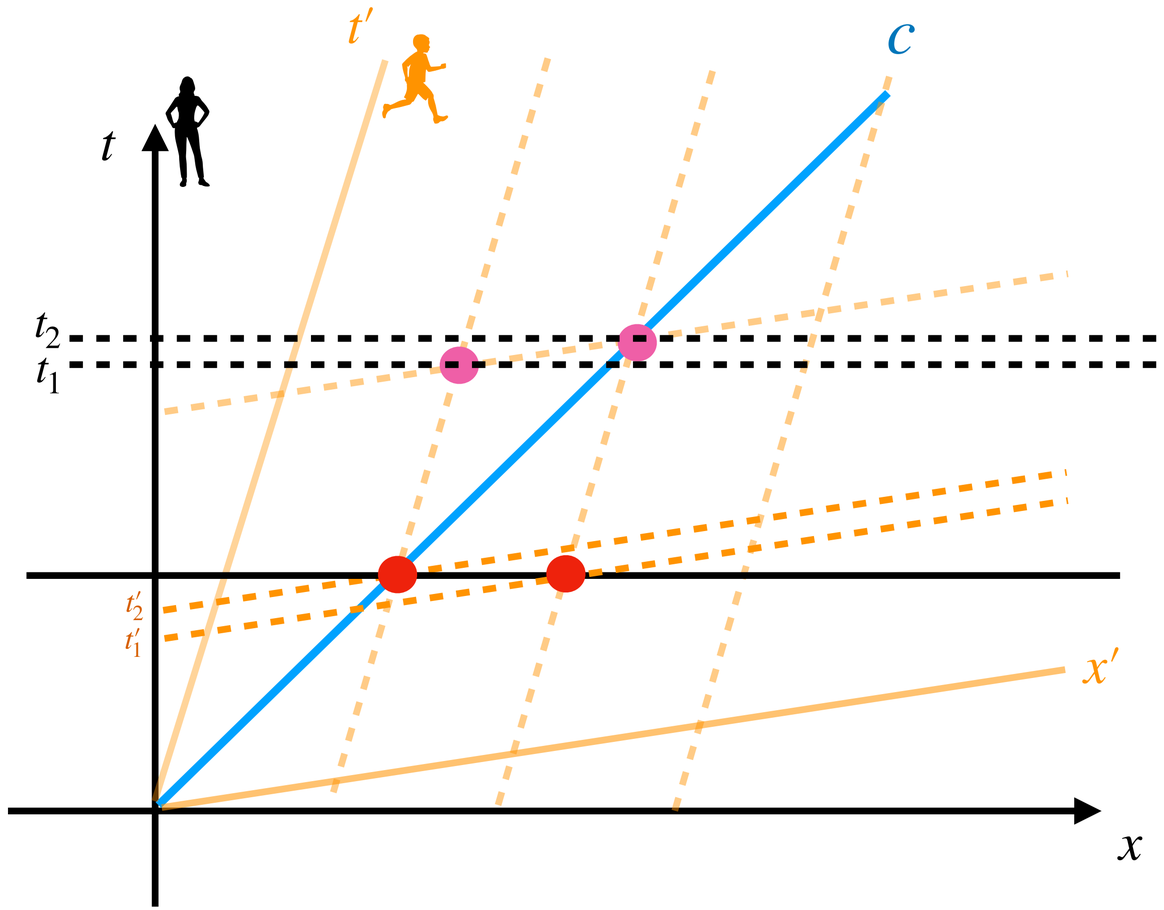
- the laws of physics remain the same under boosts, i.e., for any inertial frame
- the speed of light is constant **for inertial observers!**



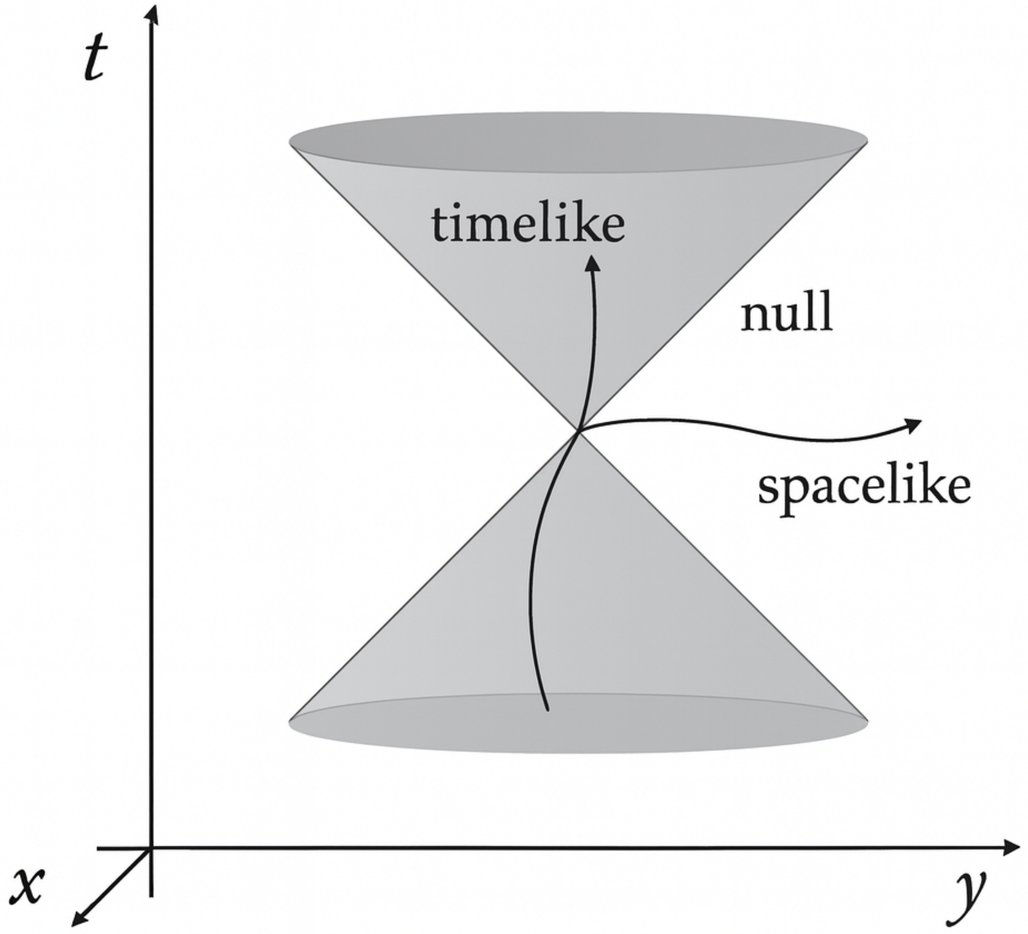


Minkowski Spacetime

- simultaneity depends on the inertial frame!
- the speed of light provides a limit on how fast things can move



Light Cones



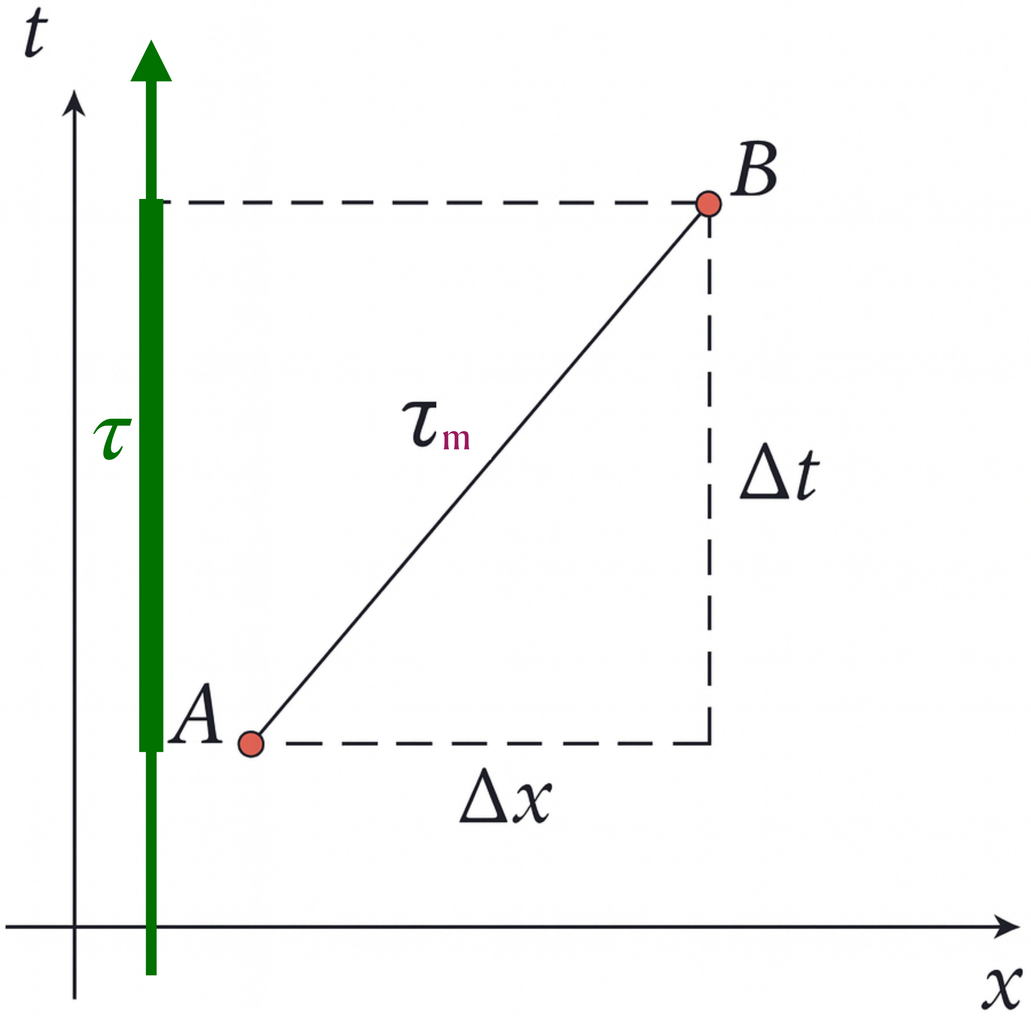
- slicing not as useful, but **causal structure** is preserved!

Exercise (7 min):

Does the relativity of simultaneity undermine the concept of objective reality or substantivalism?

Time

- **spacetime interval** is invariant for all inertial observers

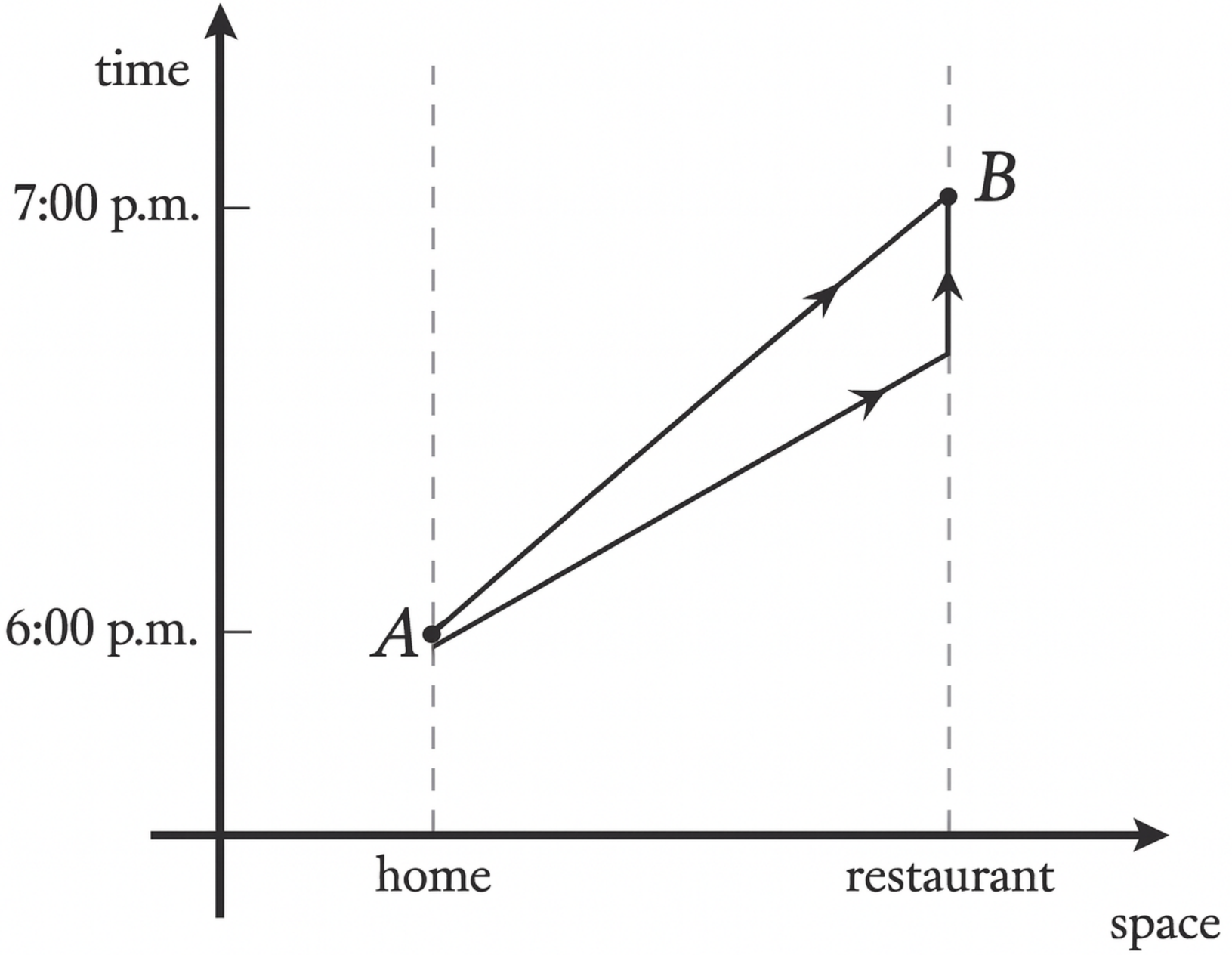


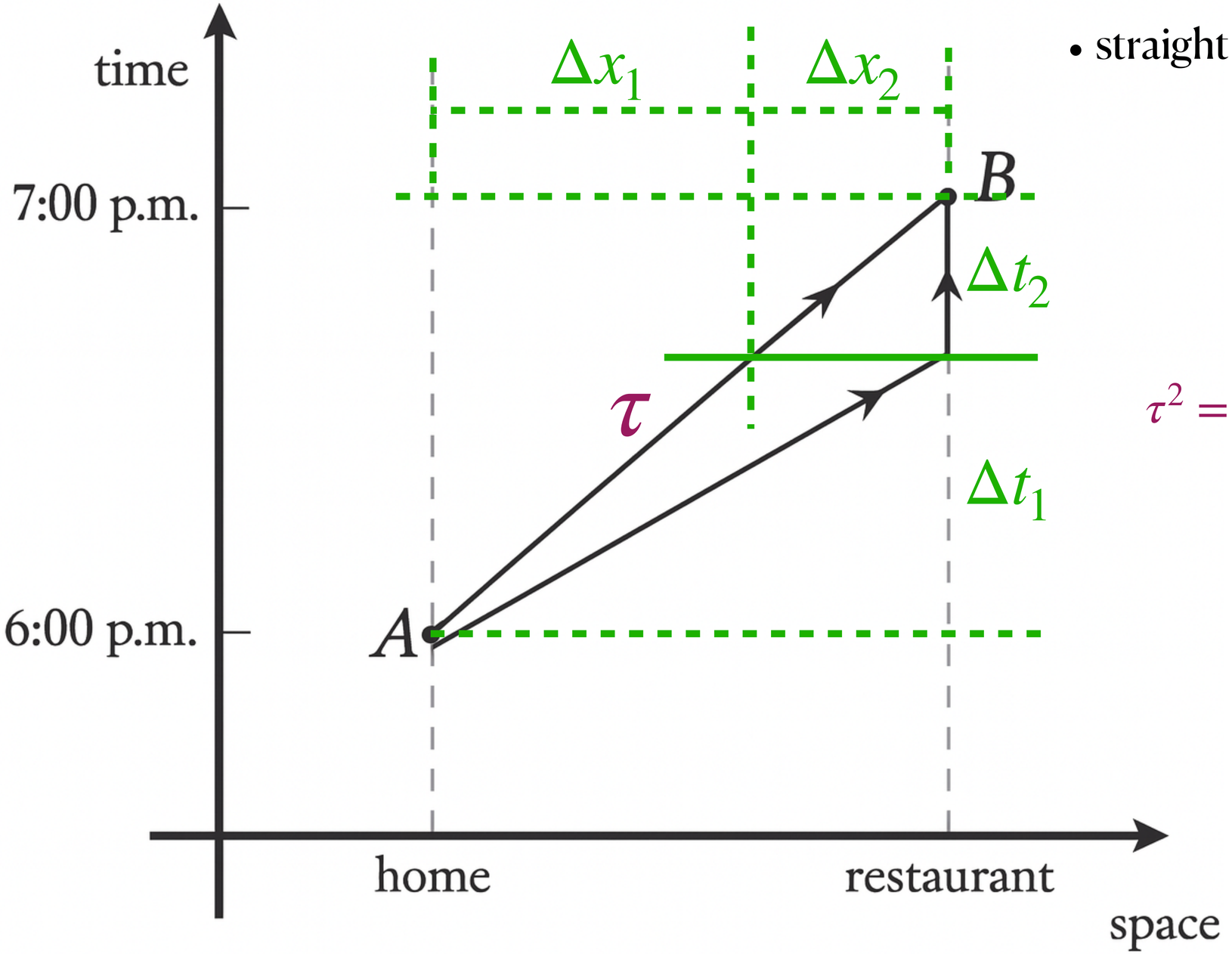
- coordinate time Δt
- proper time

$$\tau^2 = \Delta t^2 - \Delta x^2$$

- stationary observer: $\tau_{st} = \Delta t$
- moving observer: $\Delta x^2 \neq 0$,

$$\tau_m < \Delta t$$

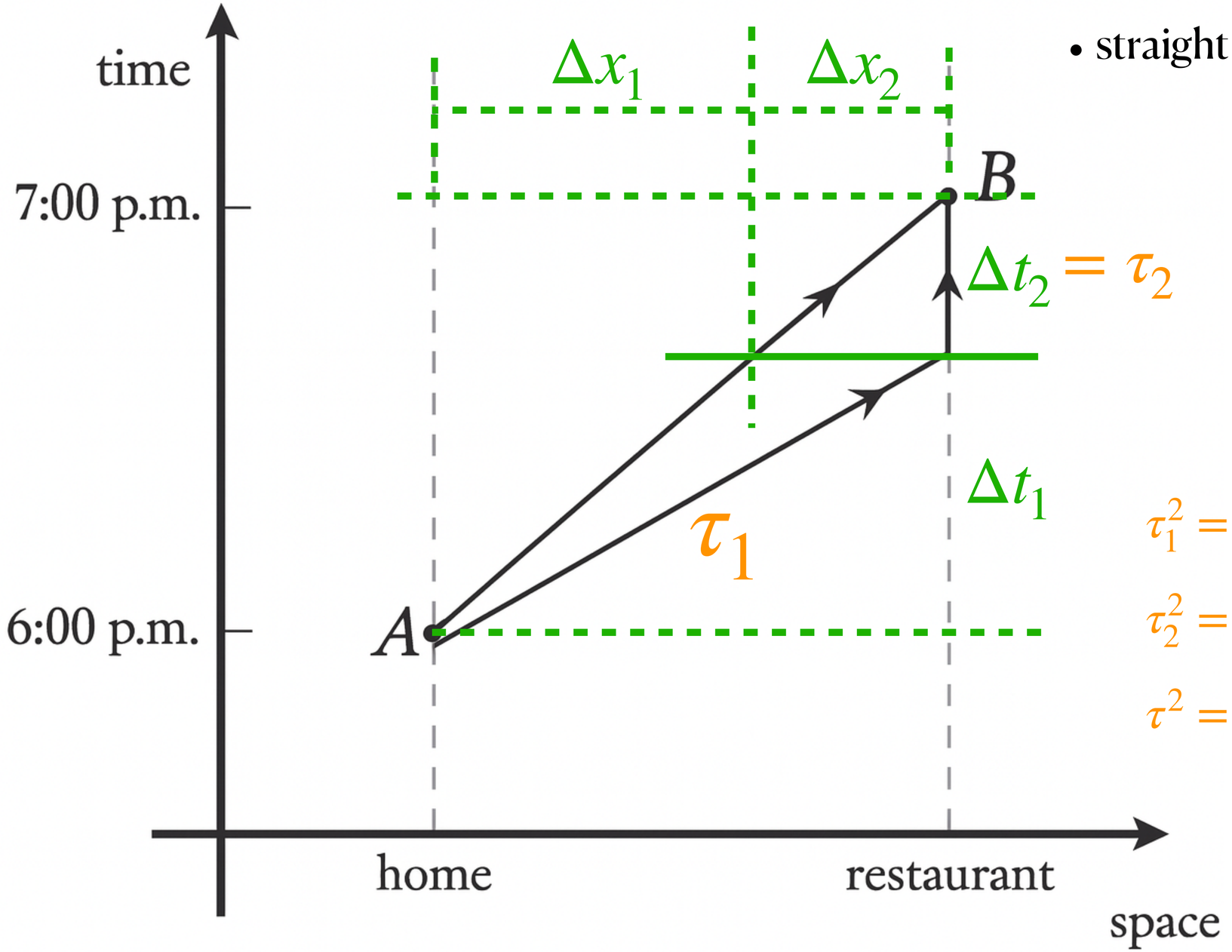

time
7:00 p.m.
6:00 p.m.
A
B
home
restaurant
space



- straight paths (inertial trajectories)

yields longest elapsed time!

$$\tau^2 = (\Delta t_1 + \Delta t_2)^2 - (\Delta x_1 + \Delta x_2)^2$$



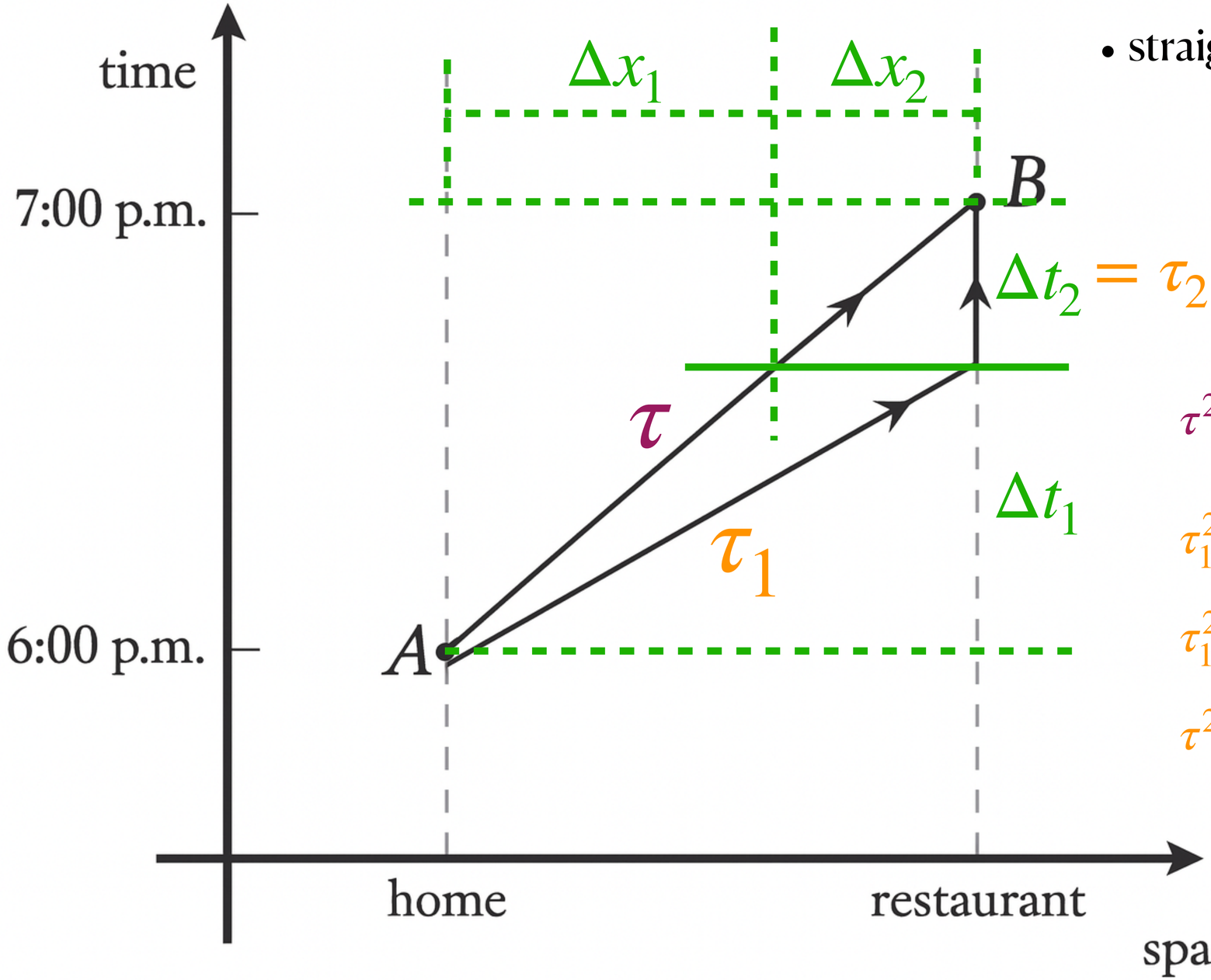
- straight paths (inertial trajectories)

yields longest elapsed time!

$$\tau_1^2 = \Delta t_1^2 - (\Delta x_1 + \Delta x_2)^2$$

$$\tau_2^2 = \Delta t_2^2$$

$$\tau^2 = \tau_1^2 + \tau_2^2 = \Delta t_1^2 + \Delta t_2^2 - (\Delta x_1 + \Delta x_2)^2$$



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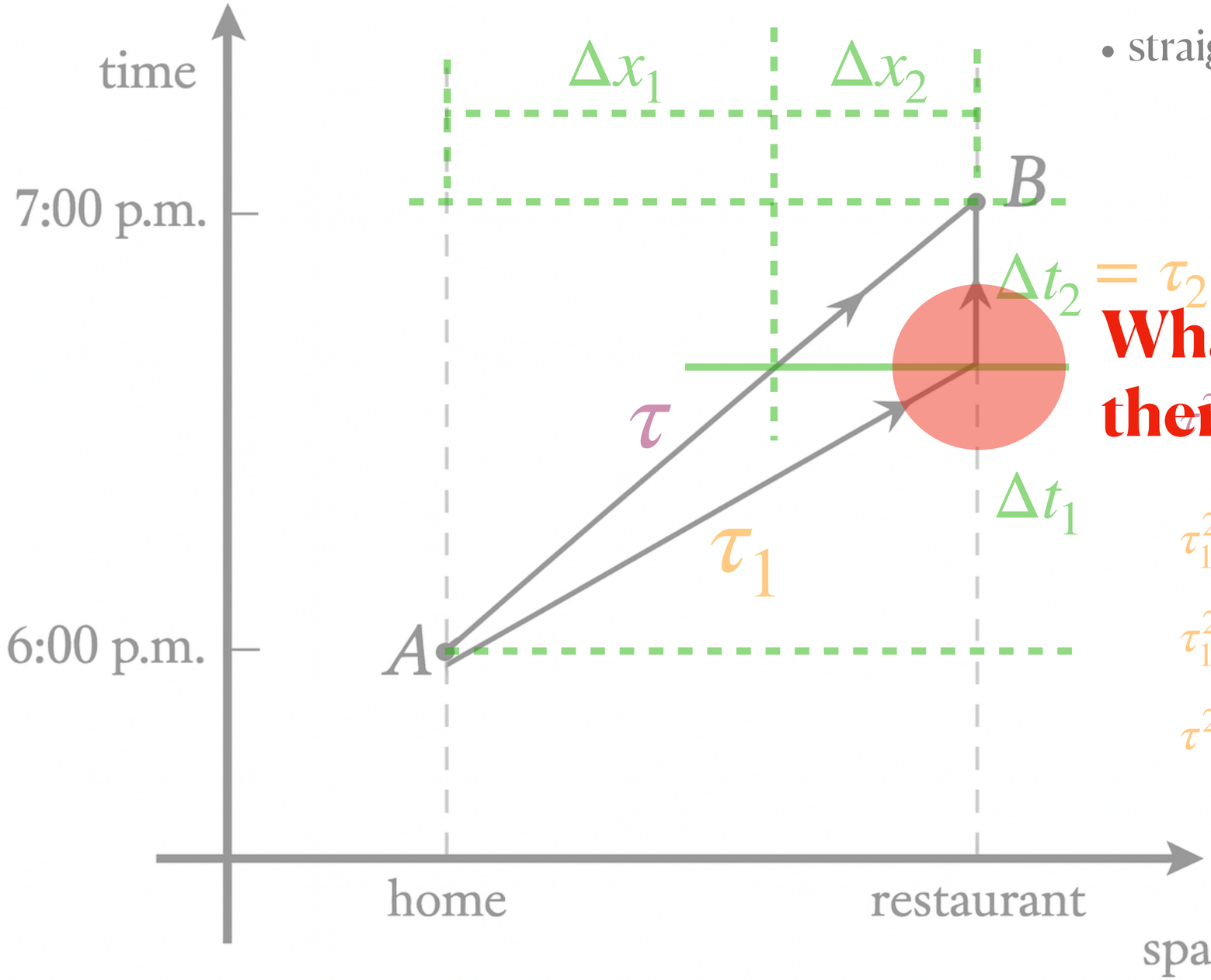
$$\tau_1^2 = \Delta t_2^2$$

$$\tau^2 = \tau_1^2 + \tau_2^2 = \Delta t_1^2 + \Delta t_2^2 - (\Delta x_1 + \Delta x_2)^2$$

$$\tau^2 - \tau^2 = 2\Delta t_1 \Delta t_2 \geq 0 !$$



- straight paths (inertial trajectories)

yields longest elapsed time!

What happened there?

$$\tau^2 = (\Delta t_1 + \Delta t_2)^2 - (\Delta x_1 + \Delta x_2)^2$$

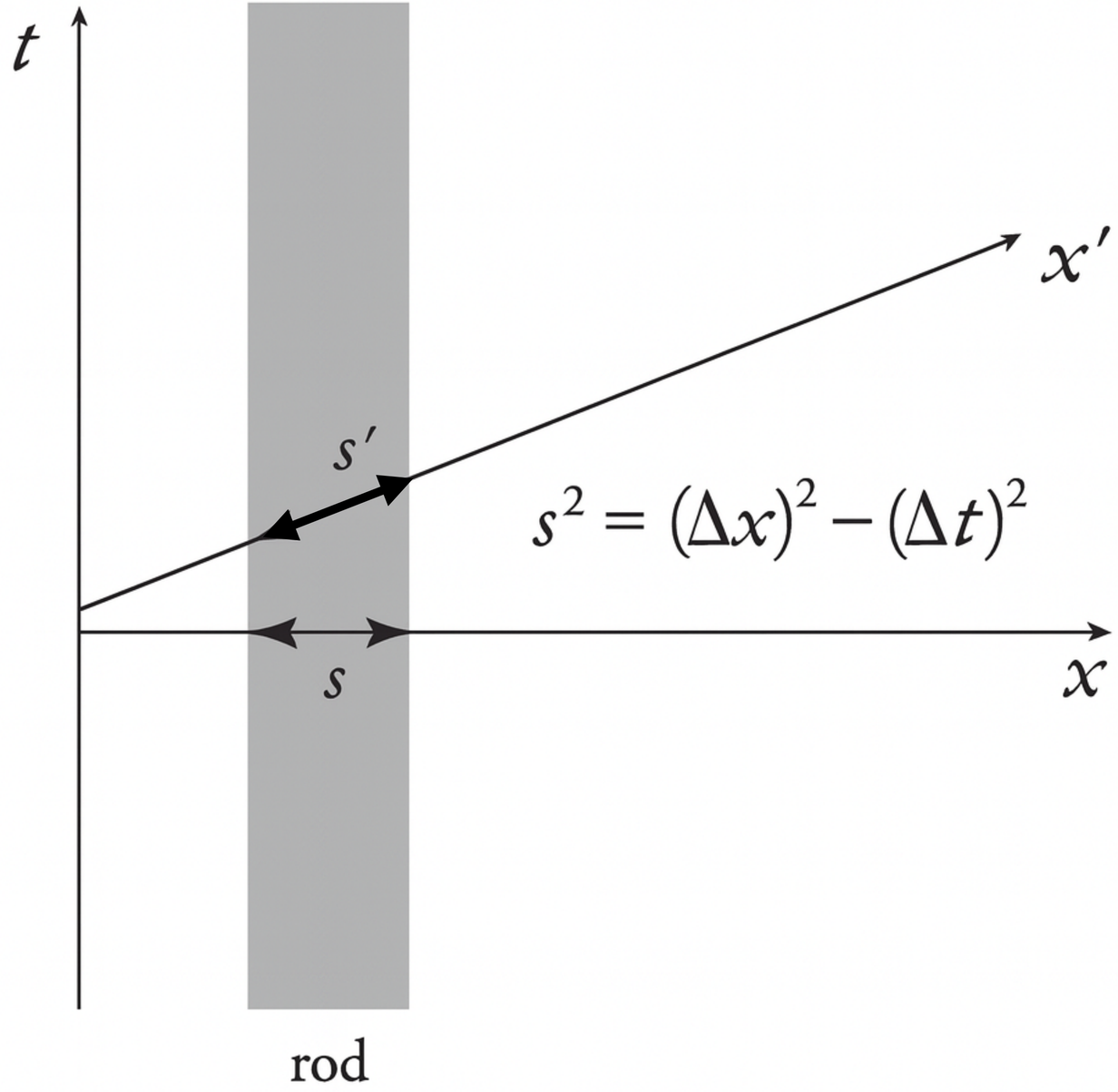
$$\tau_1^2 = \Delta t_1^2 - (\Delta x_1 + \Delta x_2)^2$$

$$\tau_1^2 = \Delta t_2^2$$

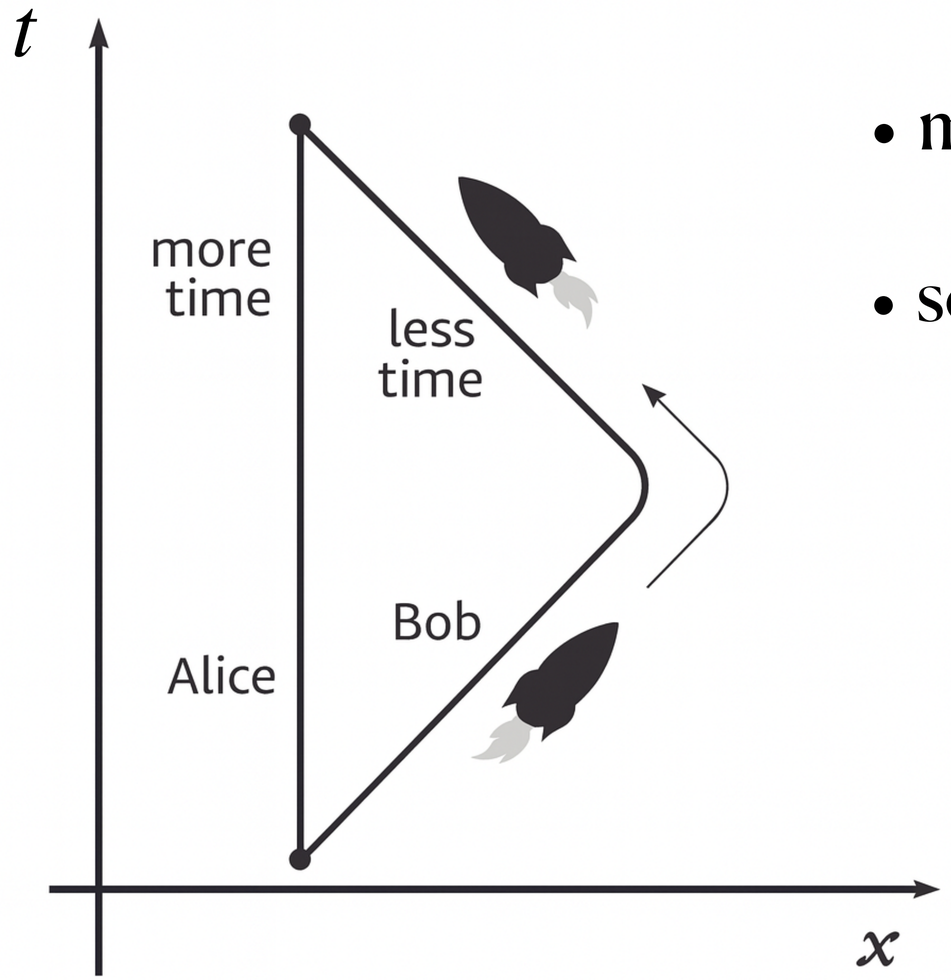
$$\tau^2 = \tau_1^2 + \tau_2^2 = \Delta t_1^2 + \Delta t_2^2 - (\Delta x_1 + \Delta x_2)^2$$

$$\tau^2 - \tau^2 = 2\Delta t_1 \Delta t_2 \geq 0 !$$

Lenght Contraction

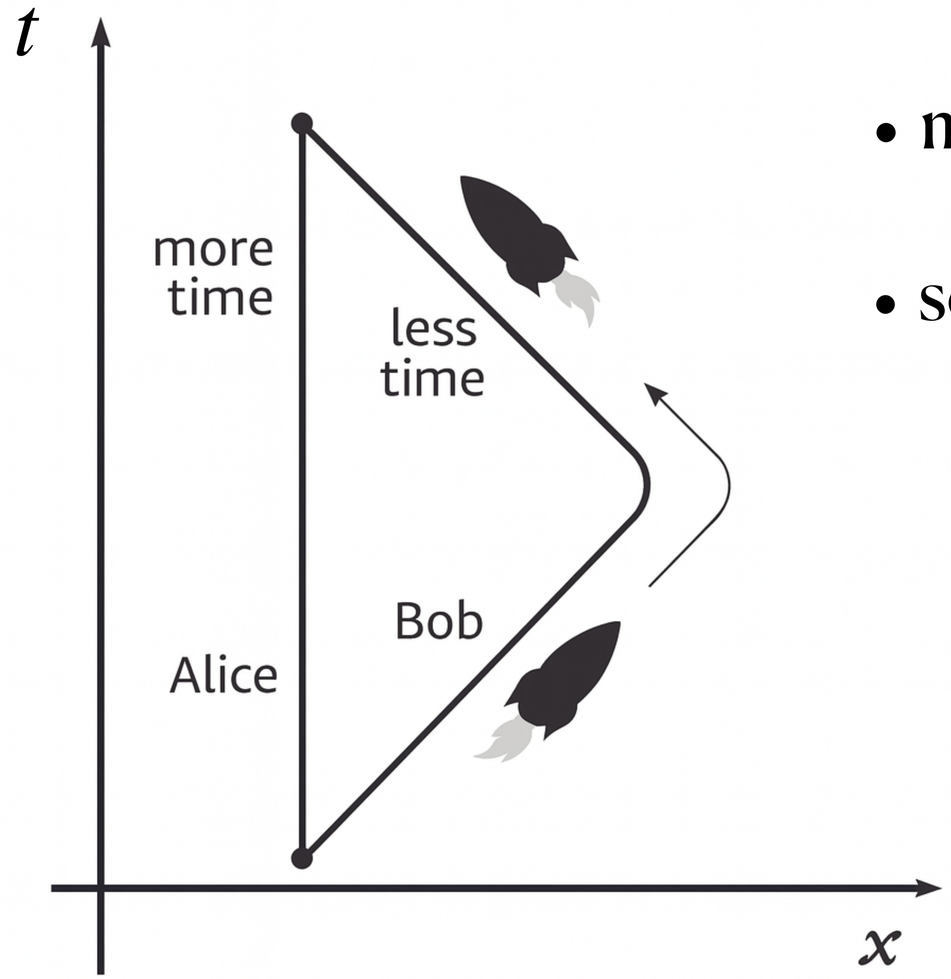


The Twin ~~Paradox~~ Experiment

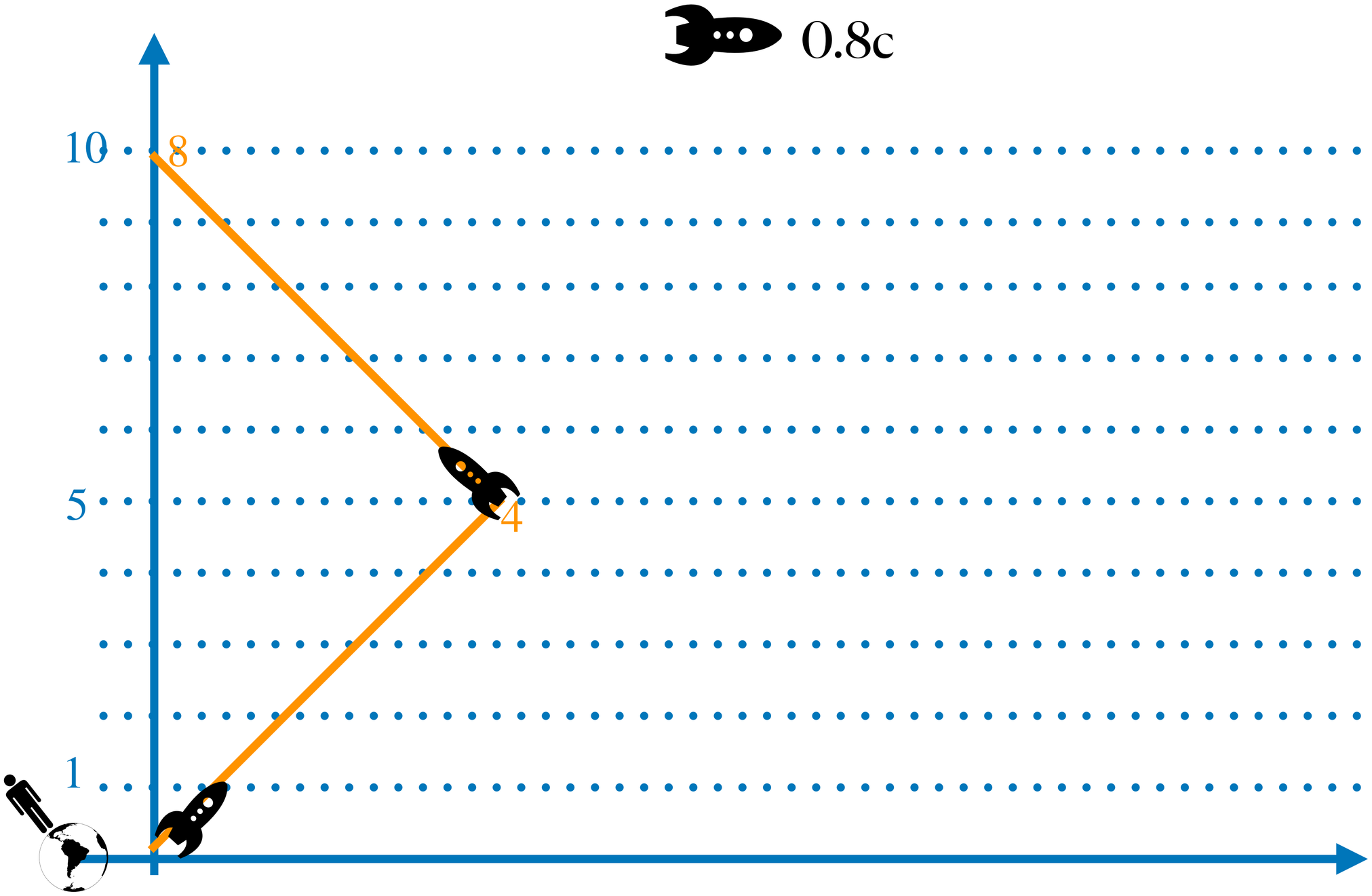


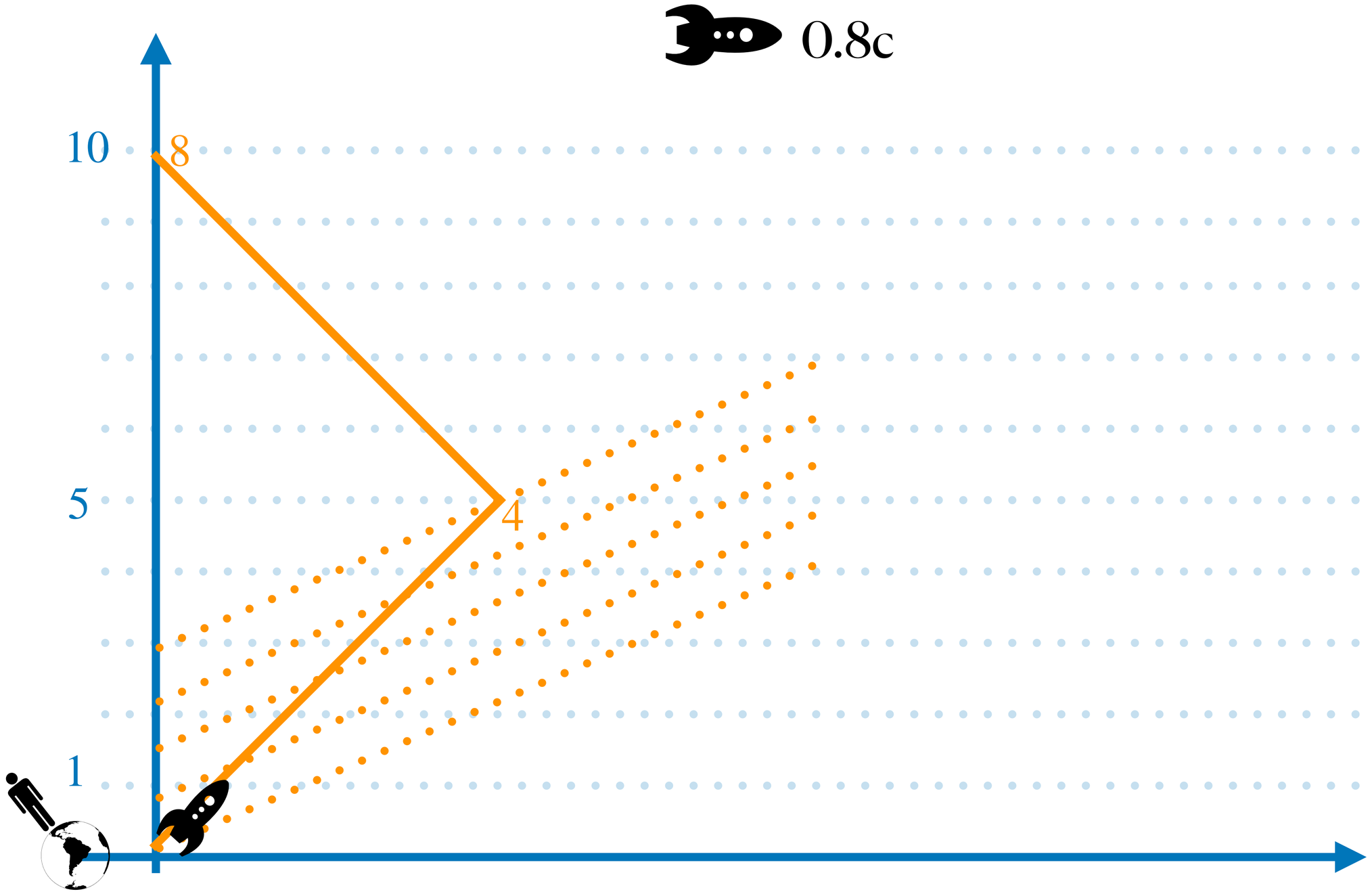
- motion is relative, no?!
- so, whose time is actually dilating?

The Twin ~~Paradox~~ Experiment



- motion is relative, no?!
- so, whose time is actually dilating?
  - acceleration breaks the symmetry, but responsible for the effect?


0.8c
10
8
5
4
1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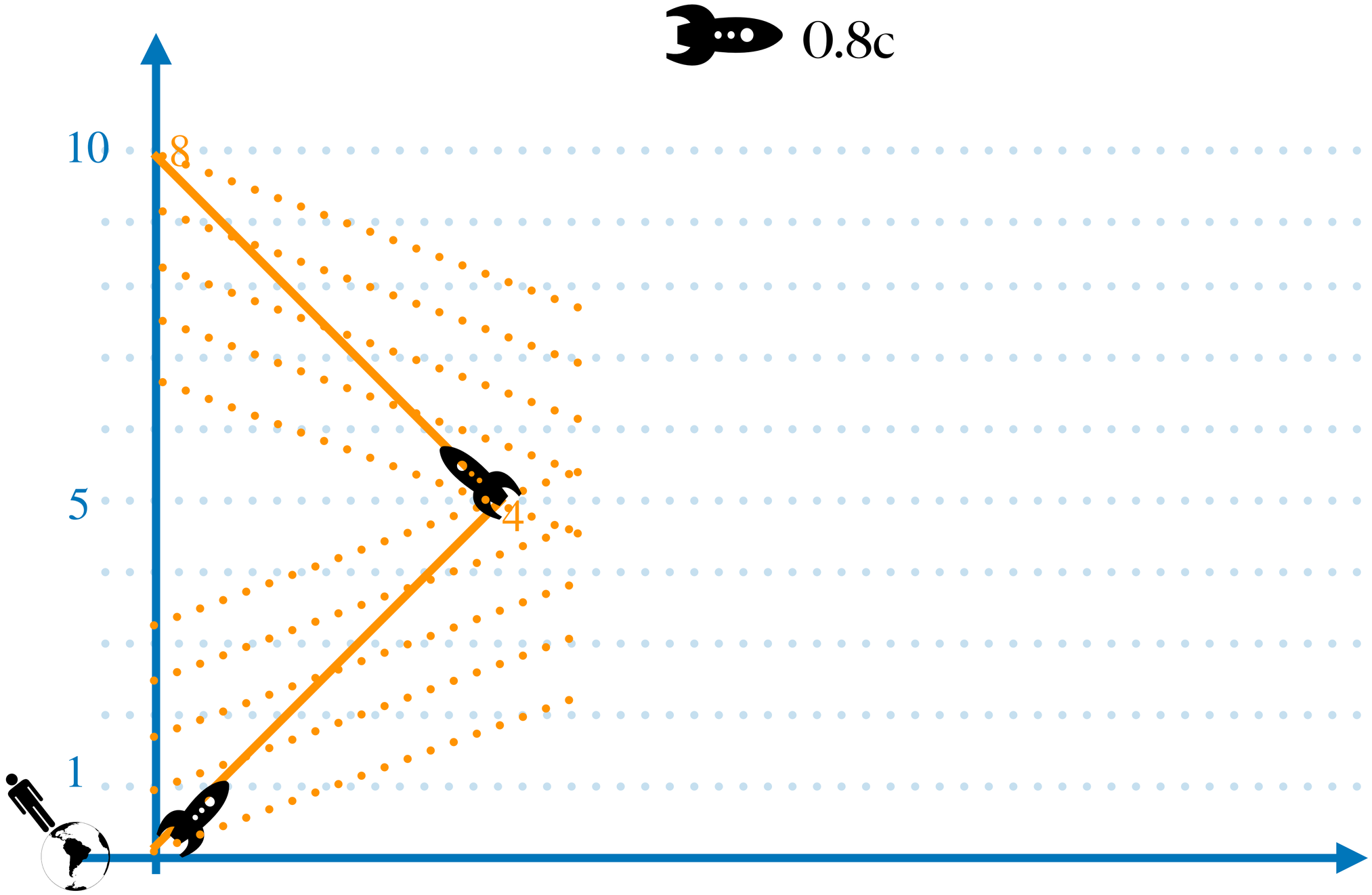
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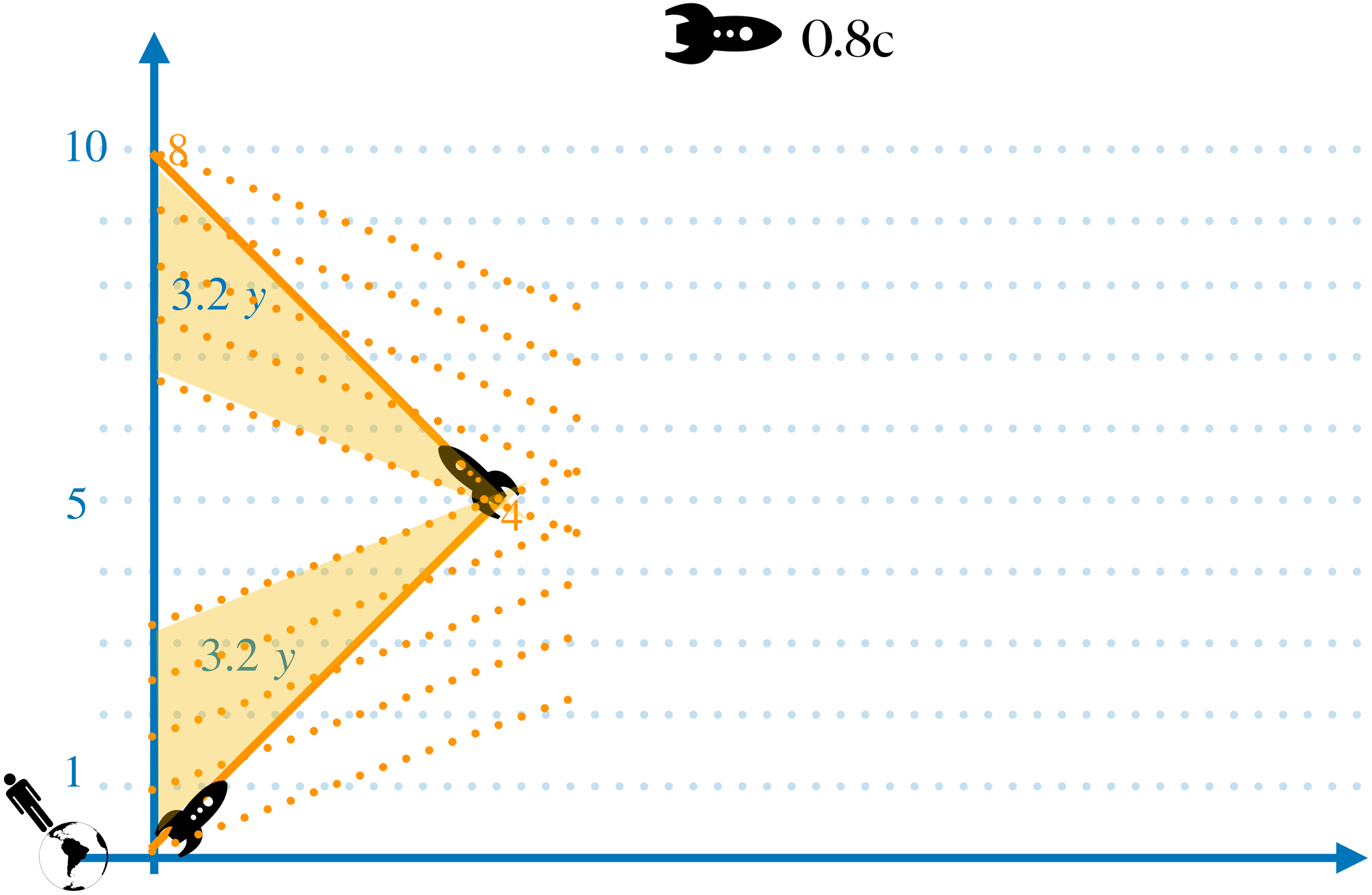
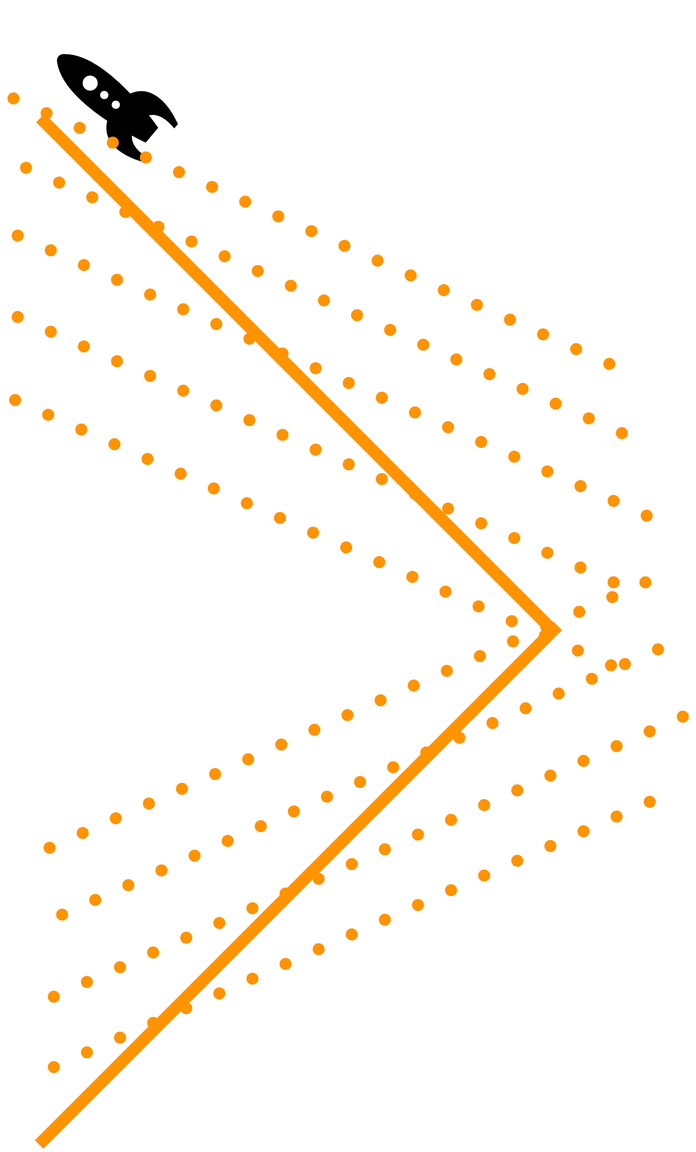
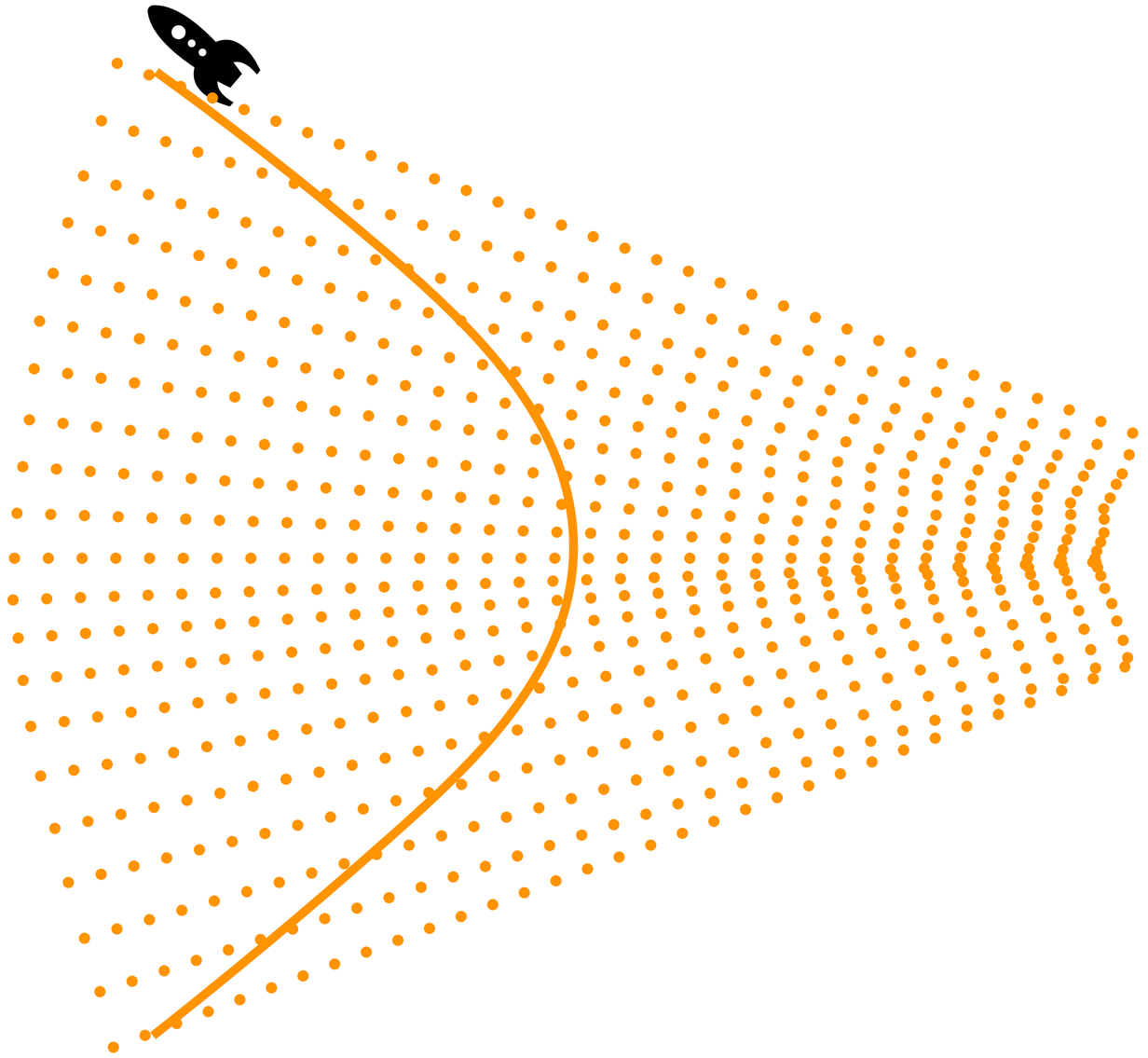
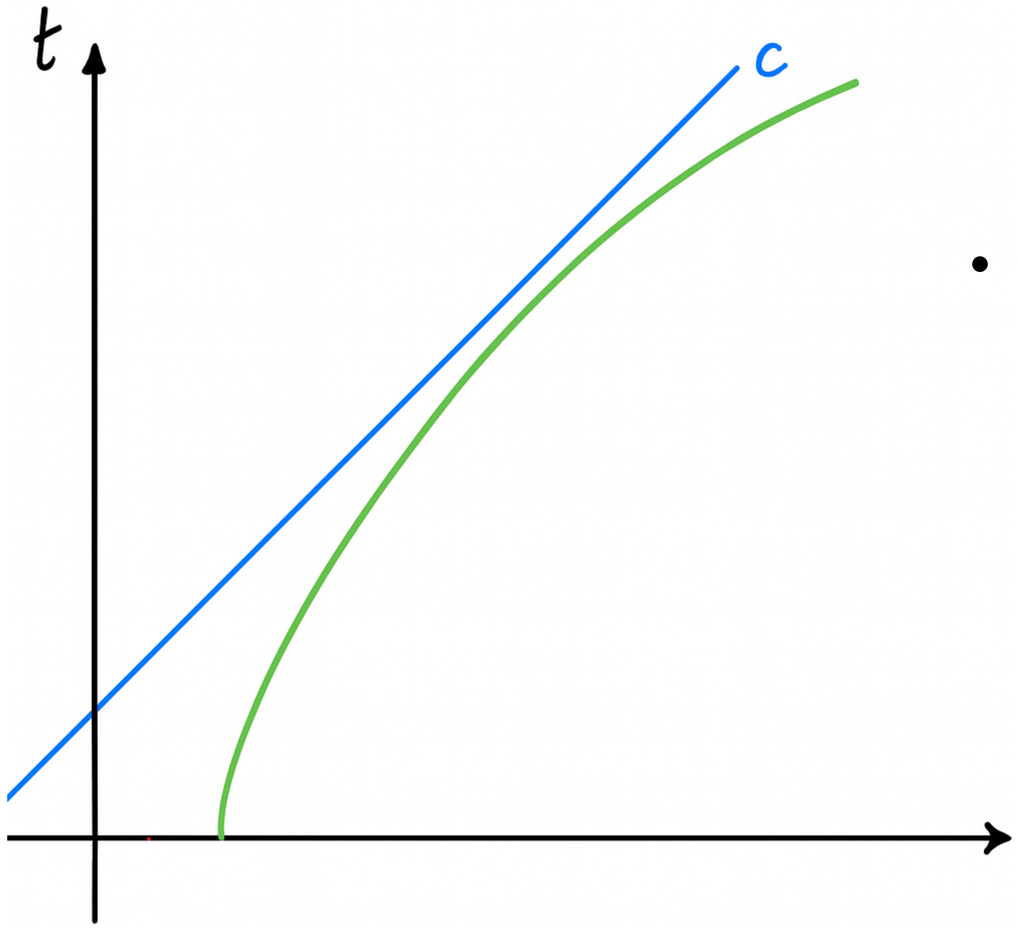

0.8c
10
5
1
8
4
3.2 y
3.2 y

Solution to the Twins Paradox!



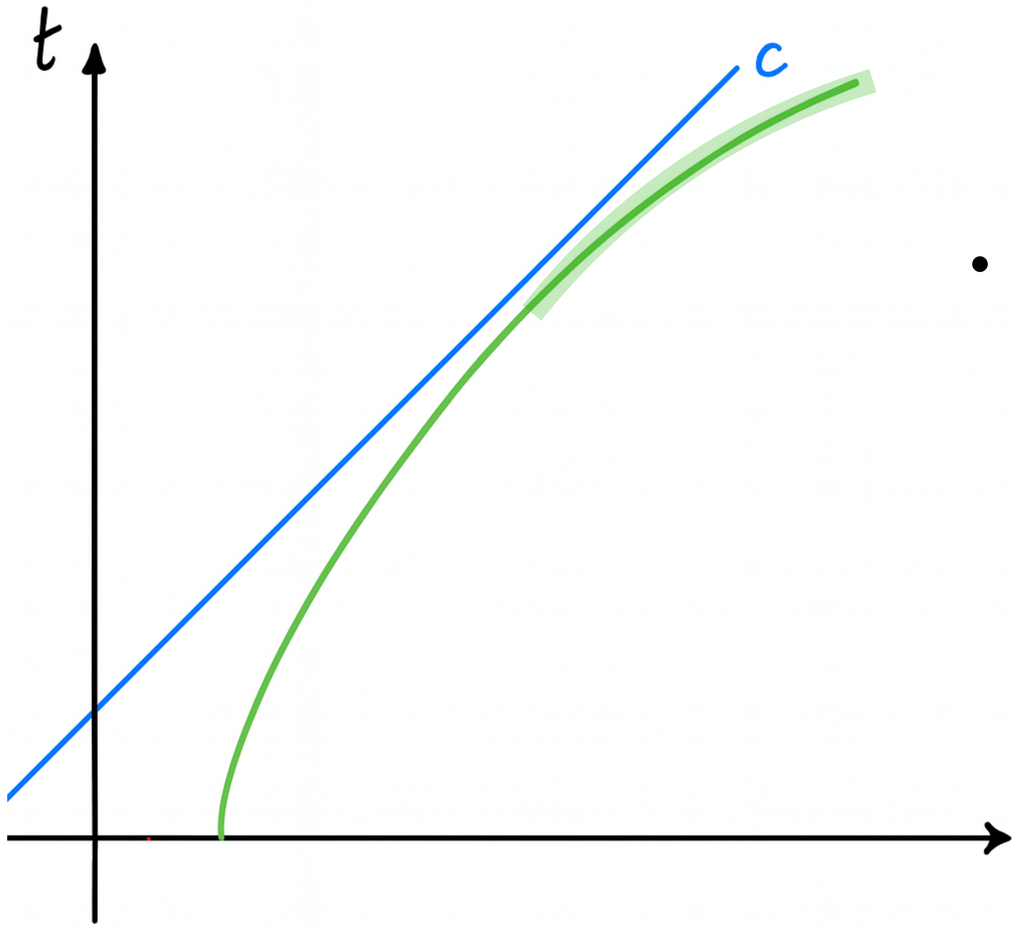


Acceleration in Newtonian physics



- constant acceleration: PARABOLA — $x \propto t^2$

Acceleration in Newtonian physics



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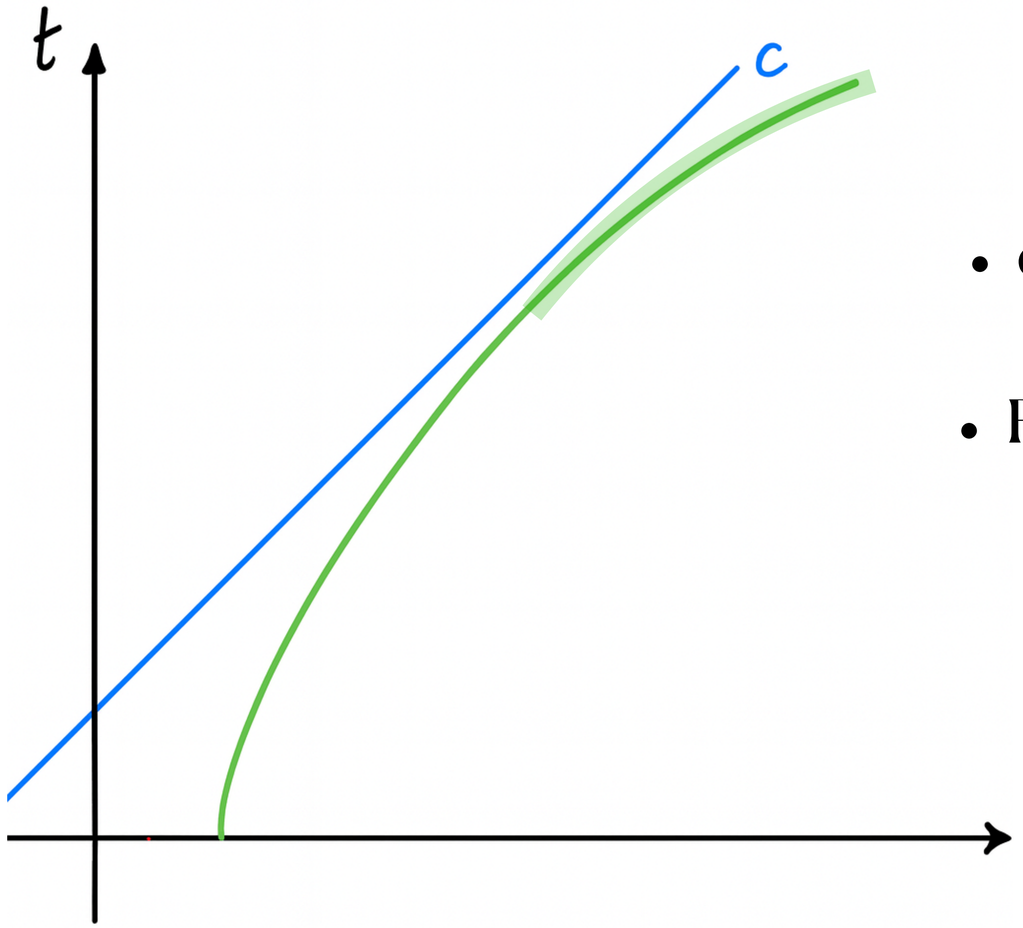
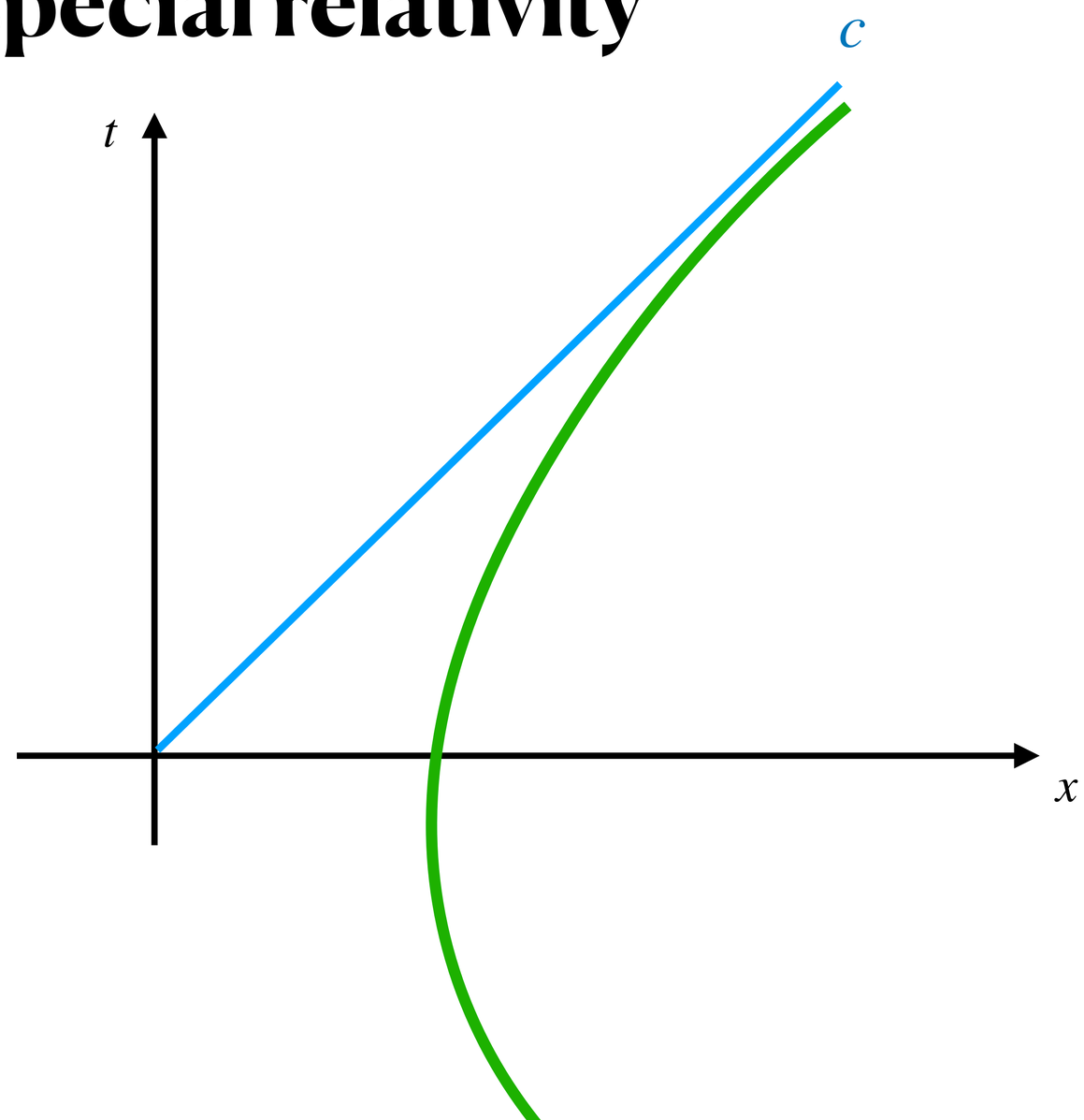
Acceleration in Newtonian physics



- constant acceleration: PARABOLA — $x \propto t^2$
- Faster-than-light travel is **impossible**!

Acceleration in special relativity

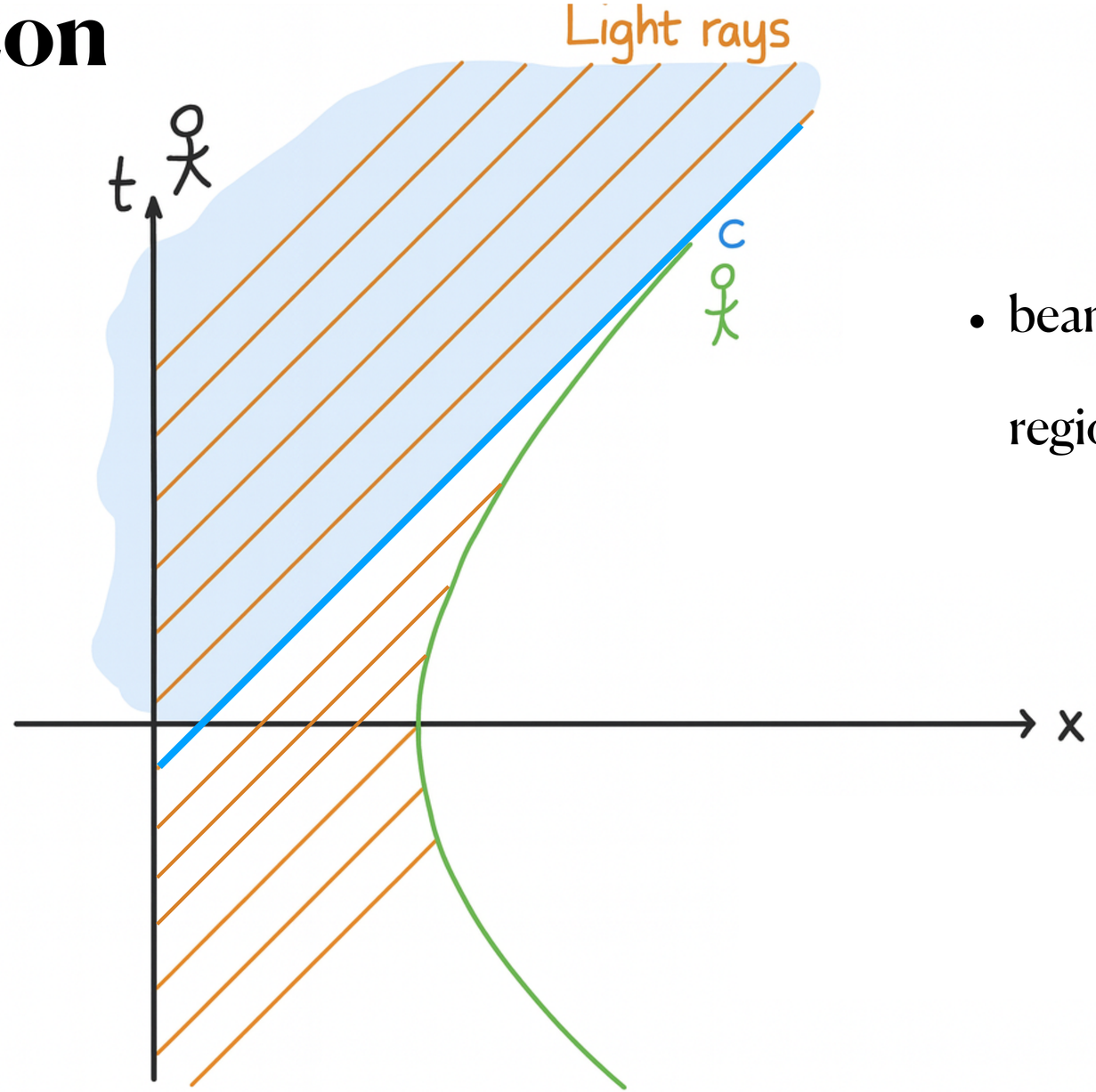


- constant acceleration: HYPERBOLA —

$$x = \sqrt{1 + t^2}$$

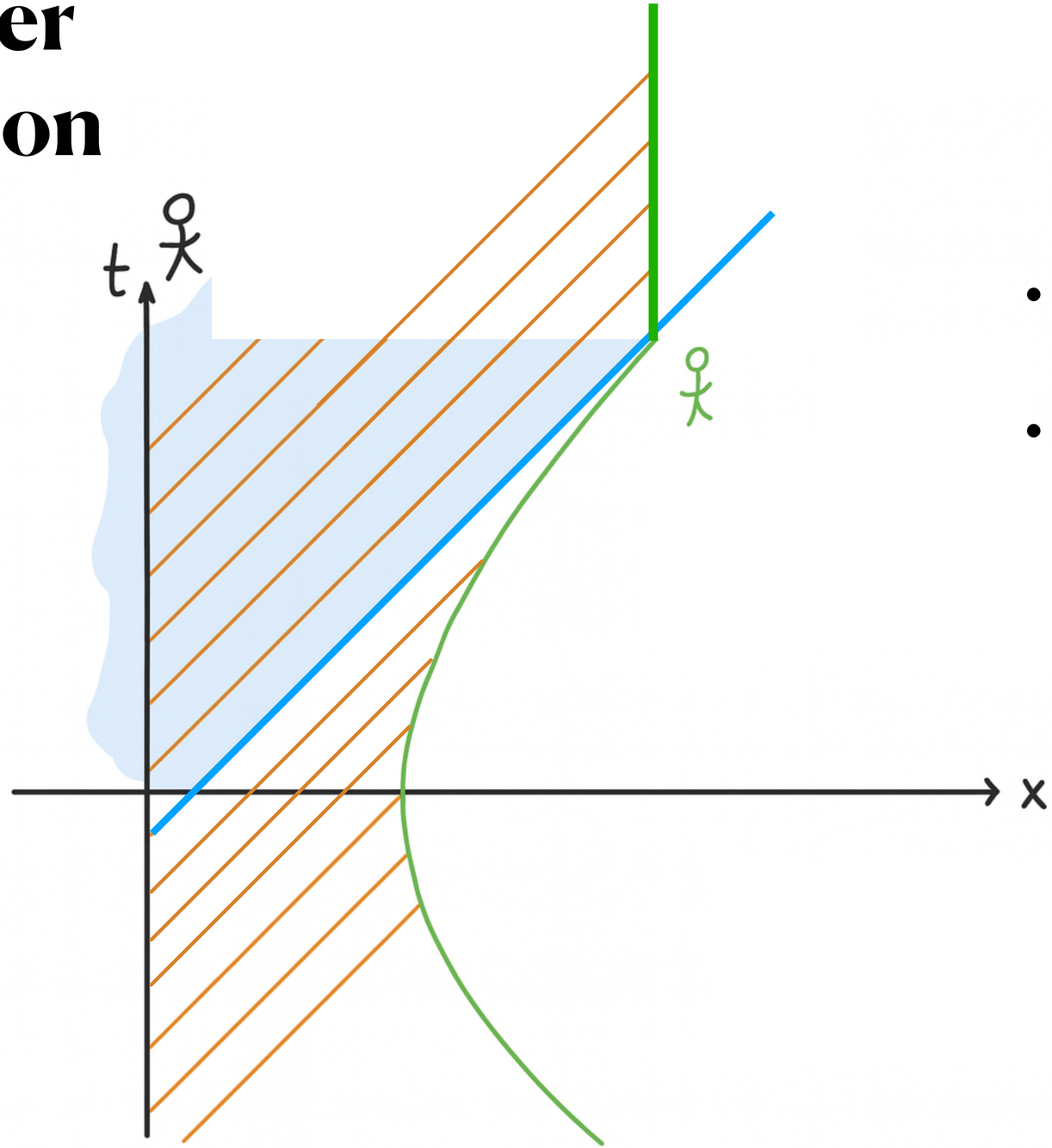
- never reaches the speed of light!

Rindler Horizon



- beams of light sent from inside shaded region never reach Rindler!
  - what could he do?!

Rindler Horizon



- horizon is ultimately artificial!
- get back to being inertial, dude!

- what about...