Physics 253

Patrick LeClair

About me

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- PhD 2002 Eindhoven (NL) / Physics

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- introduce yourself to your neighbors

Core principles

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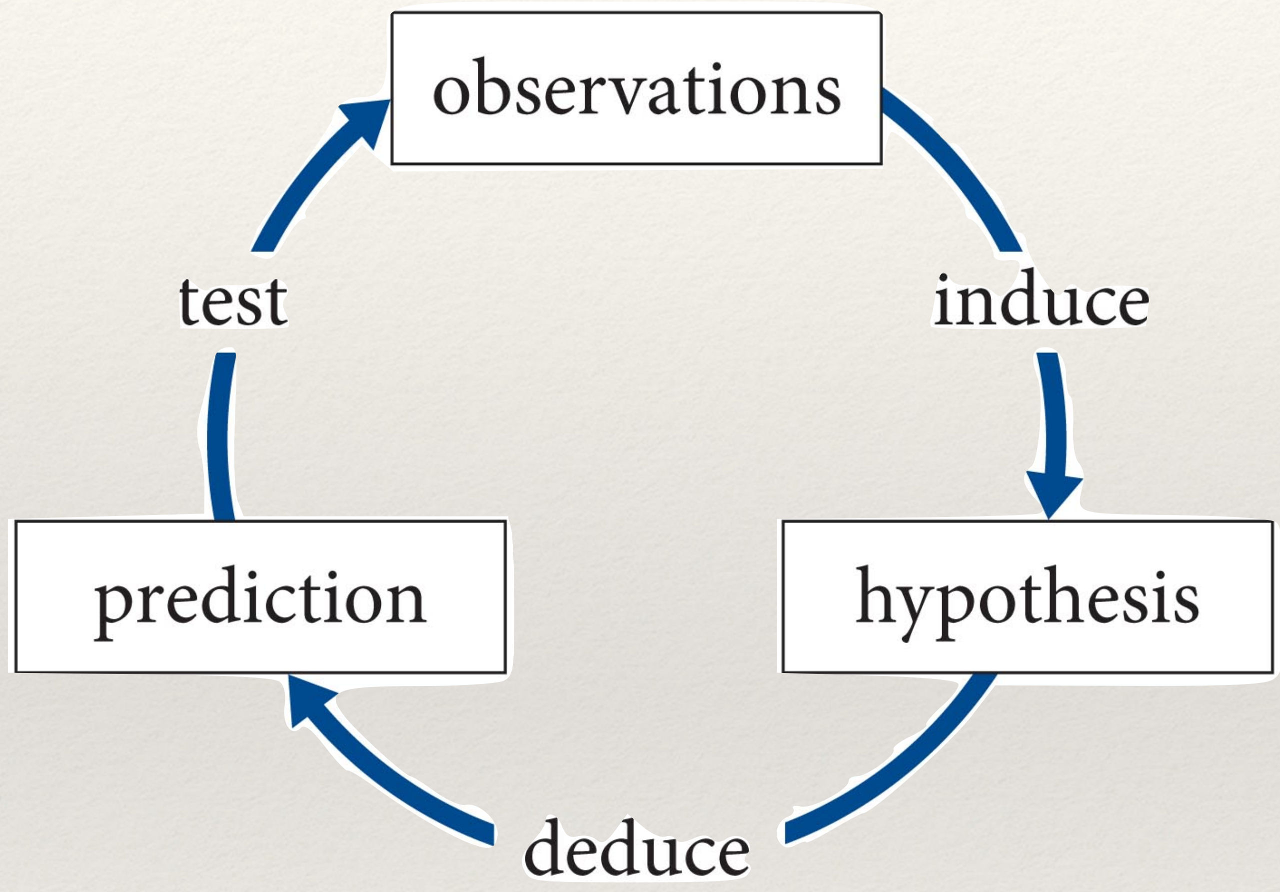
- above all, favor understanding *why* over details at first

The scientific method

An iterative process used to construct laws of nature.

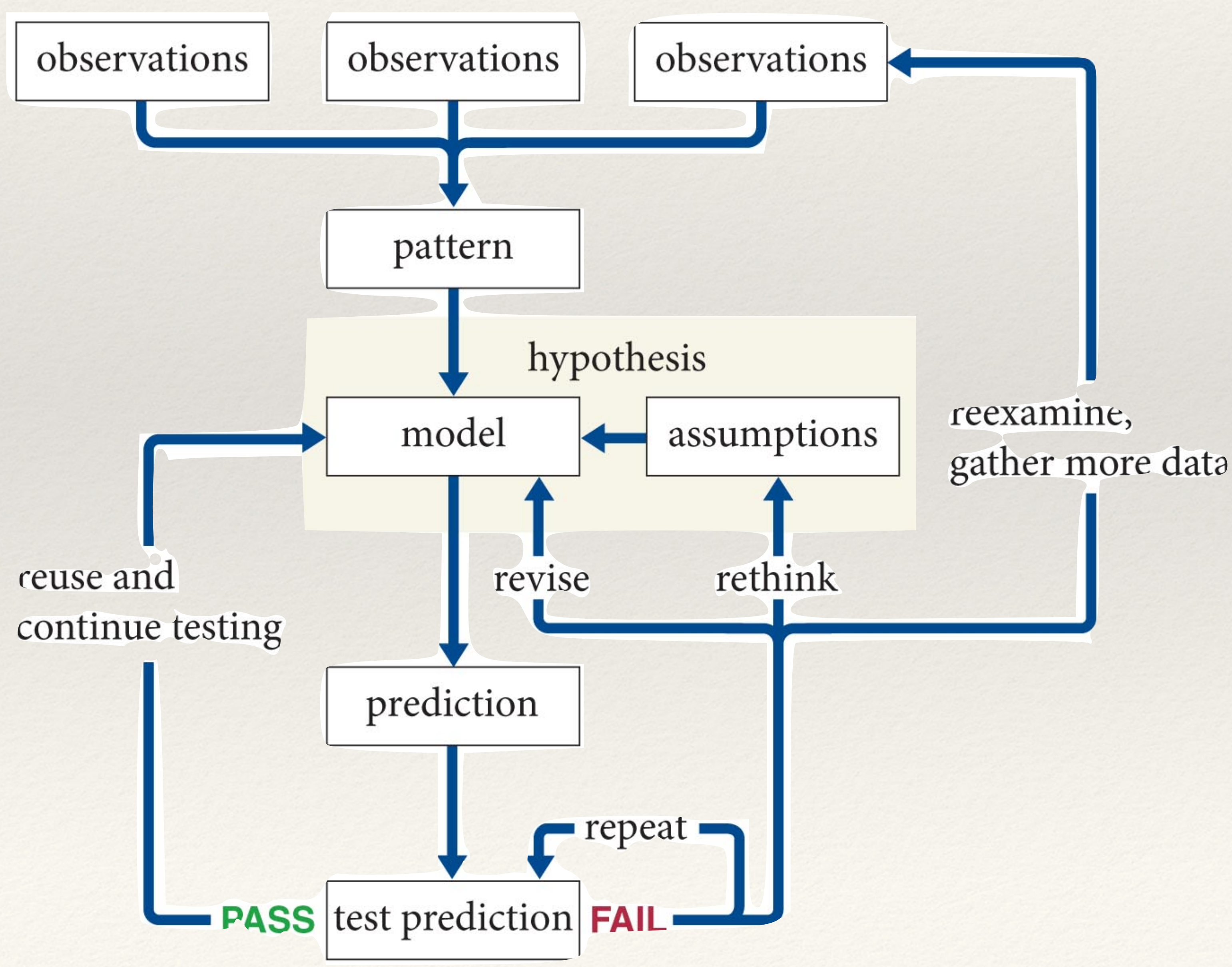


If the prediction is inaccurate you modify the hypothesis
Evidence and *Observations* are critical

If the predictions prove to be accurate test after test it is elevated to the status of a law or a theory.

To do this, construct models

- forming a hypothesis almost always involves developing a **model**
- a **model** is a simplified representation of some phenomenon.



A question

- A hydrogen atom has a + proton and a - electron
- They should attract each other and combine, but instead remain some distance apart
- The hydrogen atom has some measurable *size*
- Why? This shouldn't work! What keeps it stable?

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  - subtle - requires special relativity (or motivates it)
  - so is this where light comes from? why do hot objects glow?

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- Why is matter stable at all?
- We will need to invent relativity and quantum physics for both!

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- Why is matter stable at all?
  - *We need to invent quantum mechanics for this. Seriously.*
- **Then**: all sorts of new things we can use

Learning

- principles vs practice - first one, then the other
  - first *why* and then *how*
  - can you see the *shape* of the answer before calculating?
- good strategies, and not so good strategies
- numbers are not your friend - symbolic solutions are
- your best and worst PH/Sci/Eng courses? why?
  - how does this inform your strategy?

Solving problems

- Find, given?
- Sketch
- Relevant equations?
- **Symbolic solution**
- Numerical solution
- Double check? (dimensional analysis, reduce to known case, appeal to experiment, …)

official things

- Dr. Patrick LeClair
  - pleclair@ua.edu
  - offices: 208 Gallalee (enter through 206)
  - 205-348-3040 (office; direct)
  - 857-891-4267 (cell; use wisely, txt ok)

- Office hours:
  - **MWF 1-2pm, TuTh 11am-12**
- *(many) other times by appointment*

official things

Lecture:

- 0009 Bevill, you found it
- MWF 11-11:50
  - we'll need most of this time to explain things
  - will go over problems, but only so many
  - a big part of learning is solving on your own … with help
- some notes provided (scanned or otherwise)
- no attendance policy, I will try to make it worth your time

What will we cover?

- Relativity
- Thermal radiation & Planck’s hypothesis; photons
- Wave mechanics & matter waves
- Schrödinger’s equation
- Atomic structure; quantum model of the atom
- multi-electron atoms & molecules
- periodic solids, band theory
- Spin, Fermi-Dirac statistics
- applications, such as:
  - semiconductors
  - lasers
  - magnetic resonance

we will adapt as necessary
feel free to suggest topics for “applications”

Grading and so forth

- homework (15%, drop single lowest)
- hour exams (three @ 15% each; 29 Jan, 21 Feb, 27 Mar)
- participation (10%)
  - online using PackBack Questions
- comprehensive final (30%)

Exam rules

- just to get this out of the way, from the syllabus:

Cellphones and other unapproved electronic devices **must be turned completely off** and placed with all other belongings on the floor. All watches must be put away. Do not put your phone or watch in your lap or on your chair or desk. Physically holding or concealing or otherwise using your cell phone, smart watch, or any other unapproved electronic device during the exam will be treated as academic misconduct.

If for any reason you must have access to your phone during an exam, an instructor or proctor must be present while you handle it. Failure to have an instructor or proctor present will be treated as academic misconduct.

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- assigned roughly weekly
- typical: assigned Friday, due following Friday (posted as a PDF on BlackBoard)

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- there are *many* of you, and HW grades are usually >90% for those who complete it
  - also, we are aware of Chegg and the rest of the internet
  - credible attempt for a problem, full credit
  - no attempt, no credit
  - I will post detailed solutions, and will give detailed feedback on request
- collaboration is fine; turn in your own work

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- *practice* is critical to get the process right [carrot]
- HW problems I assign will show up on the exam [stick]

Participation

- online. I won’t make you talk unless you want to.
- (but feel free to stop me with questions)

packback

Fearlessly curious.

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Packback is an AI-supported online discussion platform that is a space to develop critical thinking, curiosity, and writing skills.

Student Feedback

Spring 2019 Student Feedback Survey

“In past classes where Packback wasn’t used, I wasn’t all that interested in the material. I just did what I had to do to pass the class. I didn’t think I’d care about a GenEd ever before Packback.”

The Impact

Critical Questioning skills are *essential* to college and post-grad life:

- In asking effective questions while interviewing to select the right job after graduation.
- In identifying opportunities for innovation, when starting a business, or working within a team.
- In learning new skills independently after graduation, to keep adapting to a changing world!

Objectives

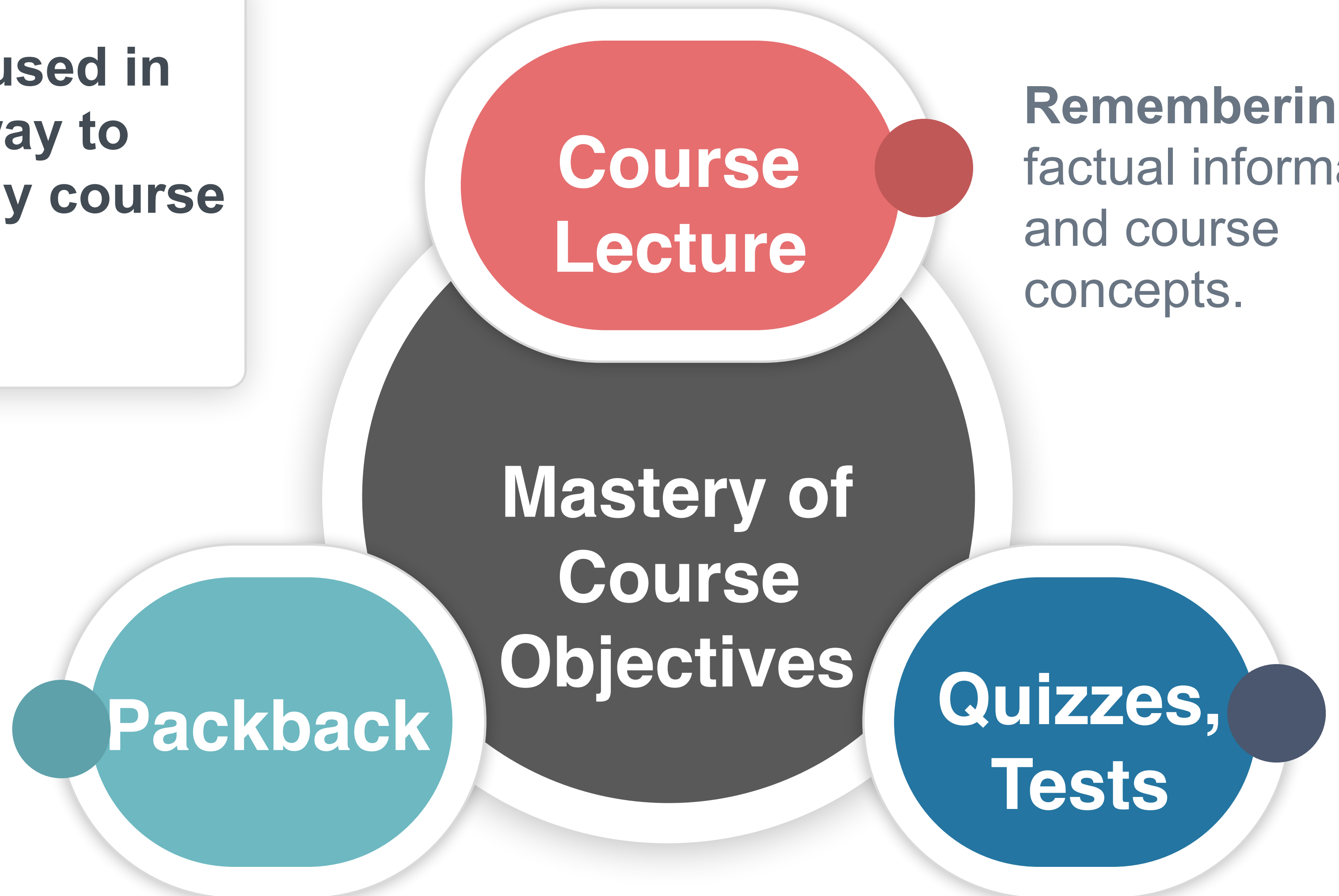
Our specific Packback course objectives

In this class, we're using Packback to:

- **Discuss material together in more detail outside class**
- **Think and discuss about the applications of course content**
- **Satisfy your curiosity!**

How Packback discussion fits into this course

Packback will be used in this course as a way to integrate and apply course concepts.

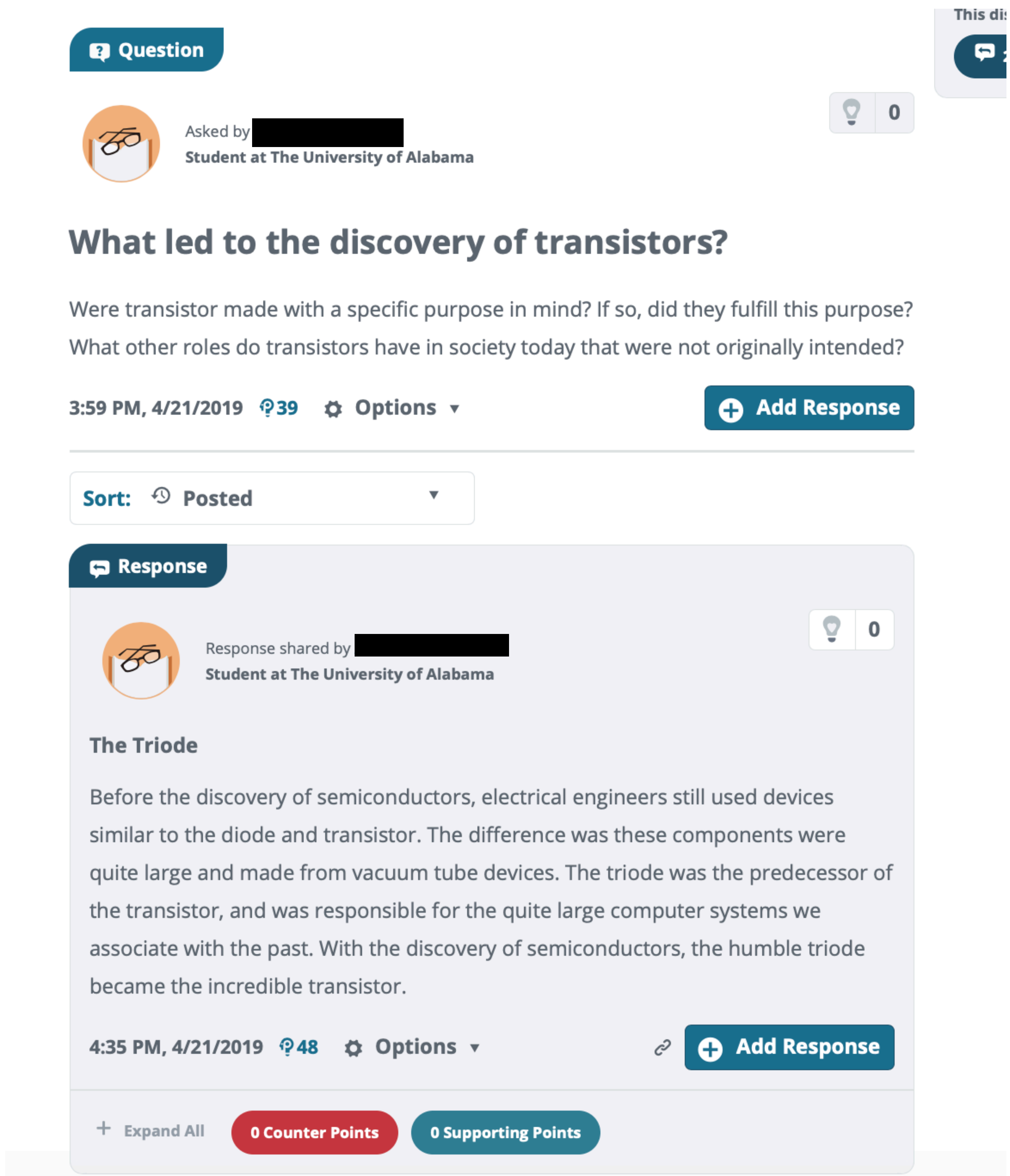


Remembering new factual information and course concepts.

Analyzing, Evaluating, and Generating discussion into broader contexts.

Proving **Understanding** of course information and concepts.

Example



Ideally: add a supporting link

Participation requirements & How you will be graded

Grading & Requirements

Packback is worth 10% of your final grade!

This is an *important* assignment, please take it *seriously* as it will affect your final grade.

It is essentially a letter grade difference, and all you have to do is post online. Which you are already doing elsewhere anyway.

Grading & Requirements

Participation Requirements

Weekly Deadline

[Monday] at [11:59 PM]

What to Post

per Deadline period

Post 3 Questions + Responses (any combination)

Other Expectations

- Some ‘catch up’ is allowed, within reason

Packback's AI
& How to check your grade

Auto-Moderation

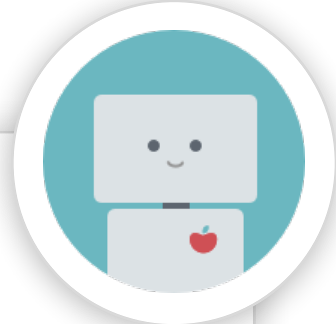
Posts on Packback are Reviewed by AI

Packback's AI

Packback's AI "flags" posts that may be violating community guidelines.

Posts are then reviewed by Packback moderators.

Offending posts are Moderated and **no longer count for credit**.



Packback's AI auto-flags for:

- **Plagiarism**
- **Closed-Ended Questions** (e.g. "What is the definition of mitosis?")
- **Class Logistics Posts** (e.g. "When is the next test"?)
- **Low effort / Low detail posts**

Auto-Moderation

What happens if your post is moderated?

Post is “Flagged”

If your post is “Flagged”, you have not yet lost points!

At this time, your post is still published and still counts for credit.

Post is “Moderated”

If your post is moderated, it is unpublished and no longer counts for credit.

If your post is “Moderated”, you receive an email notifying you.

Post is “Republished”

From the email, you can “edit & re-publish” the post.

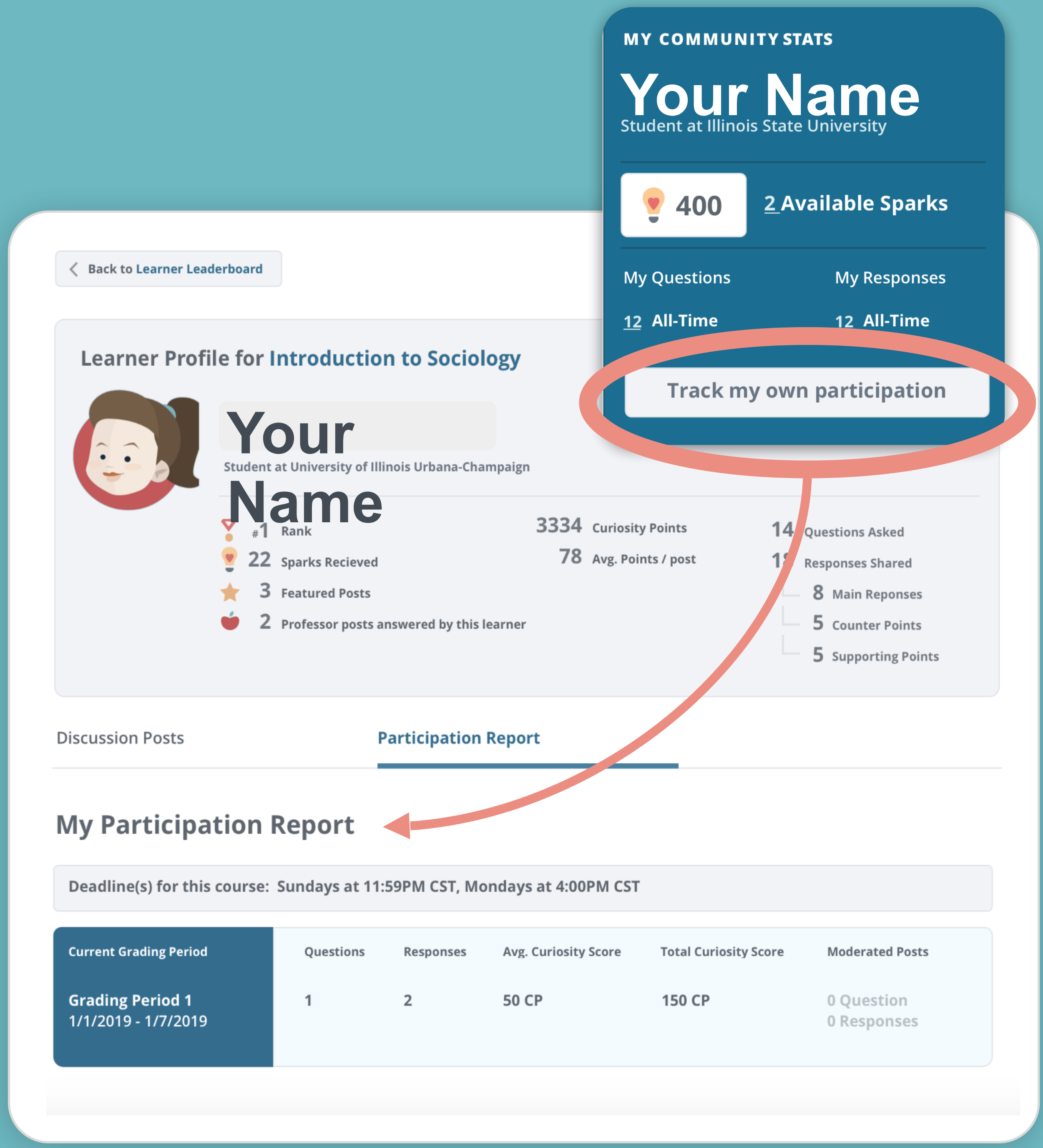
Doing so will earn back your points for the post without penalty, so long as you edit before grades are entered.

Monitor

Track Participation

You can check your current participation by Deadline period to make sure you've earned your full points for the week.

Note: If you have any Moderated posts, you can track them here!



Getting started
& Getting help

Register

Registering for Packback

You will have received an invitation in your school email inbox.

- Follow the instructions in the email to checkout and finish registration.
- Be sure to create an account with the **same email** where you were sent the invitation!

Don’t see it? Check Spam!

Didn’t get an email?

- Sign up directly on Packback
- Click “Join Community” button
- Enter the “**Community Look-Up Key**” from our course syllabus
    - *You **only** need this key if you didn’t get the invite.*

Register

Registering for Packback

community look-up key for this course is:
08ecd4d9-dda6-4339-8cf8-2cafaeb3640d

get the *access code* via RedShelf link
on BlackBoard page - fee then waived

Get Help!

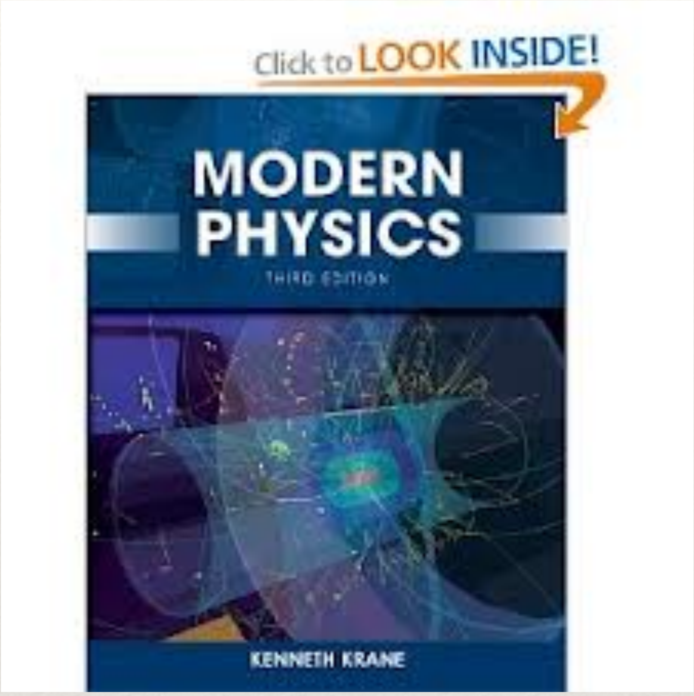
Need Help? Email Holla@packback.co

Packback's support team is available 7 days a week, and will help you will <u>all</u> technical issues.

Do <u>NOT</u> email me with Packback issues; their team will be able to help faster!

stuff you need

- textbook
  - Krane 3rd edition
  - Amazon has it
  - used / older edition / sharing OK
- calculator
  - basic with trig / log
  - graphing / etc unnecessary but fine
- paper & writing implement



useful things

Feyman lectures on physics
http://www.feynmanlectures.caltech.edu/info/

PH102 notes, including relativity
http://pleclair.ua.edu/ph102/Notes/

old PH253 content + notes
http://pleclair.ua.edu/PH253/

showing up

- we hope you will find some utility in the class
- homework/exams may rely on stuff I say in class
- missing an exam is bad.

  acceptable reason ... makeup or weight final

Schedule

- Listed in syllabus; will try to stick to it.
- Reading for each lecture should be obvious
  - (when it isn't, I will post)
- For Friday:

  skim Ch. 1

  read Ch. 2 at least through 2.4

  -or- read online notes from PH102

date	primary topic	secondary topic	reading	note	Feynman (supplemental)
8-Jan	introduction	relativity			http://feynmanlectures.caltech.edu
10-Jan	relativity	time dilation, length contraction	Krane 2.1-4		v1 ch15
13-Jan	relativity	Lorentz transformations	Krane 2.5-6		
15-Jan	relativity	dynamics	Krane 2.7-9	**add / drop without W**	v1 ch16
17-Jan	radiation	origin, radiated power	notes		v1 ch28, 32
20-Jan	**NO CLASS**			**MLK day**	
22-Jan	radiation		notes		v1 ch32
24-Jan	radiation	why is the sky blue	notes		v1 ch32
27-Jan	Planck	blackbody radiation	notes/Krane 3.1, 3.3		v1 ch 41, 42
29-Jan	**EXAM 1**				
31-Jan	photoelectric effect	exam review	Krane 3.2		
3-Feb	Compton scattering		Krane 3.4-6, notes		
5-Feb	de Broglie waves	uncertainty	Krane 4.1-4		v1 ch37, 38; v3 ch2
7-Feb	double slit expt.	propagation of uncertainty	Krane 4.4-7		v1 ch37; v3 ch1, 3
10-Feb	Schrodinger's equation	intro	Krane 5.1-3		v3 ch16
12-Feb	Schrodinger's equation	wavefunctions, 1D	Krane 5.4		
14-Feb	Schrodinger's equation	more 1D examples	Krane 5.5-6		
17-Feb	semi-classical atoms	Bohr-Rutherford model	Krane 6.1-5		
19-Feb	Bohr-Rutherford model		Krane 6.6-8		v3 ch19
21-Feb	**EXAM 2**				
24-Feb	H atom		Krane 7.1-2		v3 ch19
26-Feb	H atom	angular momentum	Krane 7.3-5		
28-Feb	H atom	spin	Kane 7.6-8	**Midterm grades due**	
2-Mar	H atom	fine structure	Krane 7.9		v3 ch12
4-Mar	many-electron atoms	Pauli / selection rules	Krane 8.1-4		v3 ch19
6-Mar	many electron atoms	periodic table, X-rays	Krane 8.5-6		
9-Mar	many electron atoms				
11-Mar	variational method	hydrogen molecule	notes		
13-Mar	variational method	diatomic molecules	notes		
	SPRING BREAK				
23-Mar	molecular structure	bonding, Hooke's law	Krane 9.1-3		v2 ch38
25-Mar	molecules	molecular orbitals	notes	**last day to drop with W**	v3 ch15
27-Mar	**EXAM 3**				
30-Mar	intro to particle statistics	fermi, boltzmann, bose	Feynman v3 ch4		v2 ch40
1-Apr	solid state	free electron approximation	Krane 11.3, notes		v3 ch15
3-Apr	**NO CLASS**			**Honor's day**	
6-Apr	solid state	semiconductors, insulators, metals	Krane 11.4-6		
8-Apr	solid state	semiconductors, doping	Krane 11.6-7		
10-Apr	solid state	pn diodes, transistors			
13-Apr	solid state	information storage			
15-Apr	particle statistics	identical particles	Feynman v3 ch4		
17-Apr	particle statistics	lasers	Feynman v3 ch9	**last day for exams, etc**	
20-Apr	lasers	two-level systems	notes		
22-Apr	crystals, x-ray diffraction		notes		
24-Apr	magnetism		notes		
27-Apr	**FINAL EXAM**	8-10:30am	in lecture hall		

PH-ENG double major

- Open to all engineering majors!
- ECE majors need as little as 4-6 additional hours to complete a second major in Physics. Also pairs well with AEM/ME and others.
- This combination of fundamental and applied science can be highly advantageous when you enter the job market.
- Contact Dr. LeClair or Dr. Williams for more information.

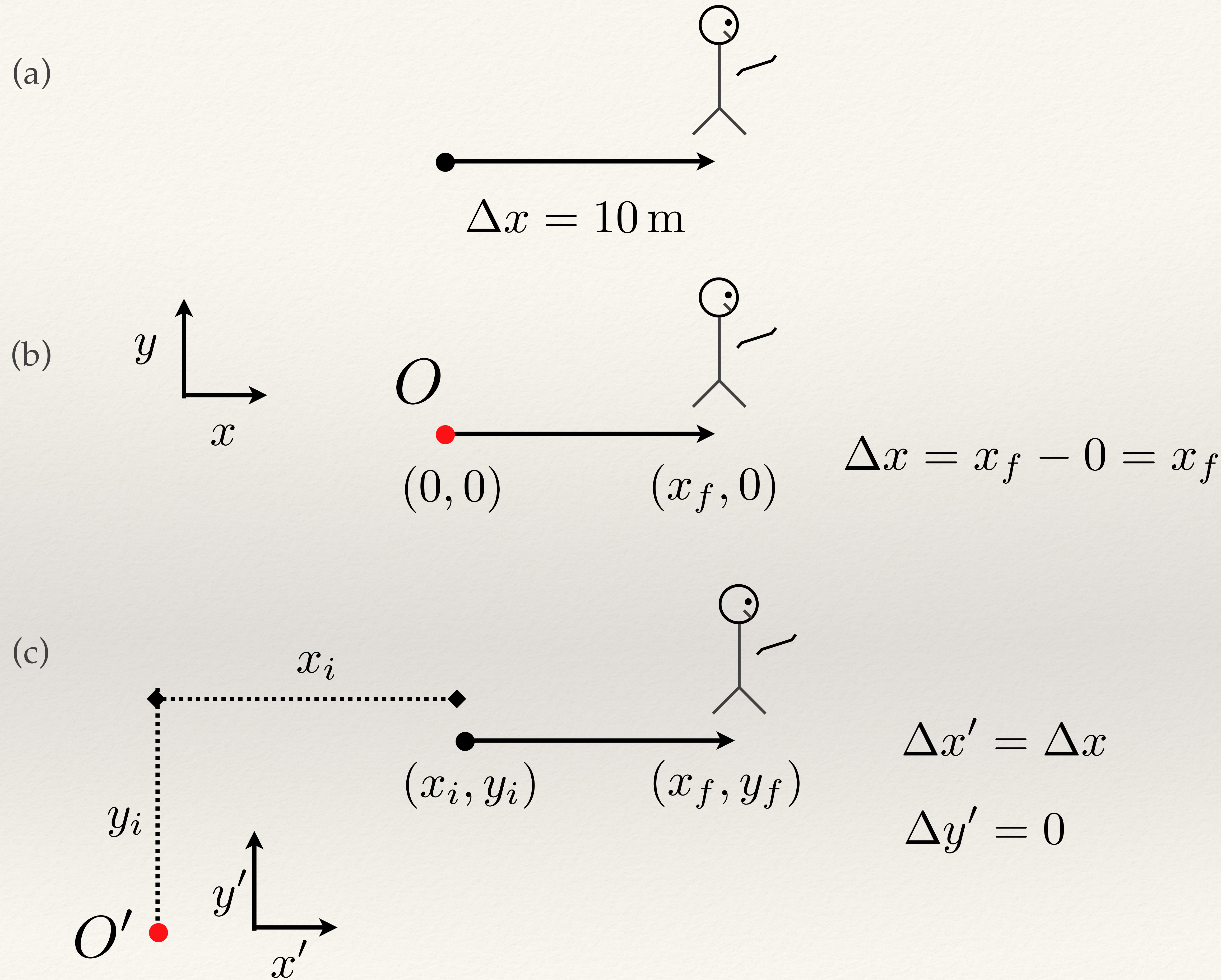
Learning Assistant Positions

- Assist in an intro Physics (PH101/102/105/106/126) or Astronomy (AY101/102) for 3-6 hrs/week
- Meet with the course instructor 1 hr each week for class preparation.
- LAs will be paid $11/hr for 4-7hr/wk depending on the classes they are scheduled to assist in and their attendance.
- Contact Dr. LeClair for more information

Questions so far?

Today

- Relativity
  - why do we need it?
  - what are the basic principles?
  - how can we find a model consistent with them?



(a)
$\Delta x = 10\,\mathrm{m}$
(b)
y
x
O
$(0, 0)$
$(x_f, 0)$
$\Delta x = x_f - 0 = x_f$
(c)
x_i
(x_i, y_i)
(x_f, y_f)
y_i
y'
O'
x'
$\Delta x' = \Delta x$
$\Delta y' = 0$

Notation: keeping it clear

$$x_{\text{what}}^{\text{frame/who}}$$

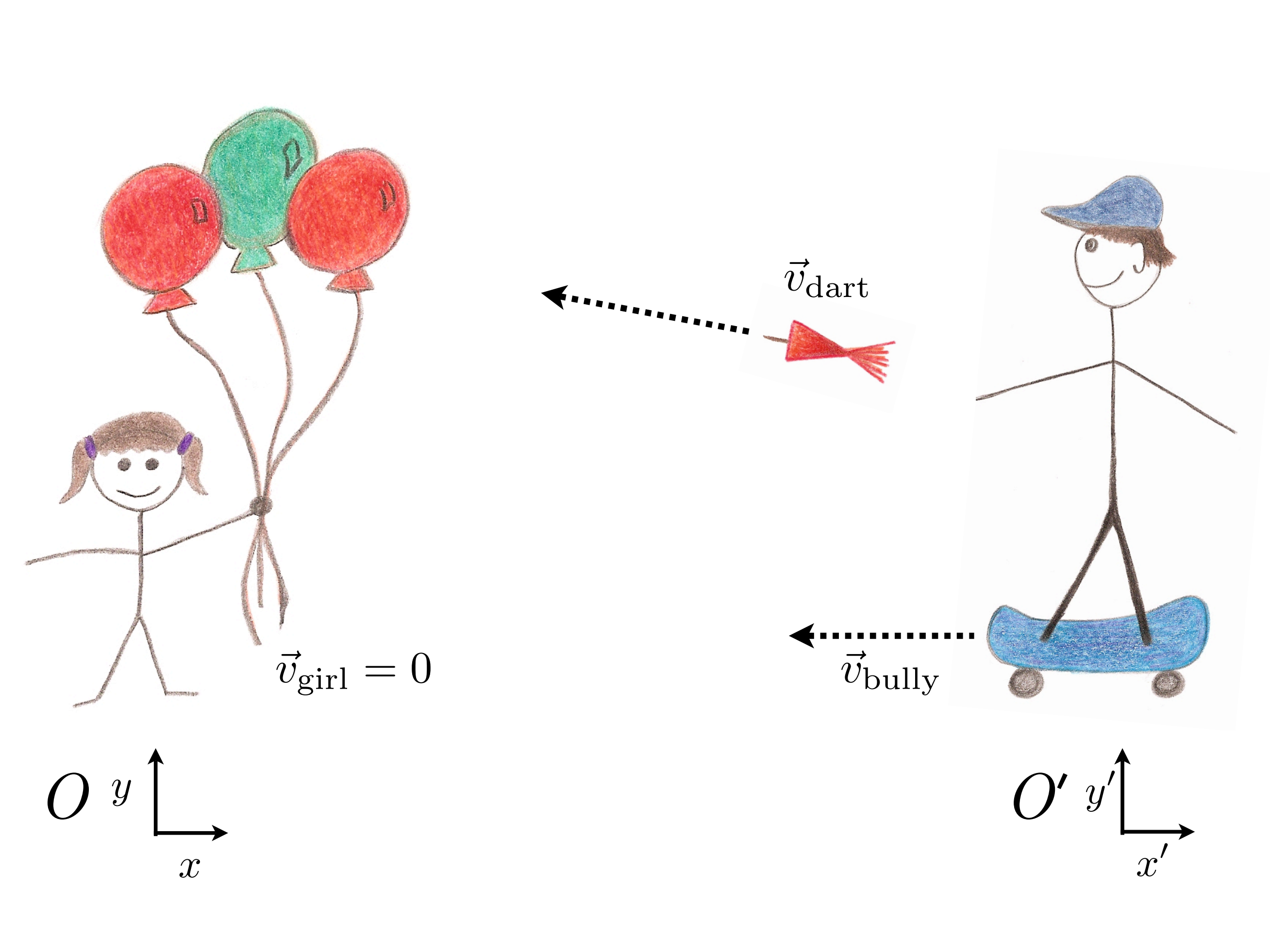
Coordinate system notation examples:

$x_{\text{final}}^{O} = x_f^{O}$ final x position of an object measured in the O coordinate system

$v_{\text{car}}^{O'} \equiv v'_{\text{car}}$ velocity of a car measured in the O′ coordinate system

$P_f^{O'} \equiv P'_f = (x'_f, y'_i)$ final position of an object measured in the O′ coordinate system

Moving reference frames



v^{O}_{bully} = velocity of bully measured from the ground $\equiv v_{\text{bully}}$

$v^{O'}_{\text{dart}}$ = velocity of dart measured from the skateboard $\equiv v'_{\text{dart}}$

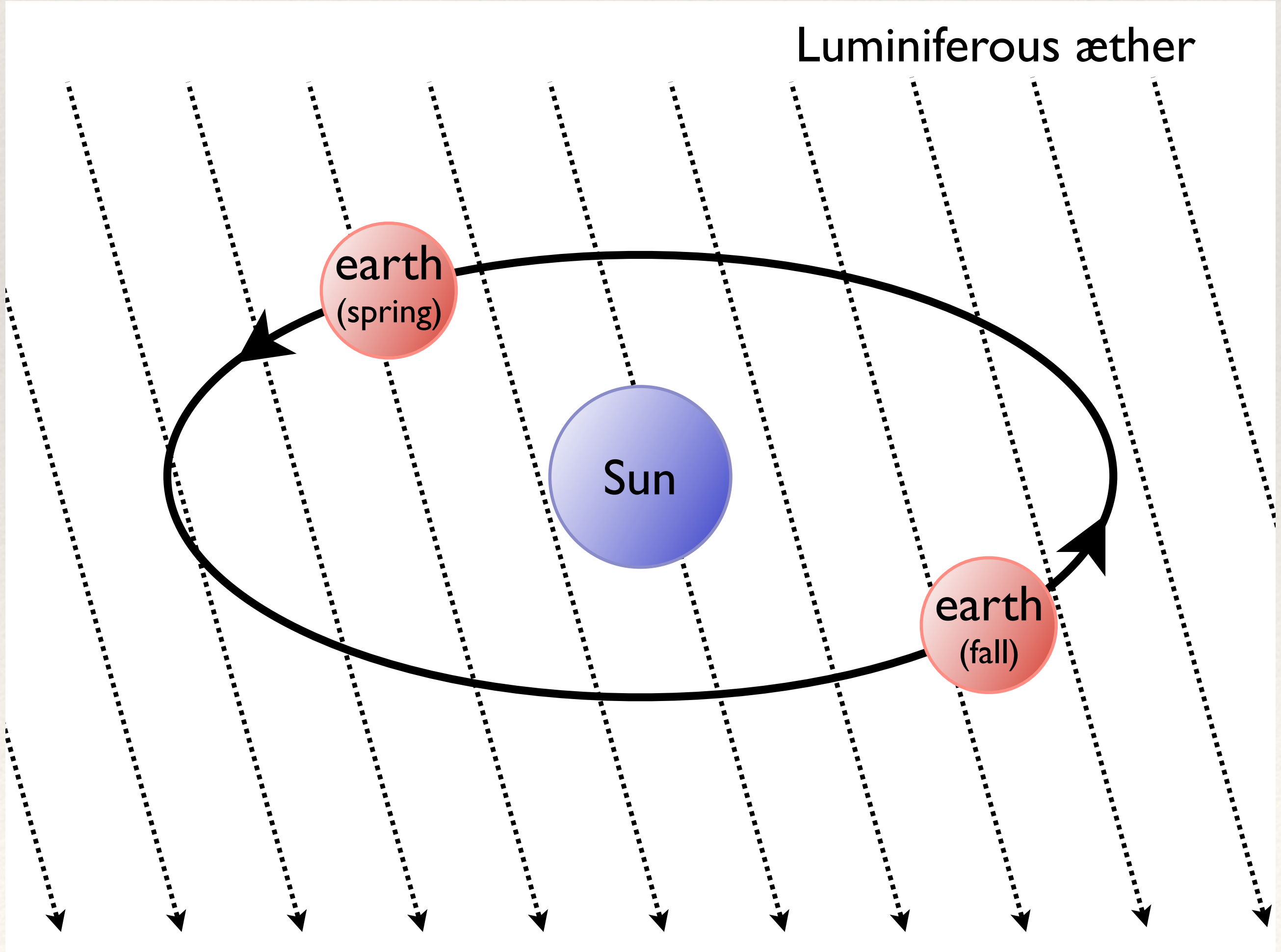
v^{O}_{dart} = velocity of the dart measured by the girl $\equiv v_{\text{dart}}$

$$v_{\text{dart}} = v'_{\text{dart}} + v_{\text{bully}}$$

velocity of the dart seen by the girl = velocity of dart relative to skateboard + velocity of skateboard relative to girl

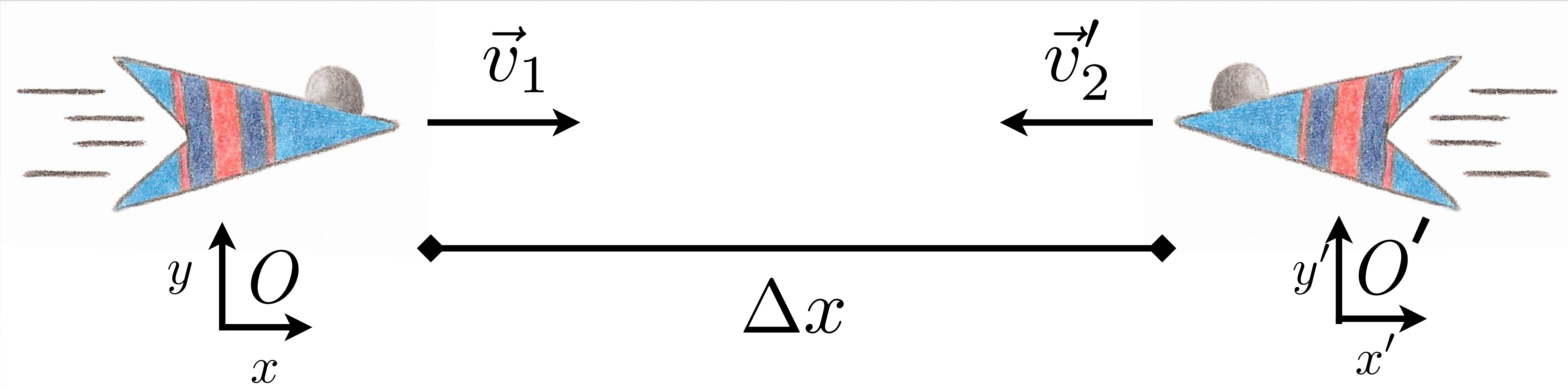
No preferred reference frame

- only *relative* motion is important
- after all, who is really moving?
- experiments: no absolute position / frame



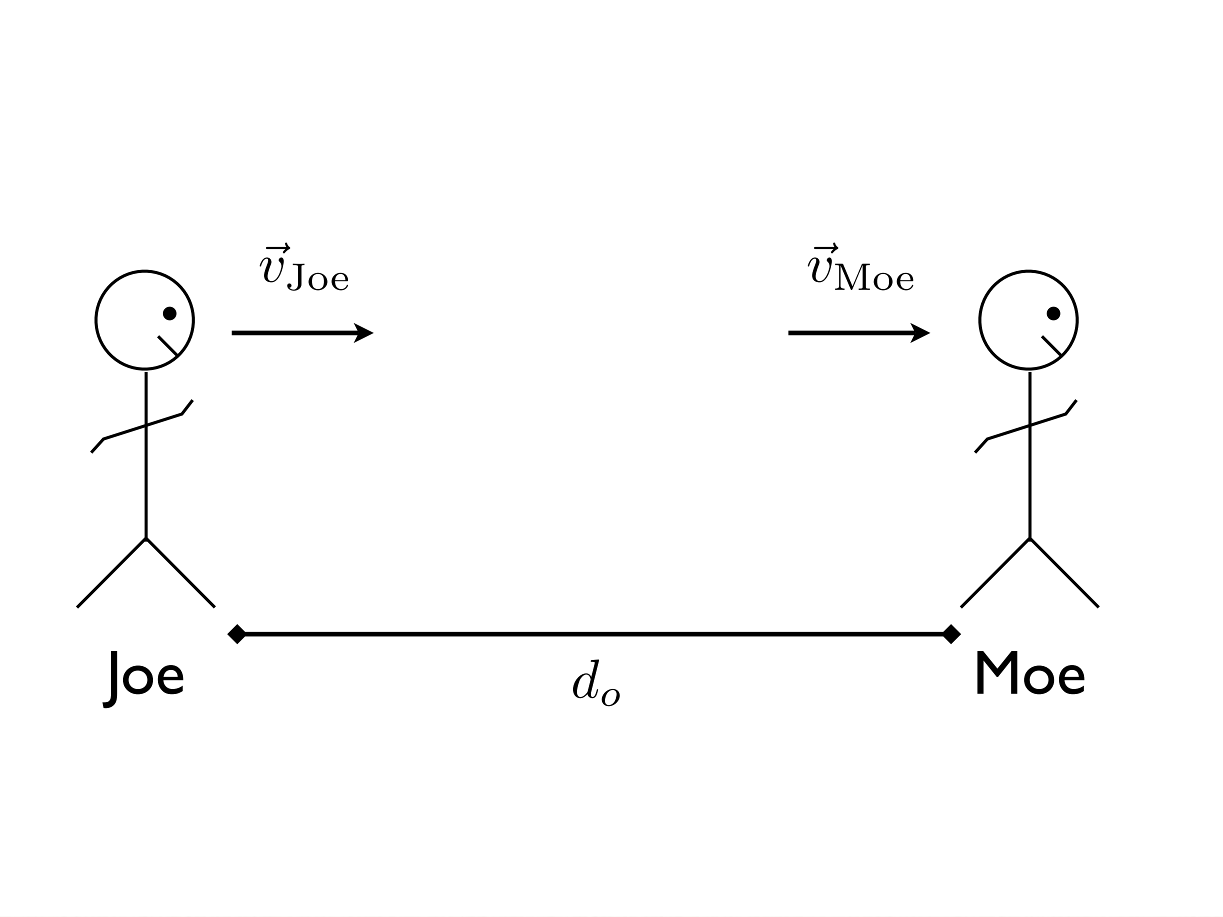
Who is moving?

- No way to say!
- Can only agree on displacement between & rate it changes.



What's your speed?

- really the same situation
- we just assume the ground is 'special'
- both agree on *displacement* and *relative* velocity



Principle of relativity:
All laws of nature are the same in all uniformly moving (non-accelerating) frames of reference. No frame is preferred or special.

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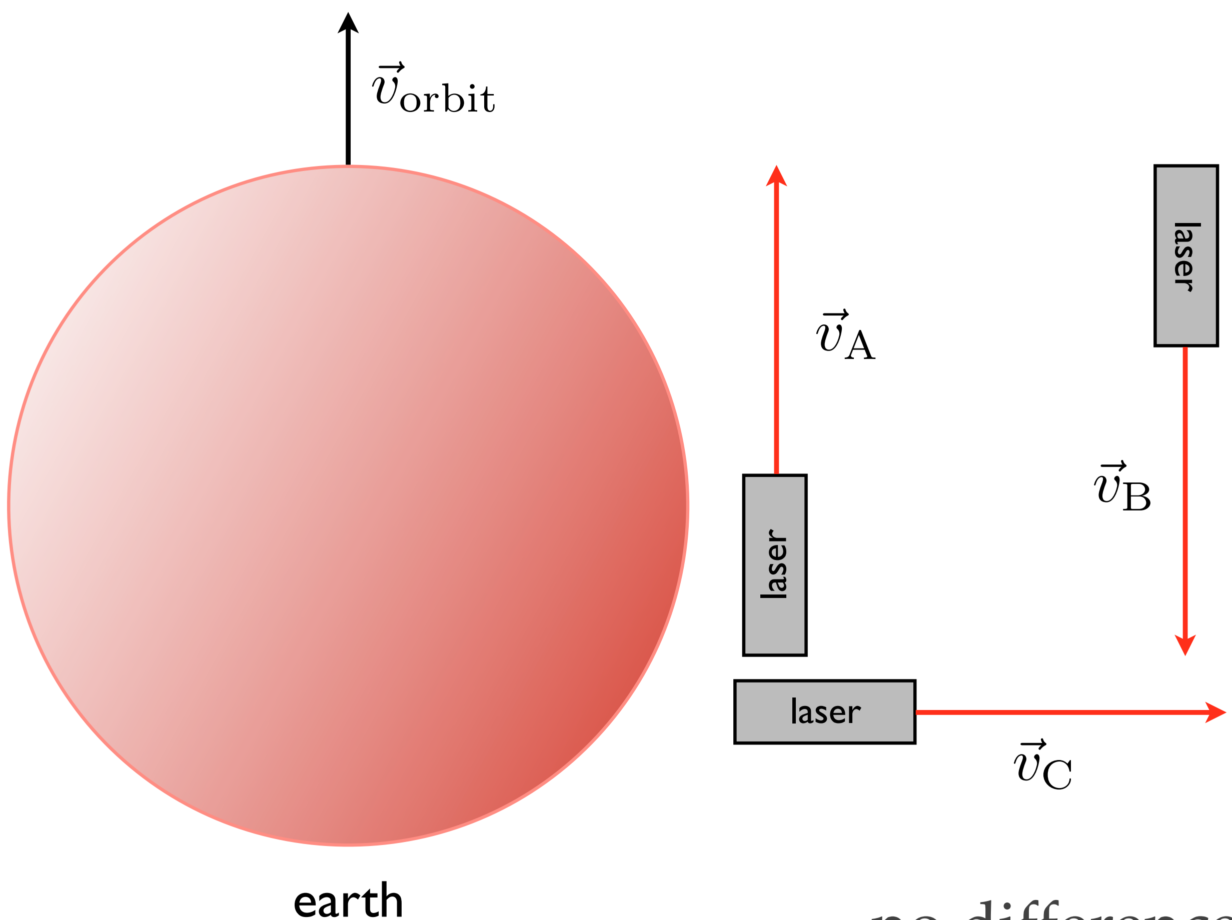
Choosing a coordinate system:

1. Choose an origin. This may coincide with a special point or object given in the problem - for instance, right at an observer's position, or halfway between two observers. Make it convenient!
2. Choose a set of axes, such as rectangular or polar. The simplest are usually rectangular or *Cartesian* x-y-z, though your choice should fit the symmetry of the problem given - if your problem has circular symmetry, rectangular coordinates may make life difficult.
3. Align the axes. Again, make it convenient - for instance, align your x axis along a line connecting two special points in the problem. Sometimes a thoughtful but less obvious choice may save you a lot of math!
4. Choose which directions are positive and negative. This choice is arbitrary, in the end, so choose the least confusing convention.

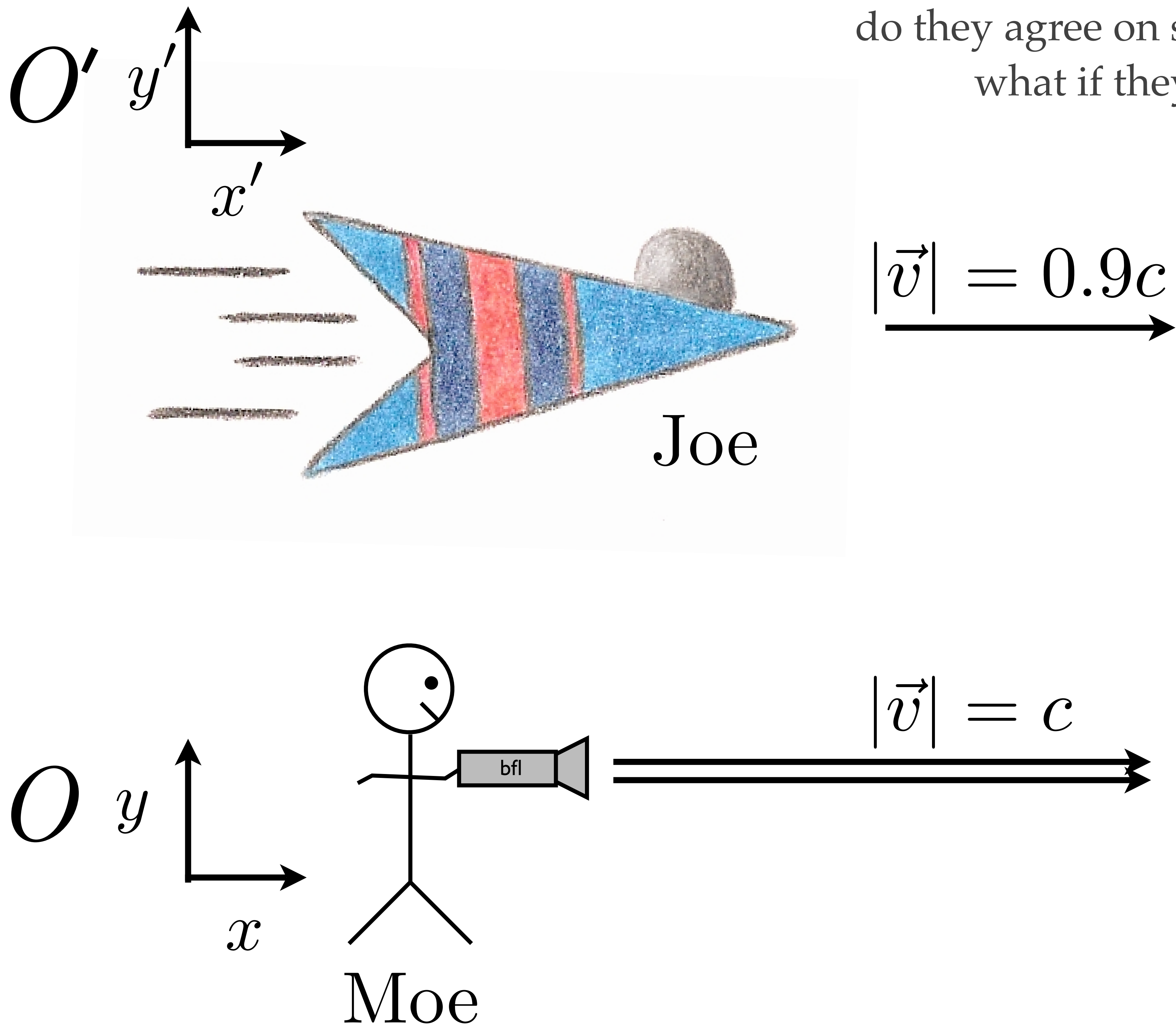
Invariance of the speed of light

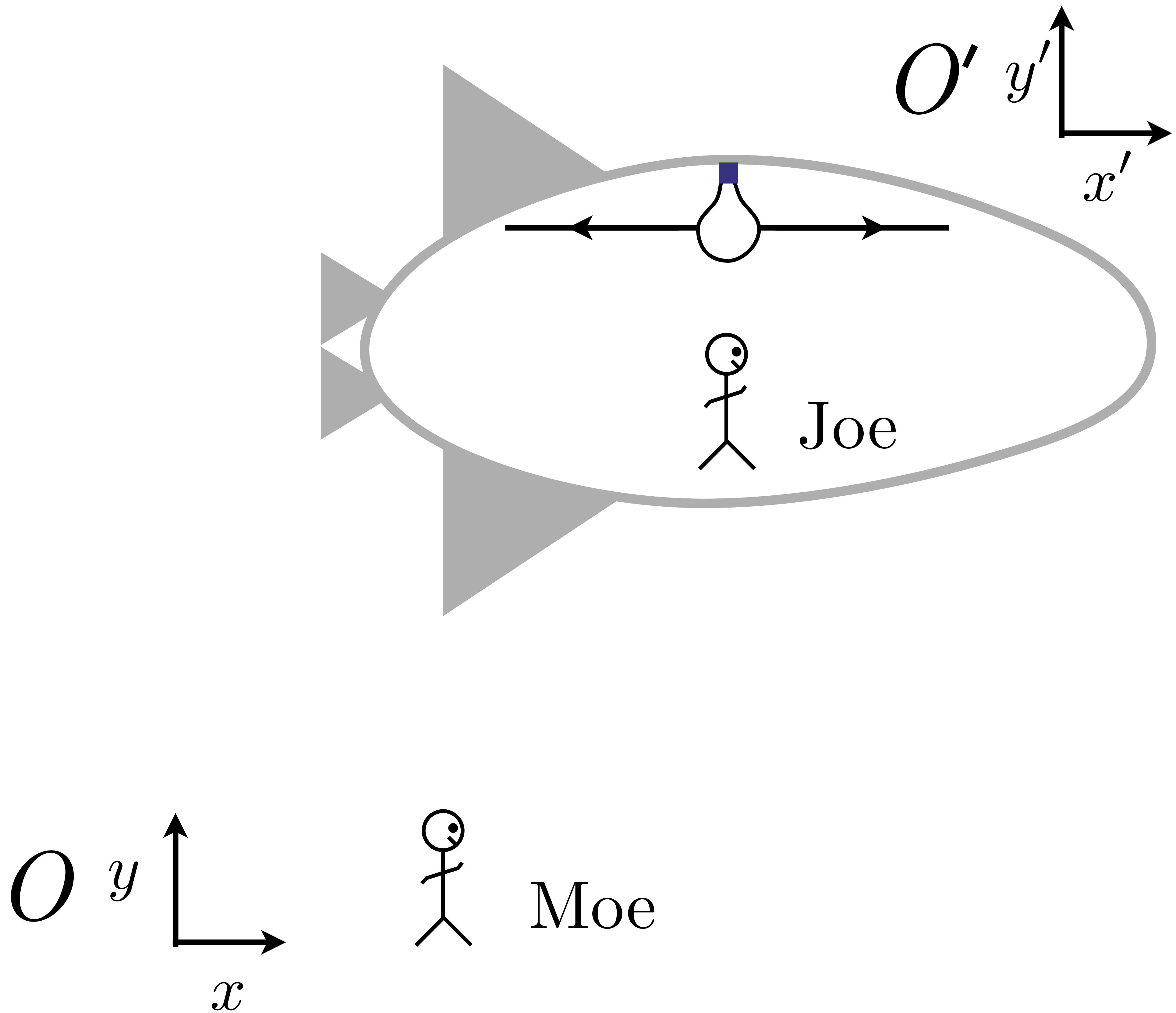


no difference
can't measure earth's velocity
relative to empty space

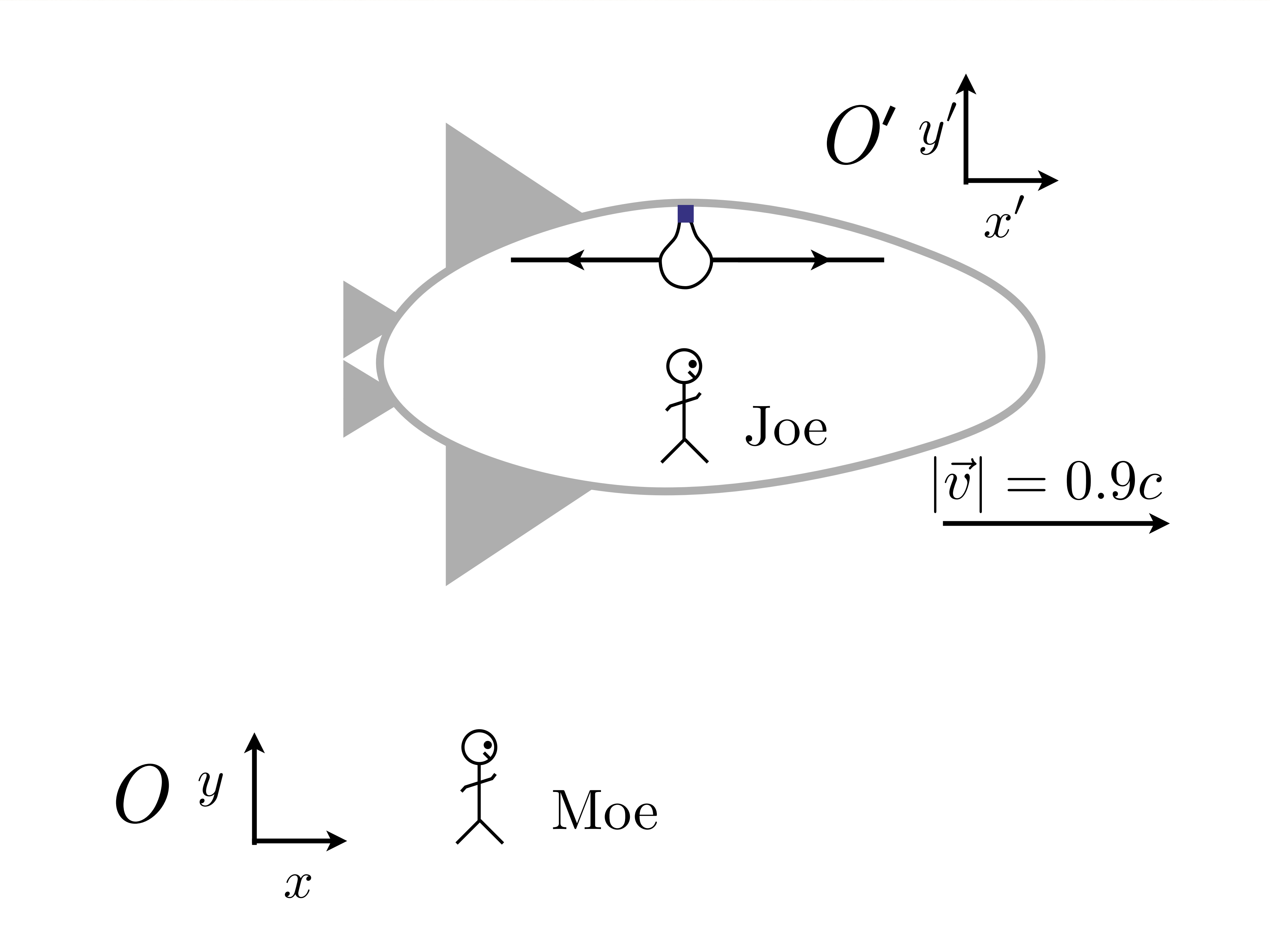
Speed of light in a vacuum is *independent* of source or observer motion.
It is an invariant constant.

do they agree on speed of light?
what if they don't?

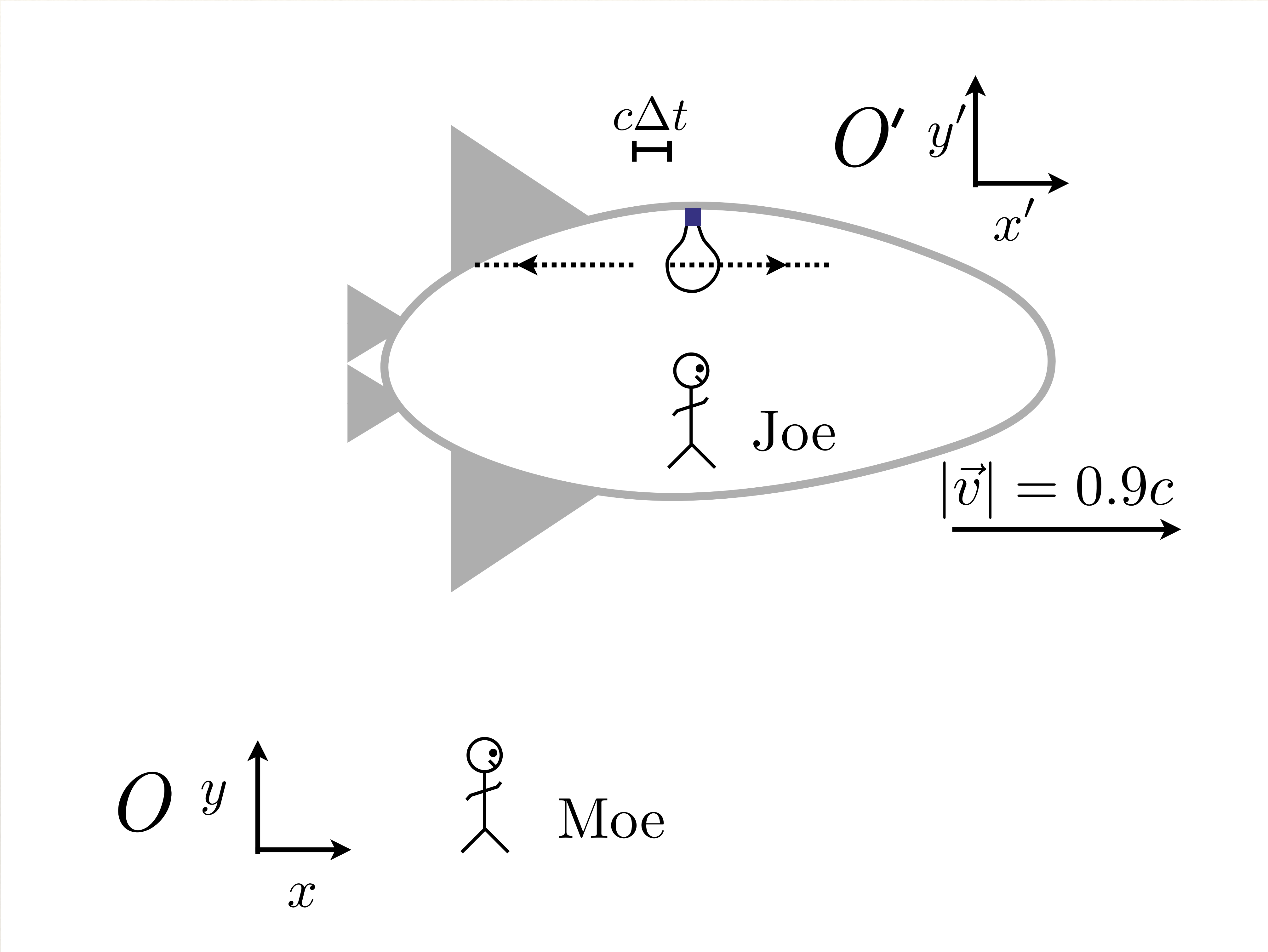




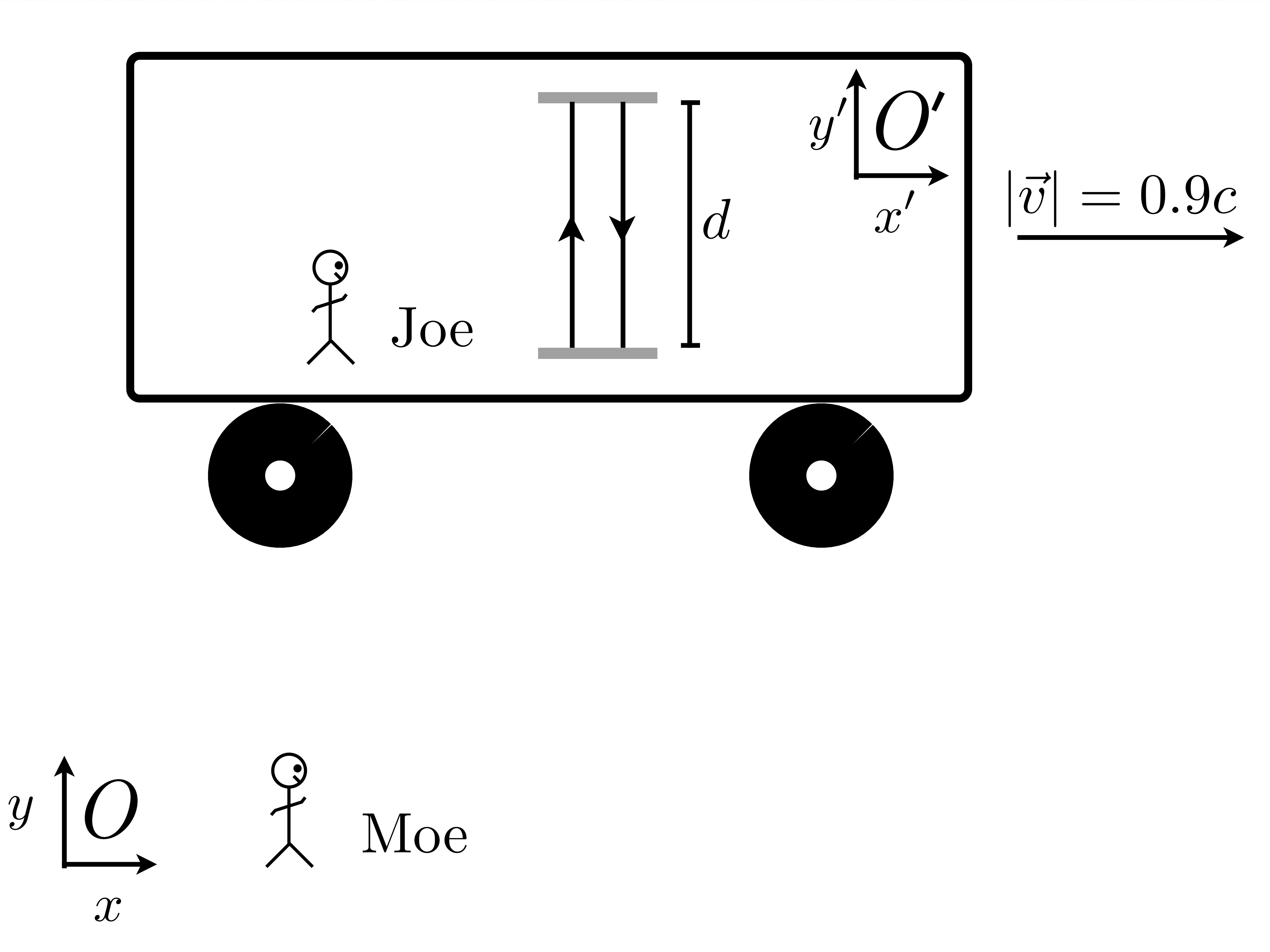
O′
y′
x′
Joe
O
y
x
Moe



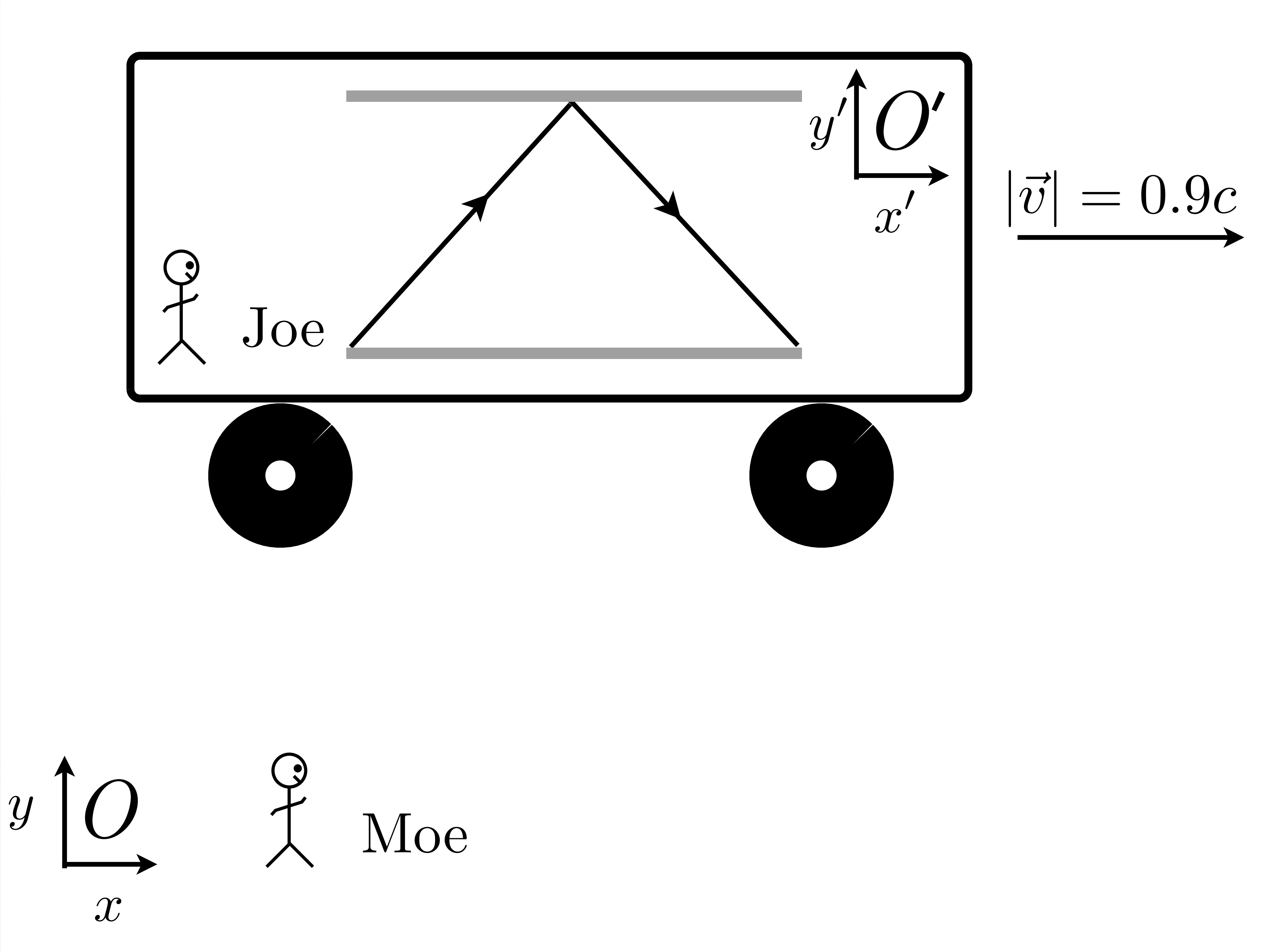
Joe flips on the light
he sees the light hit
the walls at the same time



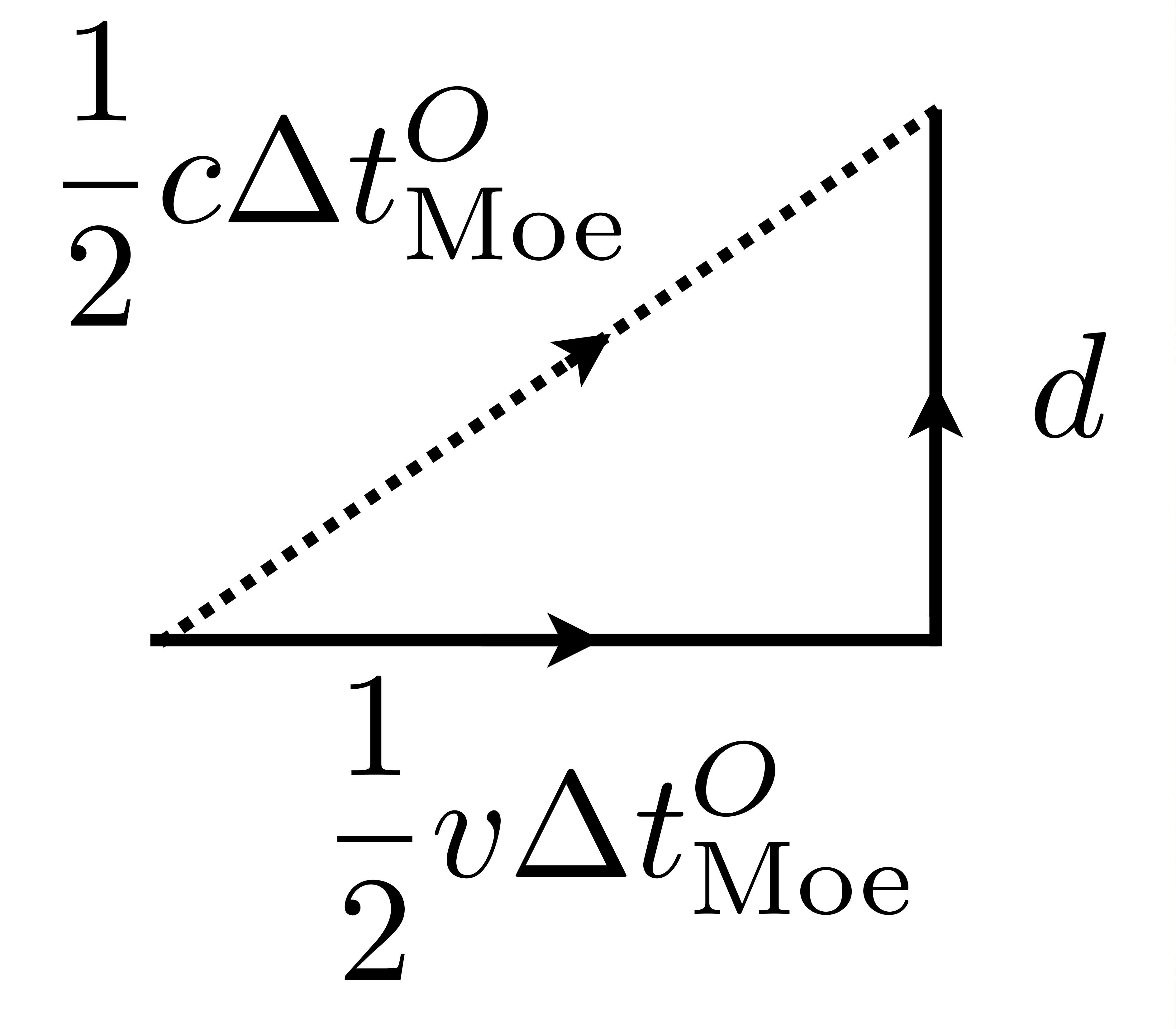
What does Moe see?
the ship moved;
the origin of the light did not



Joe bounces a laser off of some mirrors
he counts the round trips
this measures distance

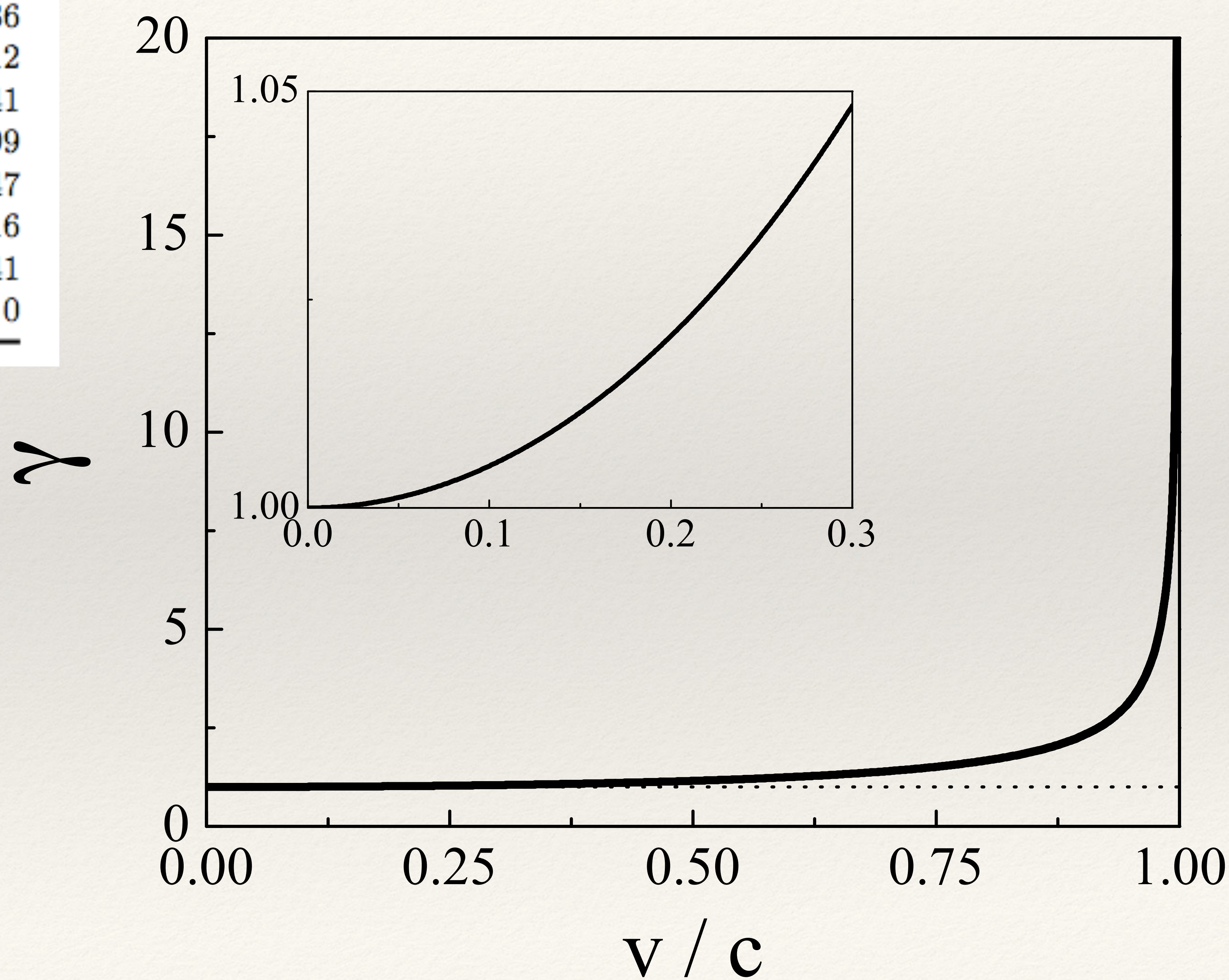


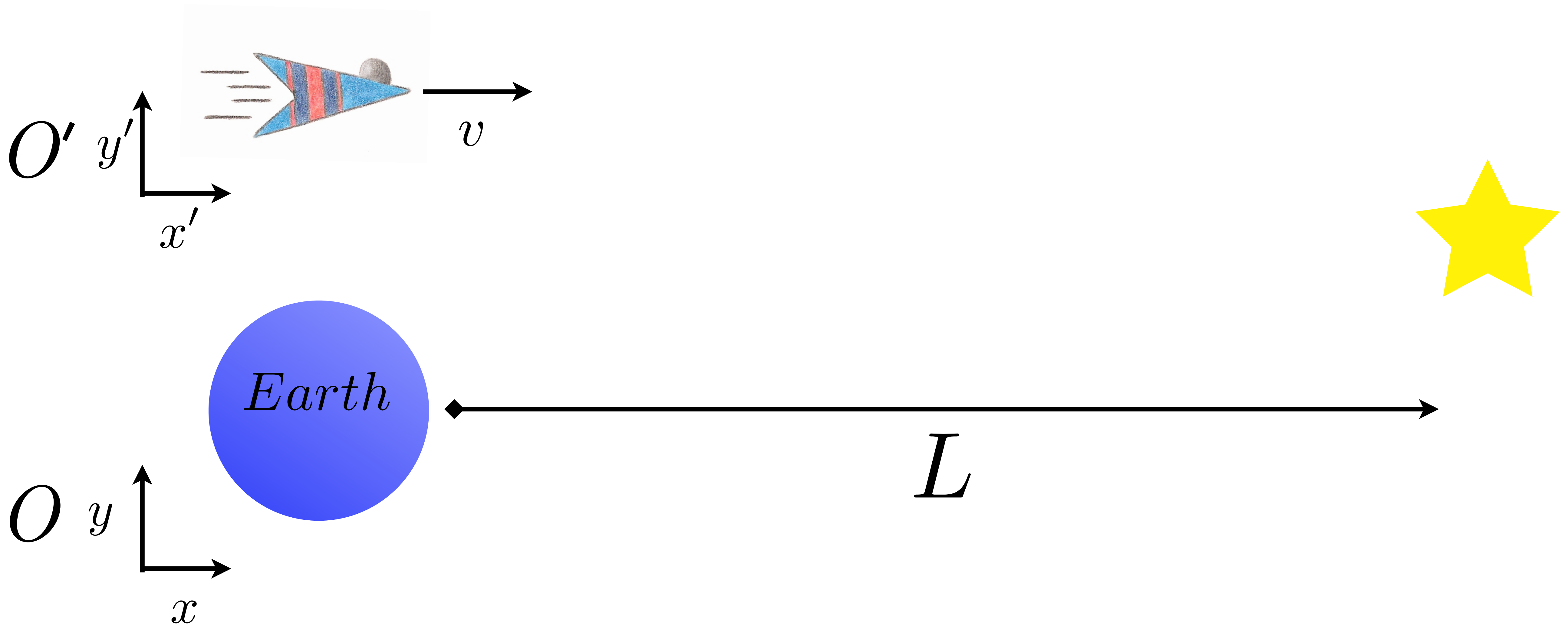
Moe sees the boxcar move;
once the light is created, it does not.
Moe sees a triangle wave



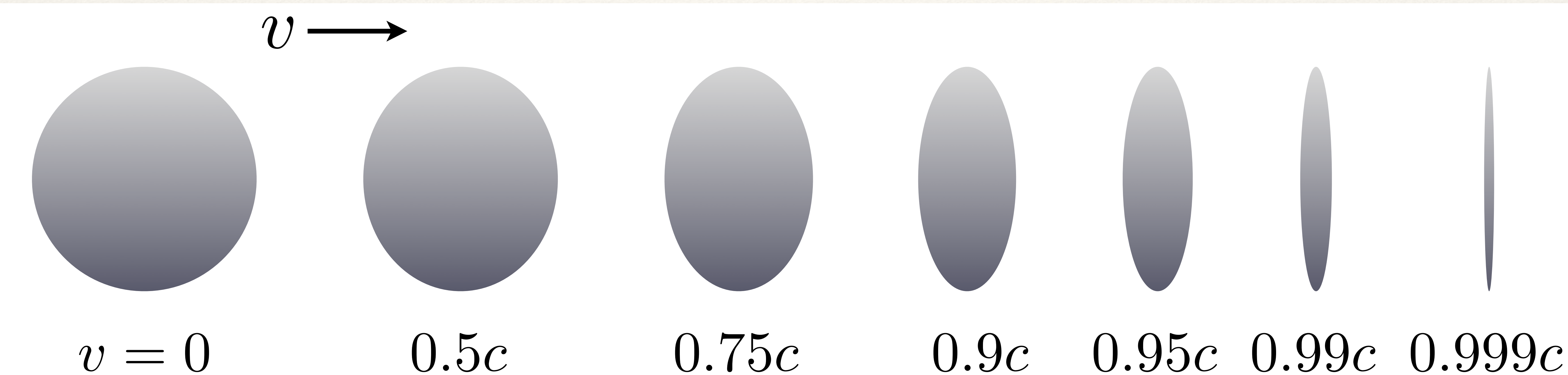
$\frac{1}{2}c\Delta t^{O}_{\mathrm{Moe}}$
d
$\frac{1}{2}v\Delta t^{O}_{\mathrm{Moe}}$

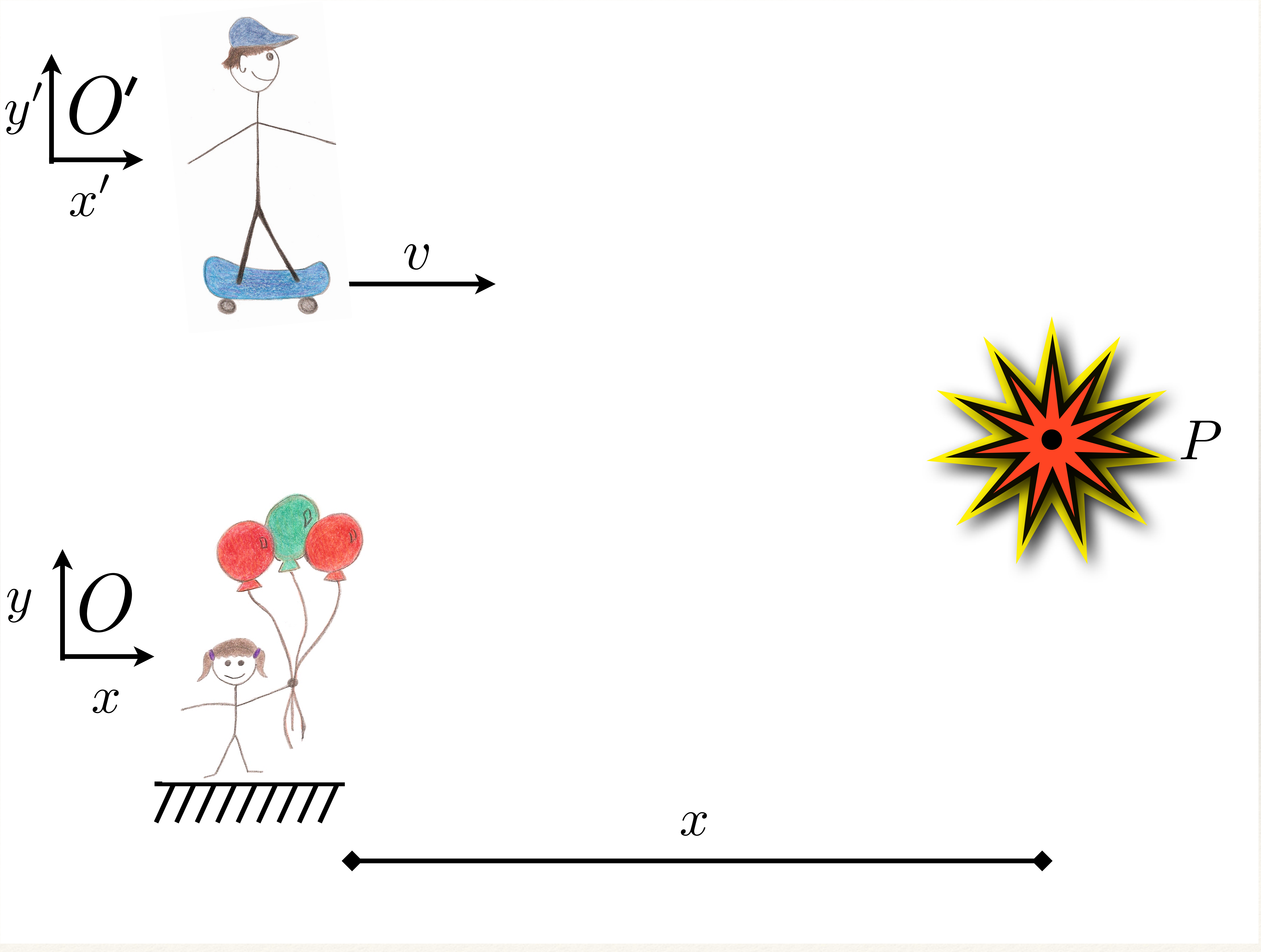
v [m/s]	$\frac{v}{c}$	γ	$1/\gamma$
0	0	0	∞
3×10^6	0.01	1.00005	0.99995
3×10^7	0.1	1.005	0.995
6×10^7	0.2	1.02	0.980
1.5×10^8	0.5	1.16	0.866
2.25×10^8	0.75	1.51	0.661
2.7×10^8	0.9	2.29	0.436
2.85×10^8	0.95	3.20	0.312
2.97×10^8	0.99	7.09	0.141
2.983×10^8	0.995	10.0	0.0999
2.995×10^8	0.999	22.4	0.0447
2.996×10^8	0.9995	31.6	0.0316
2.998×10^8	0.9999	70.7	0.0141
c	1	∞	0





O'
y'
x'
v
Earth
L
O
y
x


$v \longrightarrow$
$v = 0$
$0.5c$
$0.75c$
$0.9c$
$0.95c$
$0.99c$
$0.999c$



y'
O'
x'
v
P
y
O
x
x

Transformation of distance between reference frames:

$$x' = \gamma(x - vt) \quad (1.3$$

$$x = \gamma(x' + vt') \quad (1.3$$

Here (x,t) is the position and time of an event as measured by an observer in O stationary it. A second observer in O', moving at velocity v, measures the same event to be at positi and time (x',t').

Time measurements in different non-accelerating reference frames:

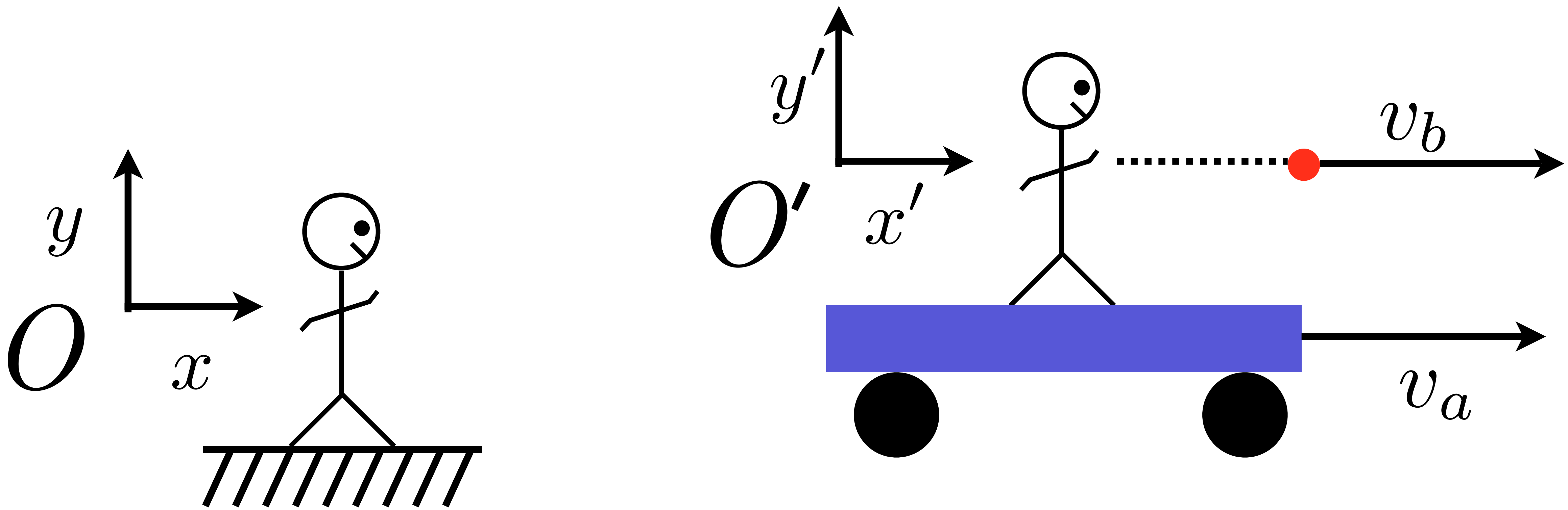
$$t' = \gamma\left(t - \frac{vx}{c^2}\right) \tag{1.46}$$

$$t = \gamma\left(t' + \frac{vx'}{c^2}\right) \tag{1.47}$$

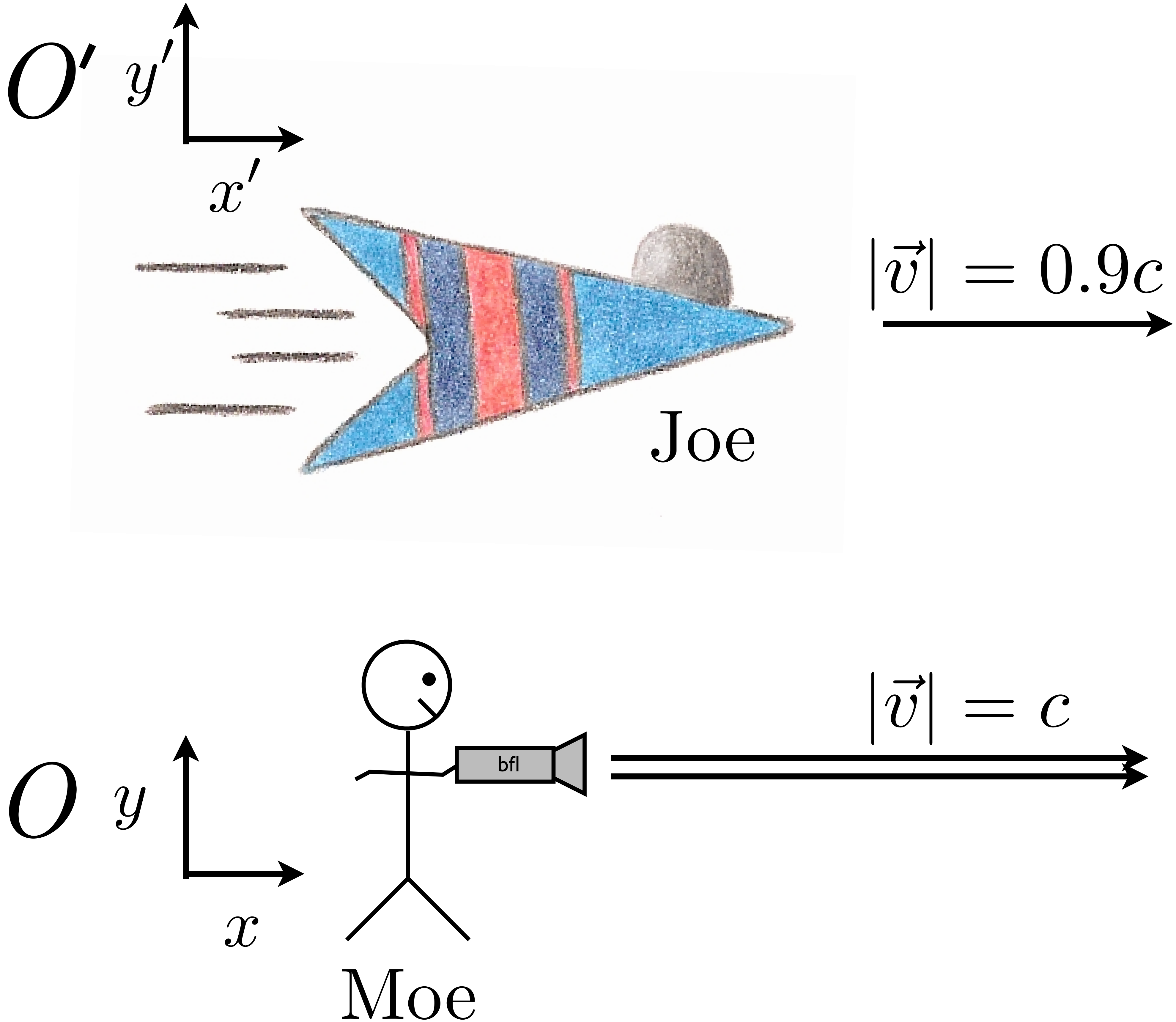
Here (x,t) is the position and time of an event as measured by an observer in O stationary to it. A second observer in O', moving at velocity v, measures the same event to be at position and time (x',t').

Elapsed times between events in non-accelerating reference frames:

$$\Delta t' = t'_1 - t'_2 = \gamma\left(\Delta t - \frac{v\Delta x}{c^2}\right) \quad (1.4$$



y
O
x
y'
O'
x'
v_b
v_a



O'
y'
x'
$|\vec{v}| = 0.9c$
Joe
$|\vec{v}| = c$
bfl
O
y
x
Moe

let’s work out some problems

1. An astronaut traveling at $v = 0.80c$ taps her foot 3.0 times per second. What is the frequency of taps determined by an observer on earth? (*Hint: be careful about the difference between time and frequency!*)

- ○ 5.0 taps/sec
- ○ 6.7 taps/sec
- ○ 1.8 taps/sec
- ○ 3.0 taps/sec

2. A spaceship moves away from earth at high speed. How do experimenters on earth measure a clock in the spaceship to be running? How do those in the spaceship measure a clock on earth to be running?

- ○ slow; fast
- ○ slow; slow
- ○ fast; slow
- ○ fast; fast

3. If you are moving in a spaceship at high speed relative to the earth, would you notice a difference in your pulse rate? In the pulse rate of the people back on earth?

- ○ no; yes
- ○ no; no
- ○ yes; no
- ○ yes; yes

4. The period of a pendulum is measured to be 3.00 in its own reference frame. What is the period as measured by an observer moving at a speed of $0.950c$ with respect to the pendulum?

- ○ 6.00 sec
- ○ 13.4 sec
- ○ 0.938 sec
- ○ 9.61 sec

1. 1.8 **taps/sec.** The 'proper time' Δt_p is that measured by the astronaut herself, which is 1/3 of a second between taps (so that there are 3 taps per second). The time interval *between taps* measured on earth is dilated (longer), so there are *less* taps per second. For the astronaut:

$$\Delta t_p = \frac{1\,\text{s}}{3\,\text{taps}}$$

On earth, we measure the dilated time:

$$\Delta t' = \gamma \Delta t_p = \frac{1}{\sqrt{1 - \frac{0.8^2 c^2}{c^2}}} \cdot \left(\frac{1\,\text{s}}{3\,\text{taps}}\right) = \frac{1}{\sqrt{1 - 0.8^2}} \cdot \left(\frac{1\,\text{s}}{3\,\text{taps}}\right) \approx \frac{0.56\,\text{s}}{\text{tap}} = \frac{1\,\text{s}}{1.8\,\text{taps}}$$

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- ○ no; no
- ○ yes; no
- ○ yes; yes

4. The period of a pendulum is measured to be 3.00 in its own reference frame. What is the period as measured by an observer moving at a speed of 0.950c with respect to the pendulum?

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- ○ 0.938 sec
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2. slow; slow. The time-dilation effect is symmetric, so observers in each frame measure a clock in the other to be running slow. Put another way, the *relative* velocity of the earth and the ship is the same no matter who you ask – each says the other is moving with some speed v, and they are sitting still. Therefore, the dilation effect is the same in both cases.

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- ○ no; no
- ○ yes; no
- ○ yes; yes

4. The period of a pendulum is measured to be 3.00 in its own reference frame. What is the period as measured by an observer moving at a speed of 0.950c with respect to the pendulum?

- ○ 6.00 sec
- ○ 13.4 sec
- ○ 0.938 sec
- ○ 9.61 sec

3. no; yes. There is no relative speed between you and your own pulse, since you are in the same reference frame, so there is no difference in your pulse rate (possible space-travel-related anxieties aside). There is a relative velocity between you and the people back on earth, however, so you would find their pulse rate *slower* than normal. Similarly, they would find *your* pulse rate slower than normal, since you are moving relative to them. Relativistic effects are always attributed to the other party – you are always at rest in your own reference frame.

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- ☆ no; yes
- ○ no; no
- ○ yes; no
- ○ yes; yes

4. The period of a pendulum is measured to be 3.00 in its own reference frame. What is the period as measured by an observer moving at a speed of 0.950c with respect to the pendulum?

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- ○ 13.4 sec
- ○ 0.938 sec
- ○ 9.61 sec

4. 9.61 **sec.** The proper time is that measured by in the reference frame of the pendulum itself, $\Delta t_p = 3.00$ sec. The moving observer has to observe a *longer* period for the pendulum, since from the observer's point of view, the pendulum is moving relative to it. Observers always perceive clocks moving relative to them as running slow. The factor between the two times is just γ:

$$\Delta t' = \gamma \Delta t_p = \frac{3.0\,\text{sec}}{\sqrt{1 - \frac{0.95^2 c^2}{c^2}}} = \frac{3.0\,\text{sec}}{\sqrt{1 - 0.95^2}} \approx 9.61\,\text{sec}$$

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- ★ no; yes
- ○ no; no
- ○ yes; no
- ○ yes; yes

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- ★ 9.61 sec

6. You are packing for a trip to another star, and on your journey you will travel at $0.99c$. Can you sleep in a smaller cabin than usual, because you will be shorter when you lie down? Explain your answer.

7. A deep-space probe moves away from Earth with a speed of $0.88c$. An antenna on the probe requires 4.0 s, in probe time, to rotate through 1.0 rev. How much time is required for 1.0 rev according to an observer on Earth?

8. A friend in a spaceship travels past you at a high speed. He tells you that his ship is 24 m long and that the identical ship you are sitting in is 18 m long.

(a) According to your observations, how long is your ship?
(b) According to your observations, how long is his ship?
(c) According to your observations, what is the speed of your friend's ship?

6. No. There is no relative speed between you and your cabin, since you are in the same reference frame. You and your bed will remain at the same lengths relative to each other.

6. You are packing for a trip to another star, and on your journey you will travel at $0.99c$. Can you sleep in a smaller cabin than usual, because you will be shorter when you lie down? Explain your answer.

7. A deep-space probe moves away from Earth with a speed of $0.88c$. An antenna on the probe requires $4.0\,\mathrm{s}$, in probe time, to rotate through $1.0\,\mathrm{rev}$. How much time is required for $1.0\,\mathrm{rev}$ according to an observer on Earth?

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(c) According to your observations, what is the speed of your friend's ship?

7. 8.42 s. The time interval in the probe's reference frame is the proper one Δt_p ... which makes sense, since the antenna is part of the probe itself! The probe and antenna are moving relative to the earth, and therefore the earthbound observer measures a longer, dilated time interval $\Delta t'$:

$$\begin{aligned} \text{probe} &= \Delta t_p \\ \text{earth} &= \Delta t' \\ \Delta t' &= \gamma \Delta t_p \end{aligned}$$

As usual, we first need to calculate γ. No problem, given the probe's velocity of $0.88c$ relative

to earth:

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1}{\sqrt{1-\frac{(0.88c)^2}{c^2}}} = \frac{1}{\sqrt{1-0.88^2}} = 2.11$$

The proper time interval for one revolution Δt_p in the probe's reference frame is 4.0 s, so we can readily calculate the time interval observed by the earthbound observer:

$$\Delta t' = \gamma \Delta t_p = 2.11 \cdot (4.0\,\text{s}) = 8.42\,\text{s}$$

6. You are packing for a trip to another star, and on your journey you will travel at $0.99c$. Can you sleep in a smaller cabin than usual, because you will be shorter when you lie down? Explain your answer.

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(a) According to your observations, how long is your ship?
(b) According to your observations, how long is his ship?
(c) According to your observations, what is the speed of your friend's ship?

8. 24 m; 18 m; 0.661c. Once again: if you are observing something in your own reference frame, there is no length contraction or time dilation. You always observe your own ship to be the same length. If your friend's ship is 24 m long, and yours is identical, you will measure it to be 24 m.

On the other hand, you are moving relative to his ship, so you would observe his ship to be length contracted, and measure a shorter length. Your friend, on the other hand, will observe *exactly the same thing* - he will see *your* ship contracted, by precisely the same amount. Your observation of his ship has to be the same as his observation of his ship - since you are only the two observers, and you both have the same *relative* velocity, you must observe the same length contraction. If he sees your ship as 18 m long, then you would also see his (identical) ship as 18 m long.

Given the relationship between the contracted and proper length, we can find the relative velocity easily. Your measurement of your own ship is the proper length L_p, while your measurement of your friend's ship is the contracted length L':

$$
\begin{aligned}
L_p &= \gamma L' \\
\Longrightarrow \gamma &= \frac{L_p}{L'} = \frac{24}{18} = \frac{4}{3} \\
\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} &= \frac{4}{3} \\
1-\frac{v^2}{c^2} &= \frac{3^2}{4^2} = \frac{9}{16} \\
\frac{v^2}{c^2} &= 1-\frac{9}{16} = \frac{7}{16} \\
v &= \sqrt{\frac{7}{16}}c = \frac{\sqrt{7}}{4}c \approx 0.661c
\end{aligned}
$$