hi

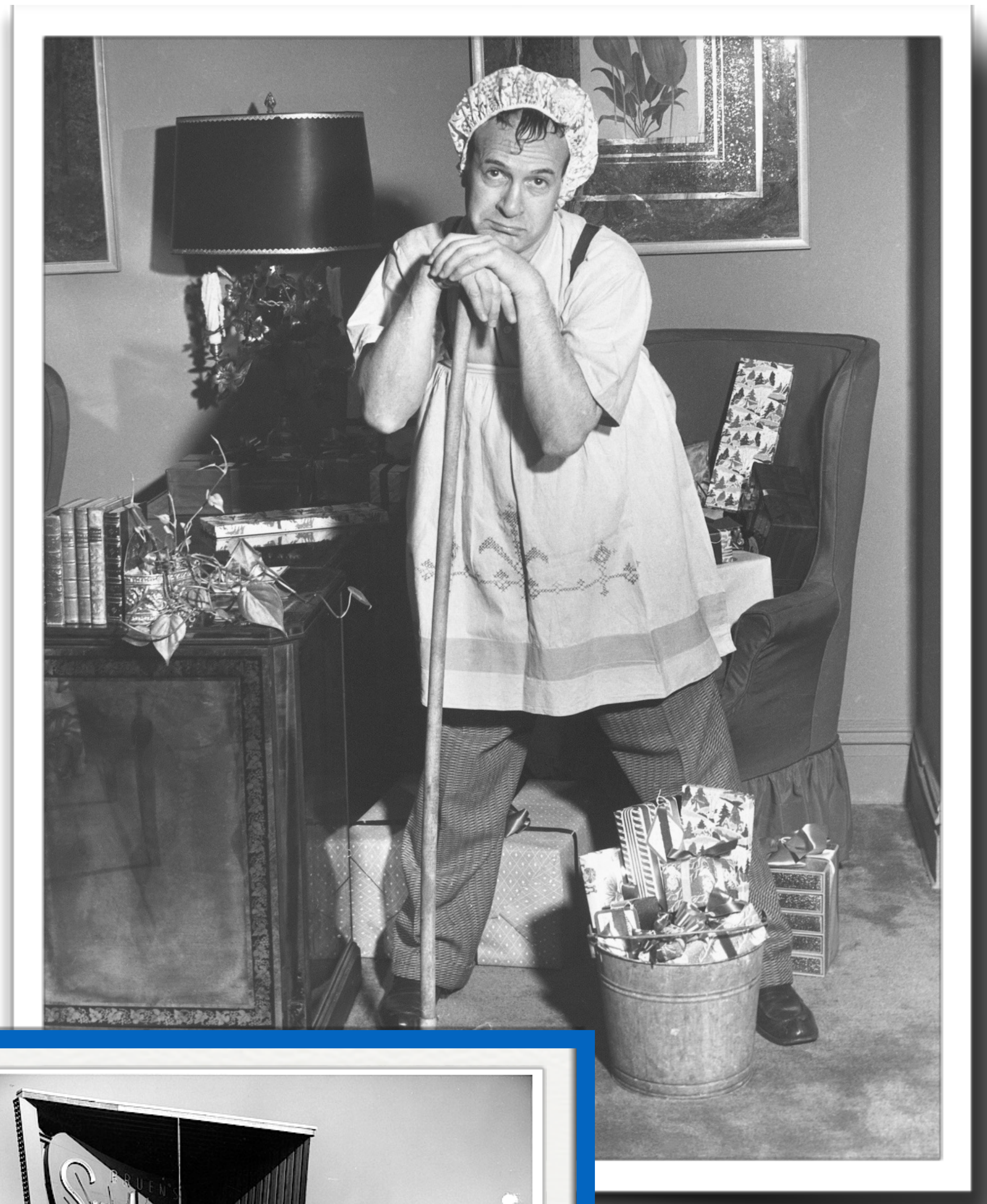
Day 12, 21.02.2019

Einstein’s Special Theory of Relativity, 2

35 days until opening day

Tower of Power week

housekeeping



Lectures forever now: Gotta come to class

- question about anything? I'll make a movie for you:

Please remember — especially true starting now:

- need to take hand-written notes
- No computers or phones are allowed.

Midterm…before Spring Break

- available: Saturday, 23 February midnight
- due: Tuesday, 26 February midnight
- covering: material beginning through HW4 content
- #attempts = 1
- weight = 2 x HW

Some LON-CAPA

still!

I've not adjusted grades for the Kepler problem yet

LON-CAPA "essay" question fields

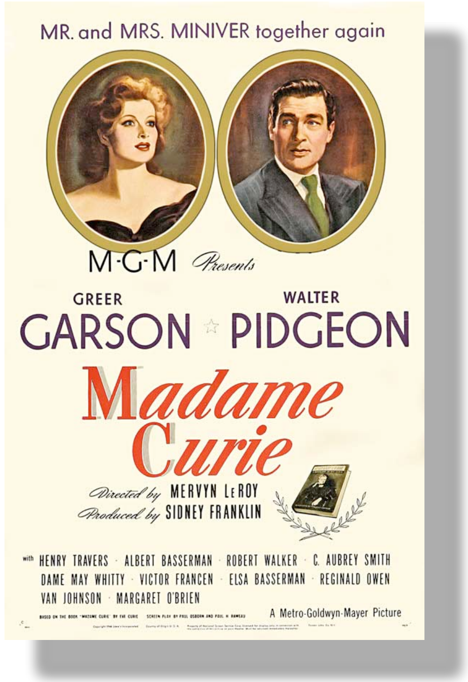
work okay?

Madame Curie movie - we have a quorum in favor

I've posted another FB poll targeting the 2 weeks after break

You "vote" for evenings when you CANNOT attend

parameters: 6:30 on an evening; I'll bring pizza (another poll for kind of pizza); you get liquids



February 2019

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
27	28	29 yadda	30 yadda	31 yadda	1	2 HW2
3	4	5 lessons 10,11,12	6	7 lesson 13	8 HW2 due	9 HW3
10	11	12 lecture	13	14 lecture	15 HW3 due	16 HW4
17	18	19 lecture	20	21 lecture	22 HW4 due	23 HW5
24 ←	25 midterm	26 → lecture	27	28 lecture	1 HW5 due	2

KEEP
CALM
AND
LET’S
REVIEW

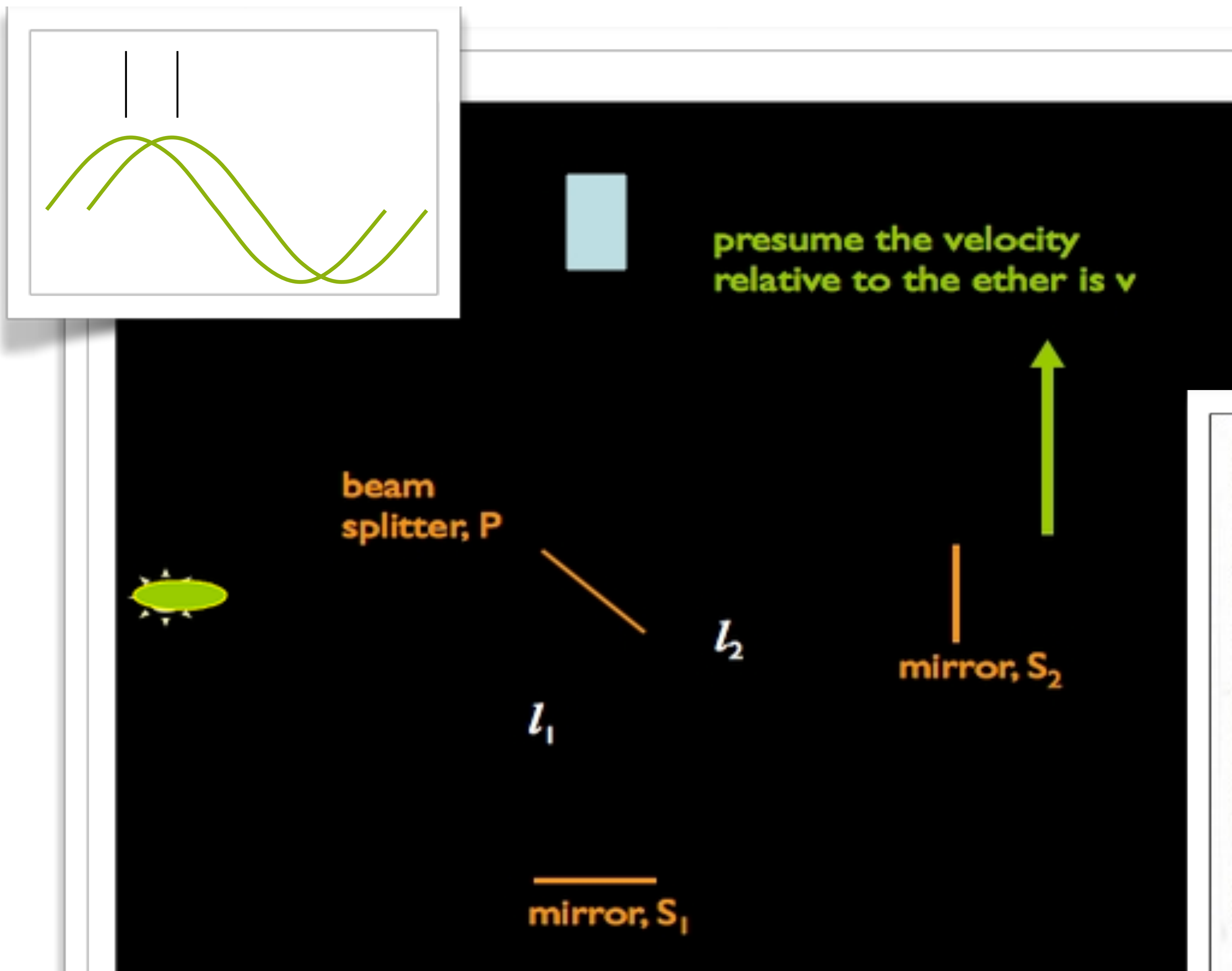
‘‘Michelson Morley Experiments’’

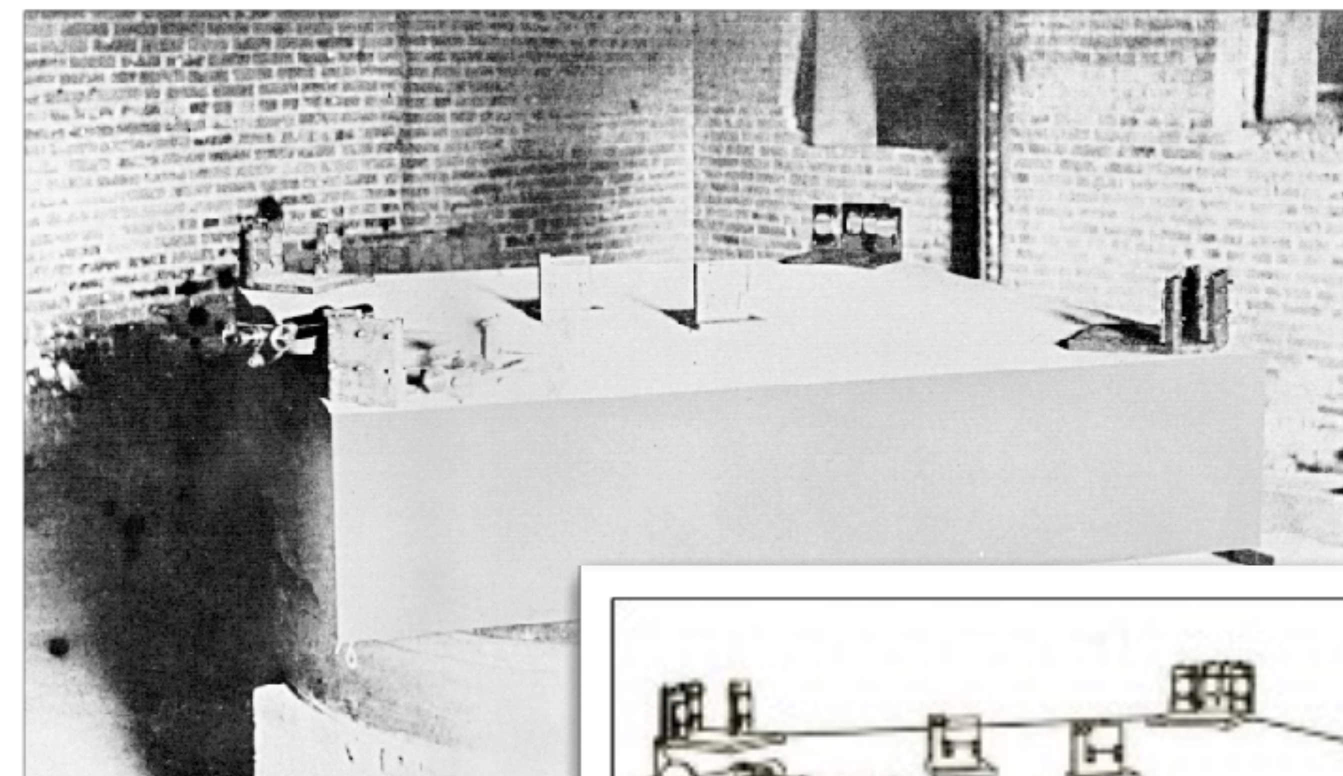
trying to measure the speed of Earth relative to Ether

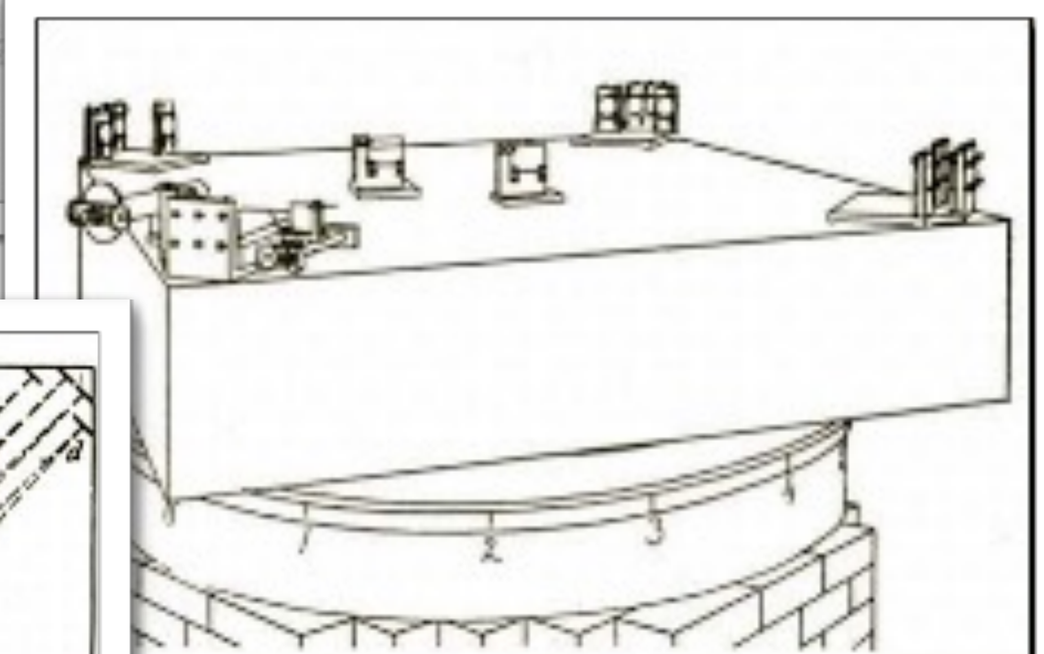
This technique was perfected by cowboy, Albert Michelson and eventually his sidekick, Edward Morley at Case Western Reserve in Cleveland between 1880 and 1888

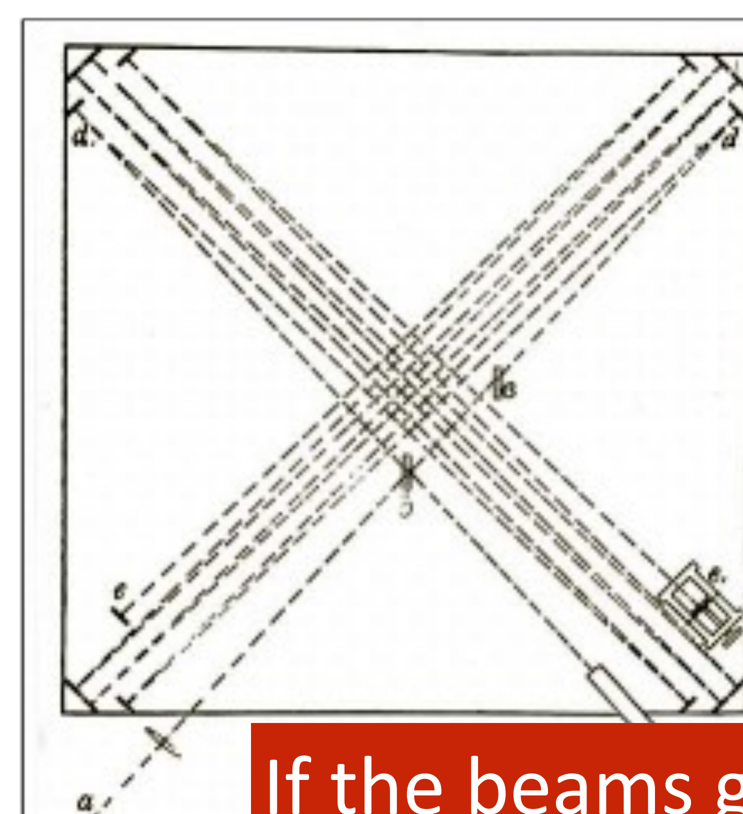
measure the fringes in light interfering from the two paths...then rotate the instrument 90 degrees - and do it again.

The differences between the two configurations is related to the time difference









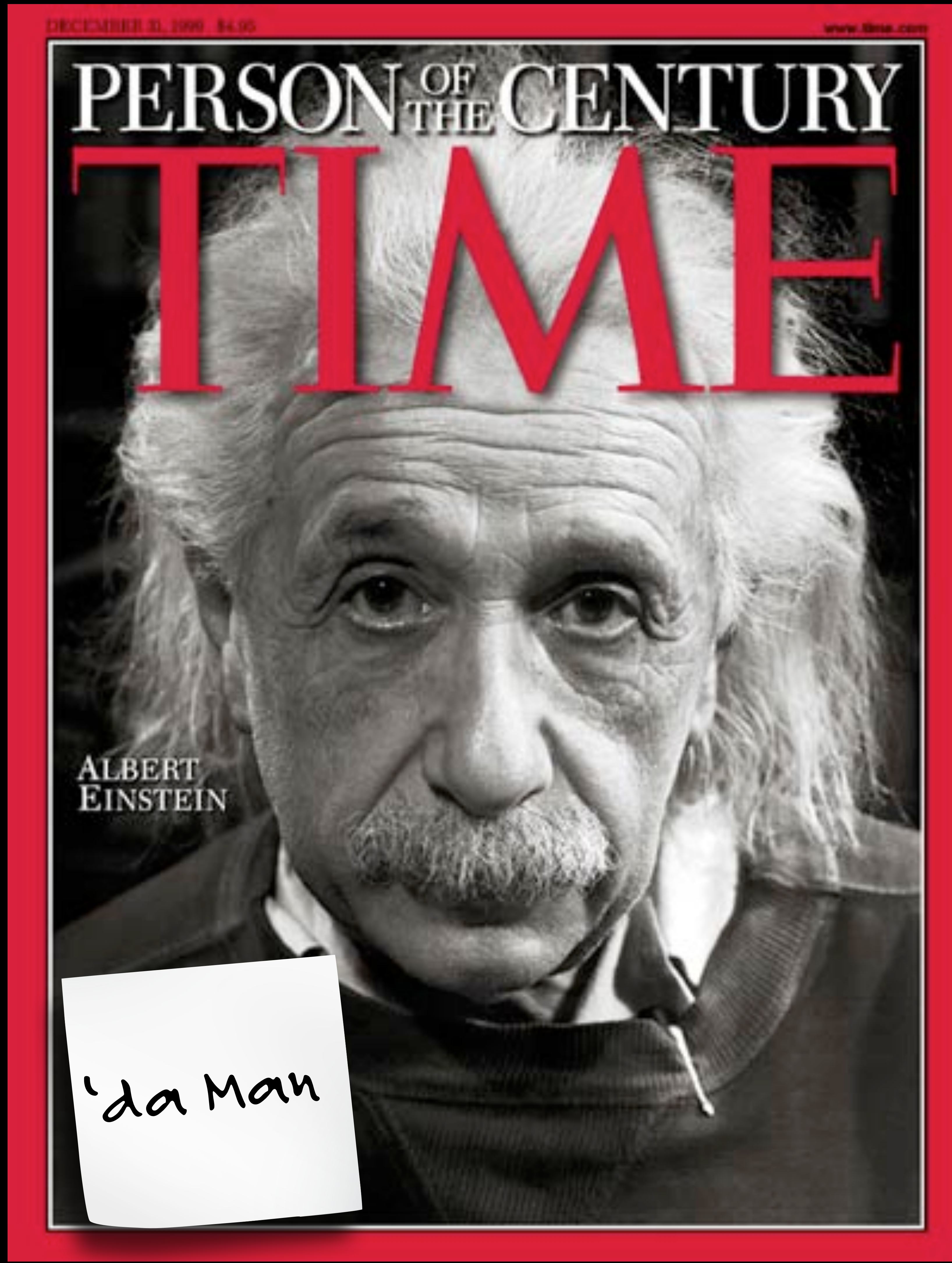
If the beams get back out of phase...one traveled through the ether differently from the other.

repeated results for Earth-ether speed:

0

zero. zip. nada. nothing. uh-uh. zilch. naught. diddly-squat.

The earth did not appear to be moving through an Ether.
The question: did Einstein know of the MM experiment?
He always said “no.”


PERSON OF THE CENTURY
TIME
ALBERT EINSTEIN
'da Man

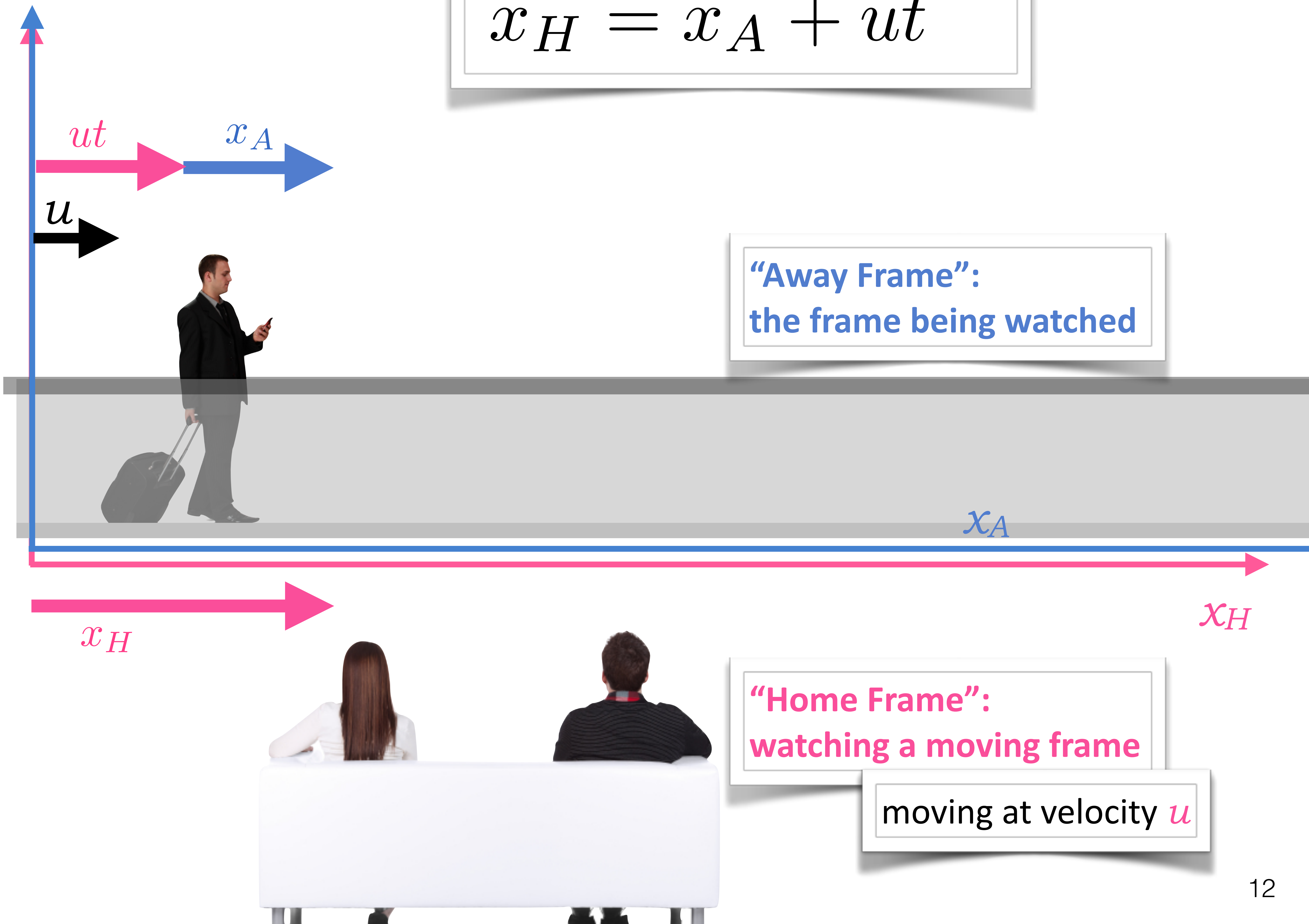
Special Relativity

frames of reference

the airport

"Galilean Transformation"

$$x_H = x_A + ut$$



"Away Frame":
the frame being watched

"Home Frame":
watching a moving frame

moving at velocity u

jargon alert:

Inertial Frame of Reference

refers to:	a Frame of Reference moving at a constant, linear velocity
entomology:	from Newton’s First Law idea
example:	a spaceship at constant speed

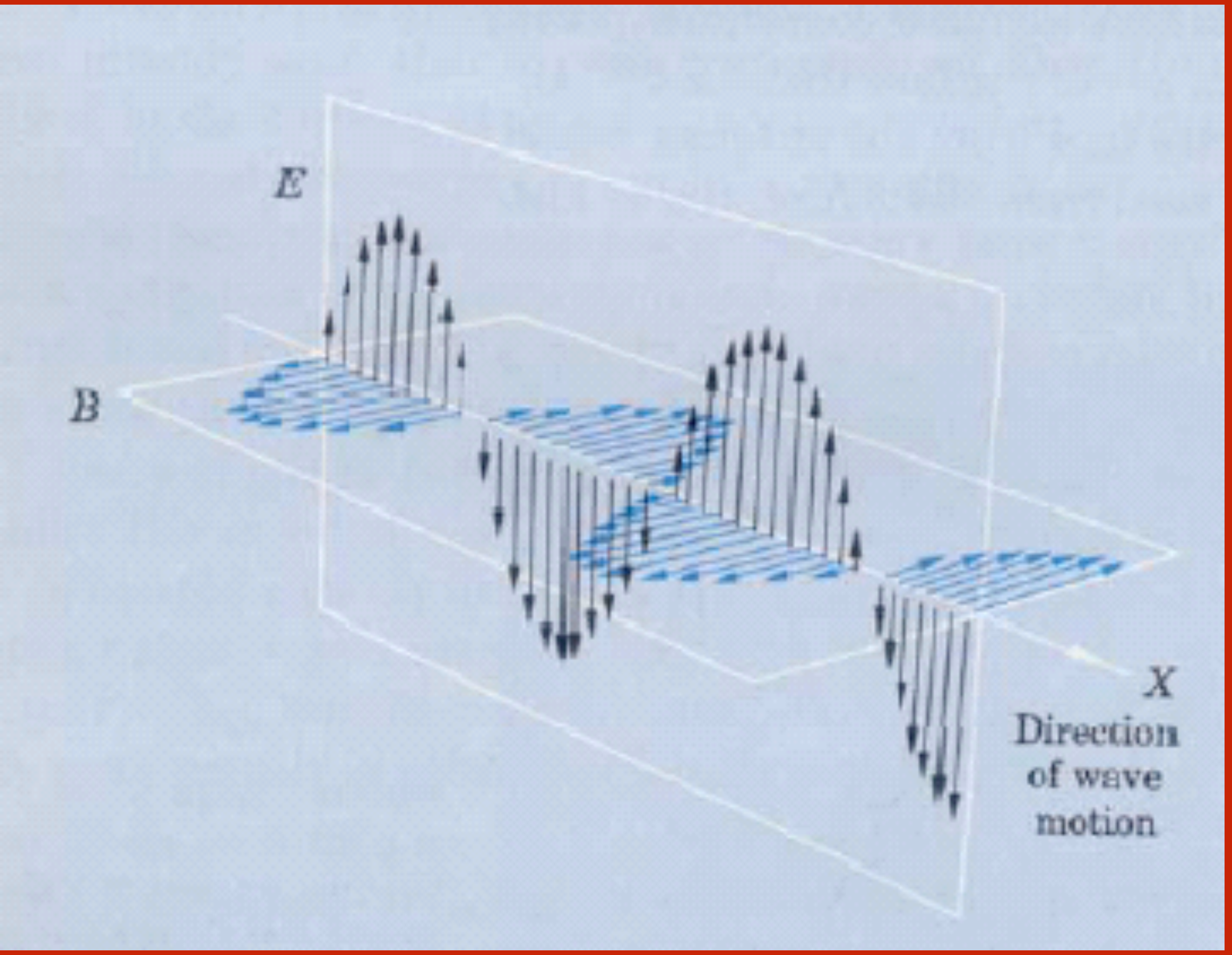
Einstein always asked

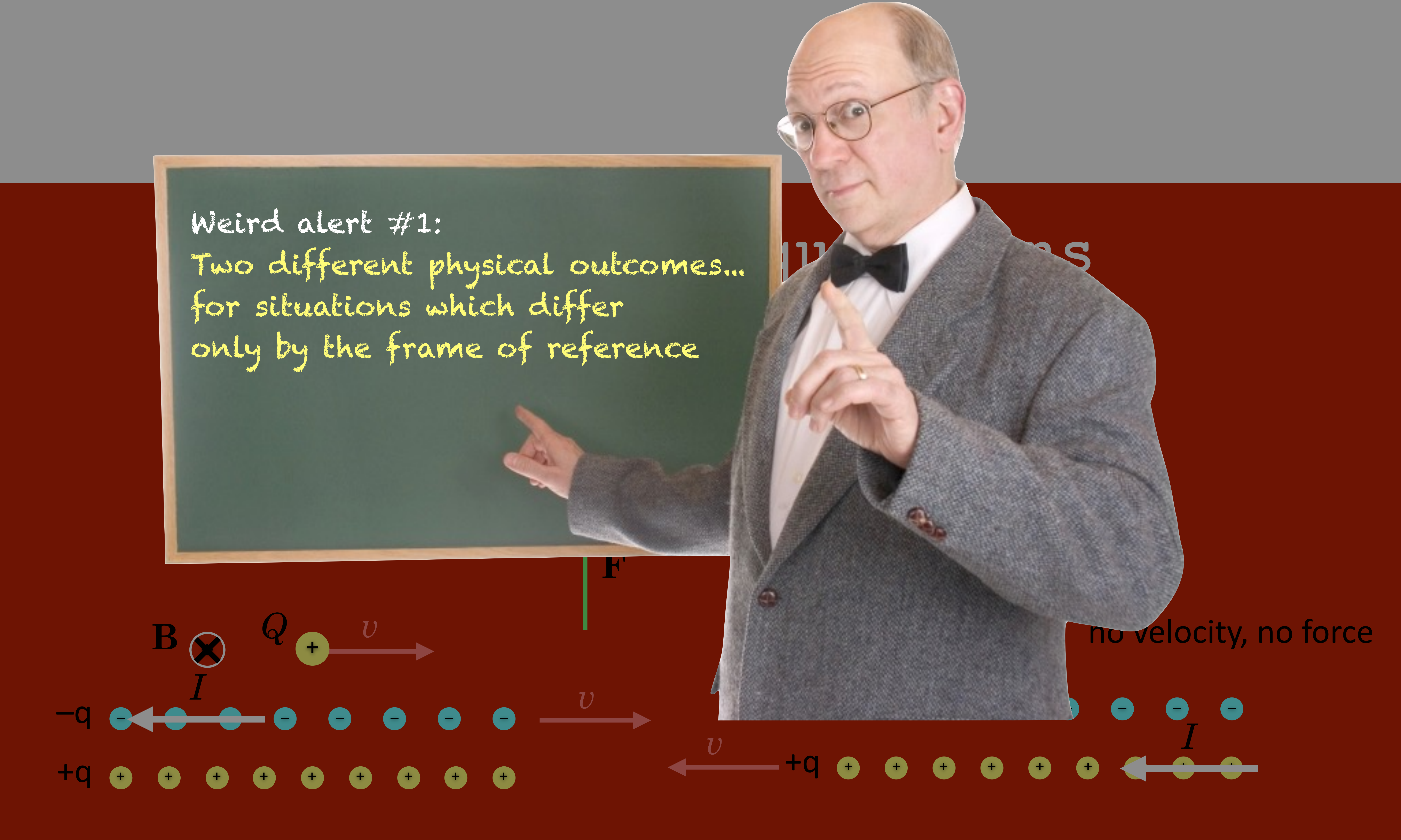
simple questions.

what if you traveled at c alongside of a light beam?

It’s stopped! No changing E, B!

No wave any more!



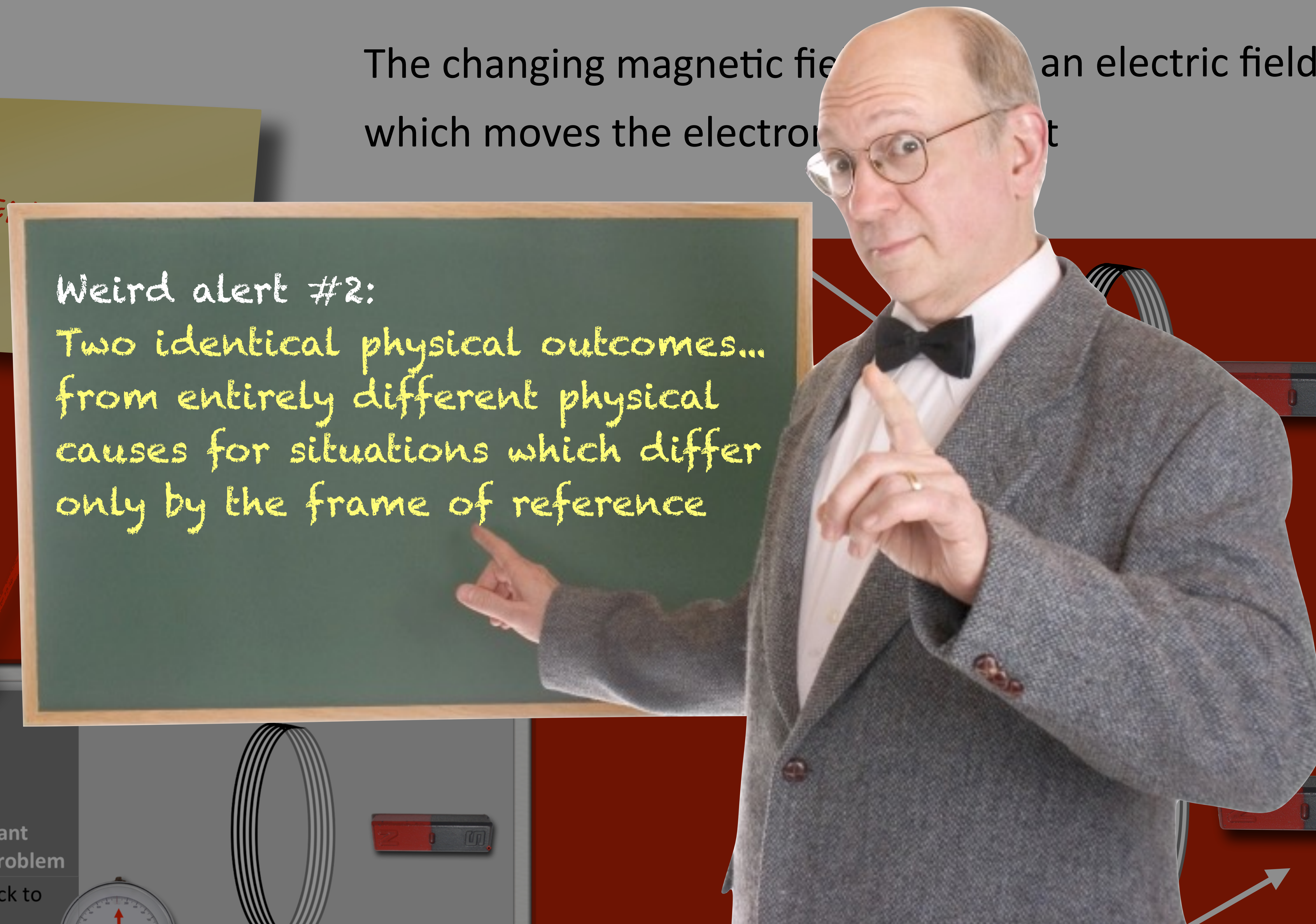


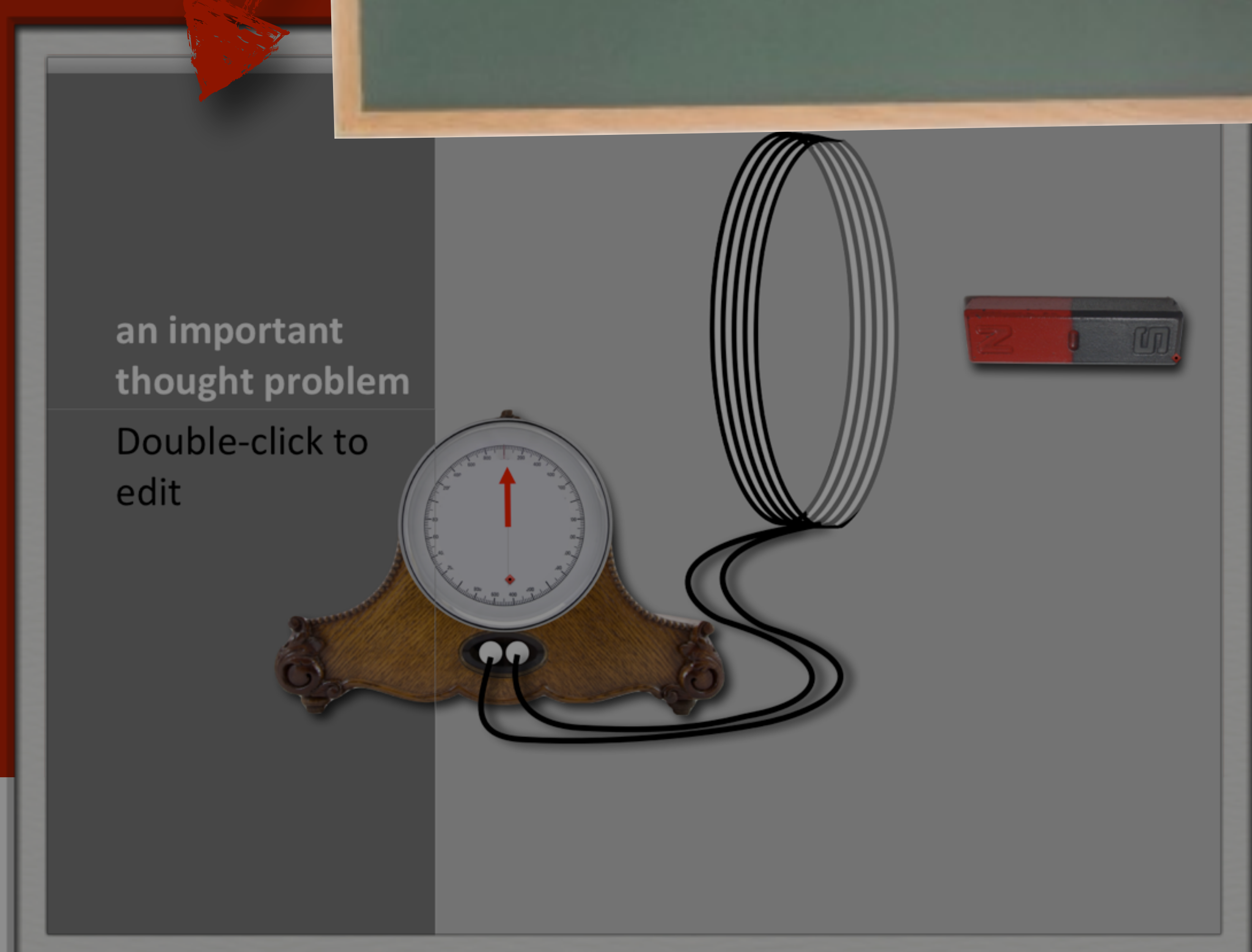
These situations differ only in the reference frame...

But, the physical effect – force or no force – is different!

The changing magnetic fie[...] an electric field in wire

which moves the electro[...]t





[...]rent

Magnetic field is constant – no electric fields

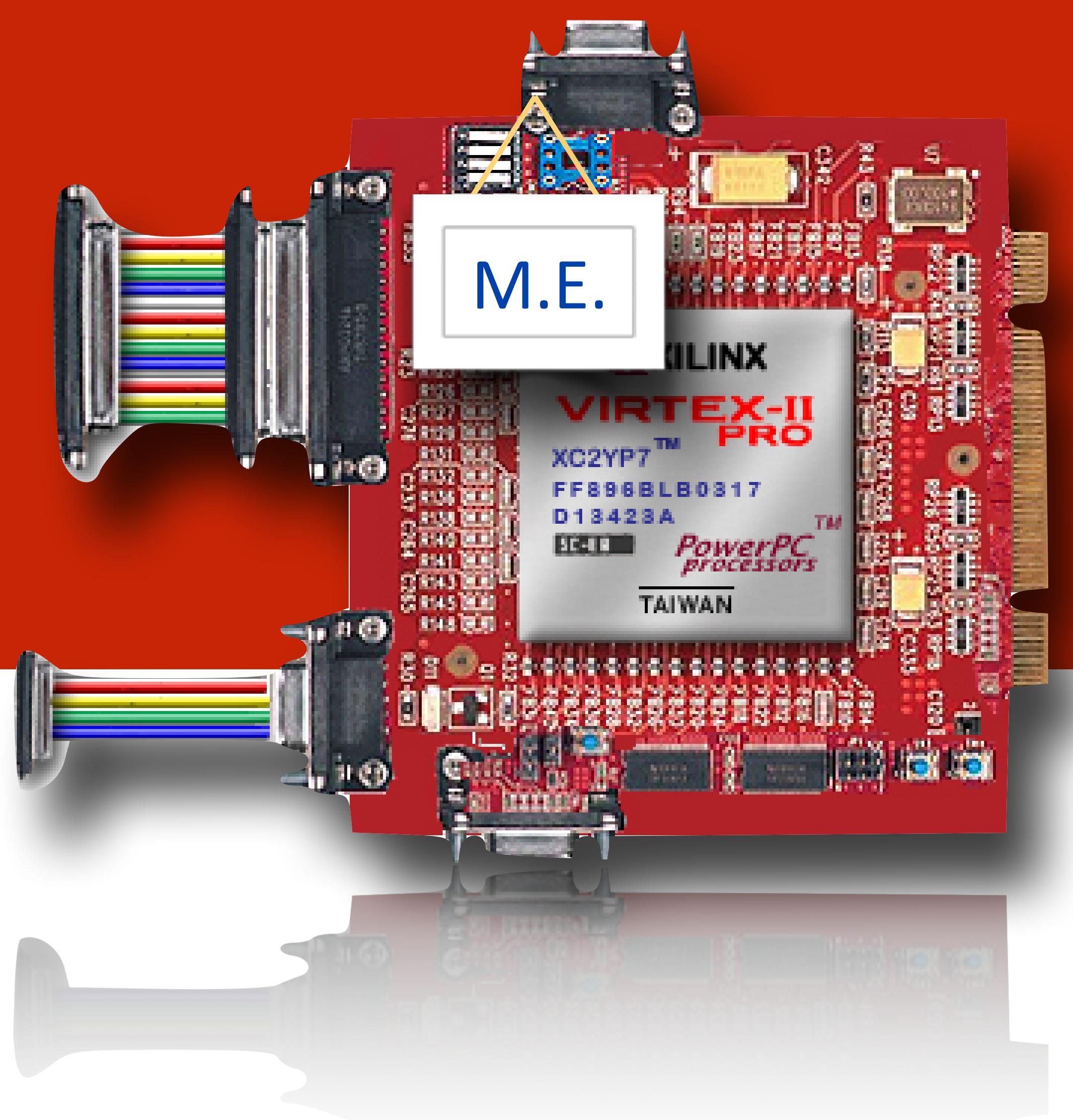
The electrons in the wire have a velocity

That produces a force on them – a current

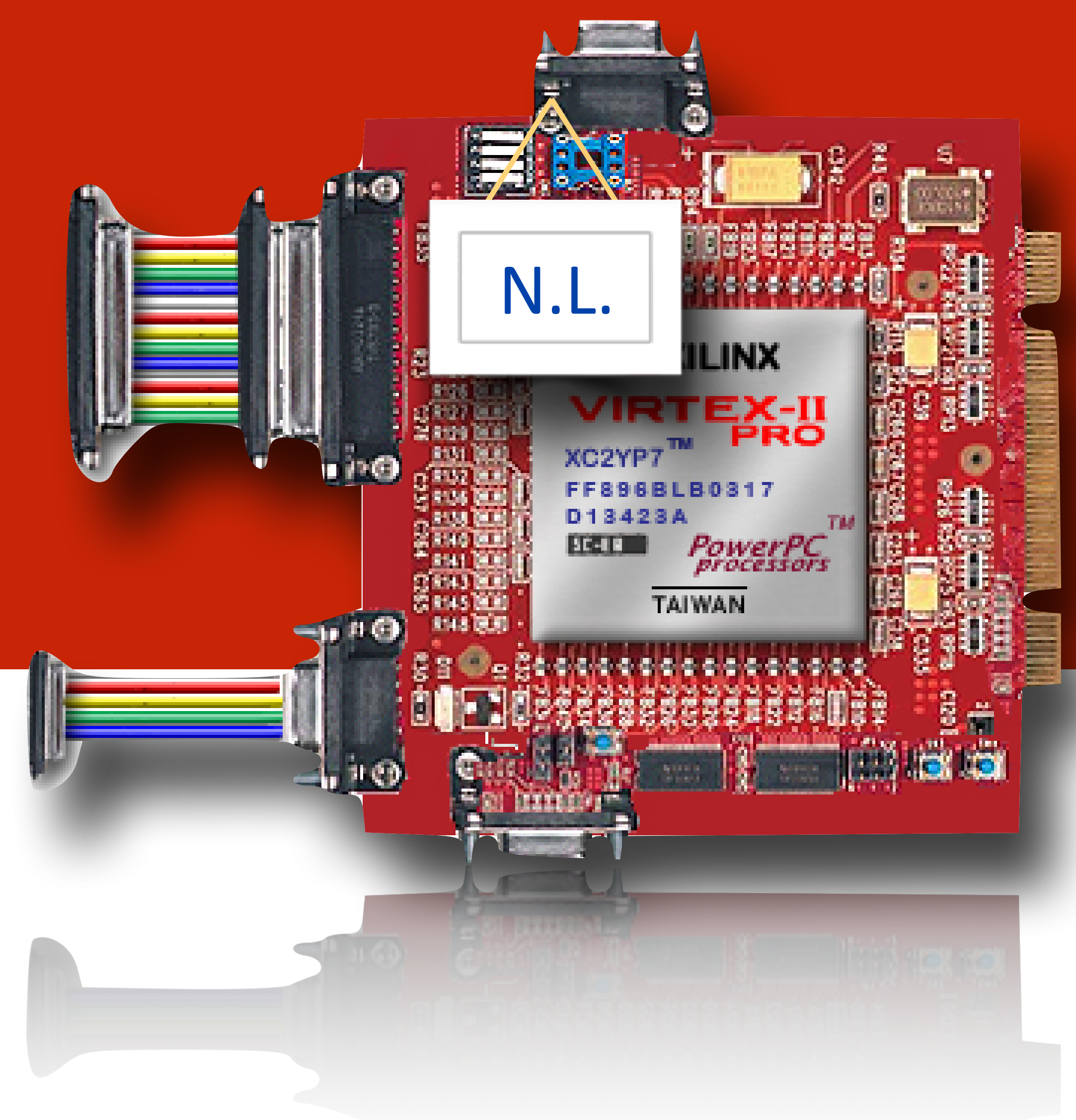
this is crazy! the two models of the world differ

in their treatment of relatively-moving frames of reference!

Seems to depend on Frame:



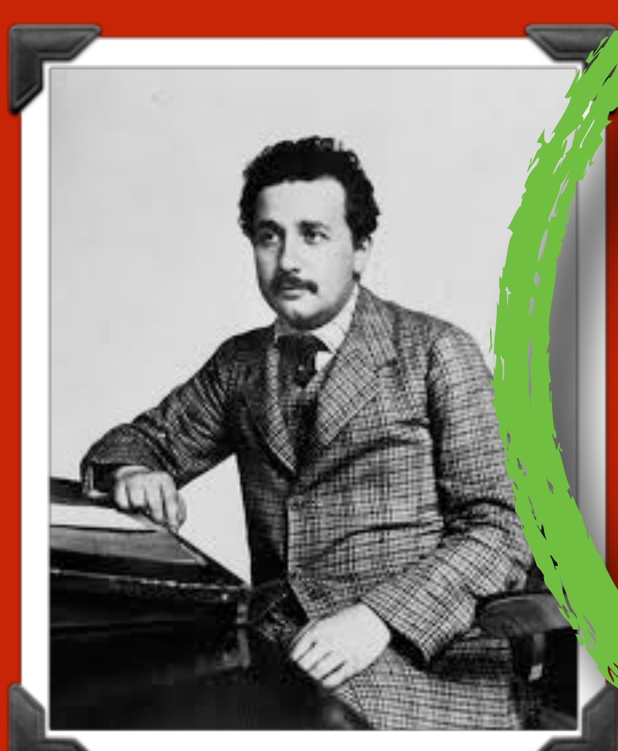
Don’t appear to depend on Frame:



2 Postulates:

"inertial frame":

constant velocity

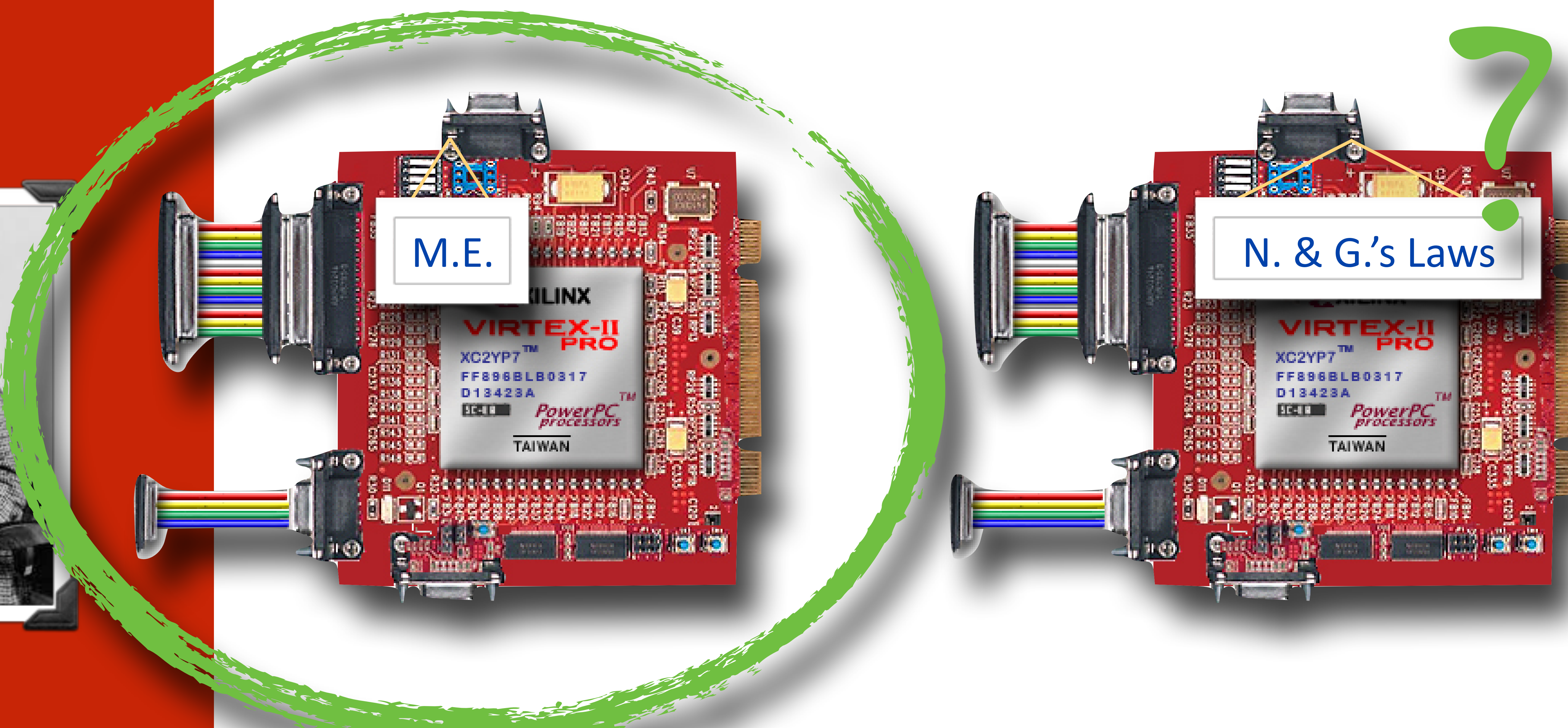


1. All laws of physics – mechanical and electromagnetic – are identical in co-moving inertial frames.

taking Galileo seriously, and then adding Maxwell

2. The speed of light is the same for all inertial observers.

taking Maxwell seriously

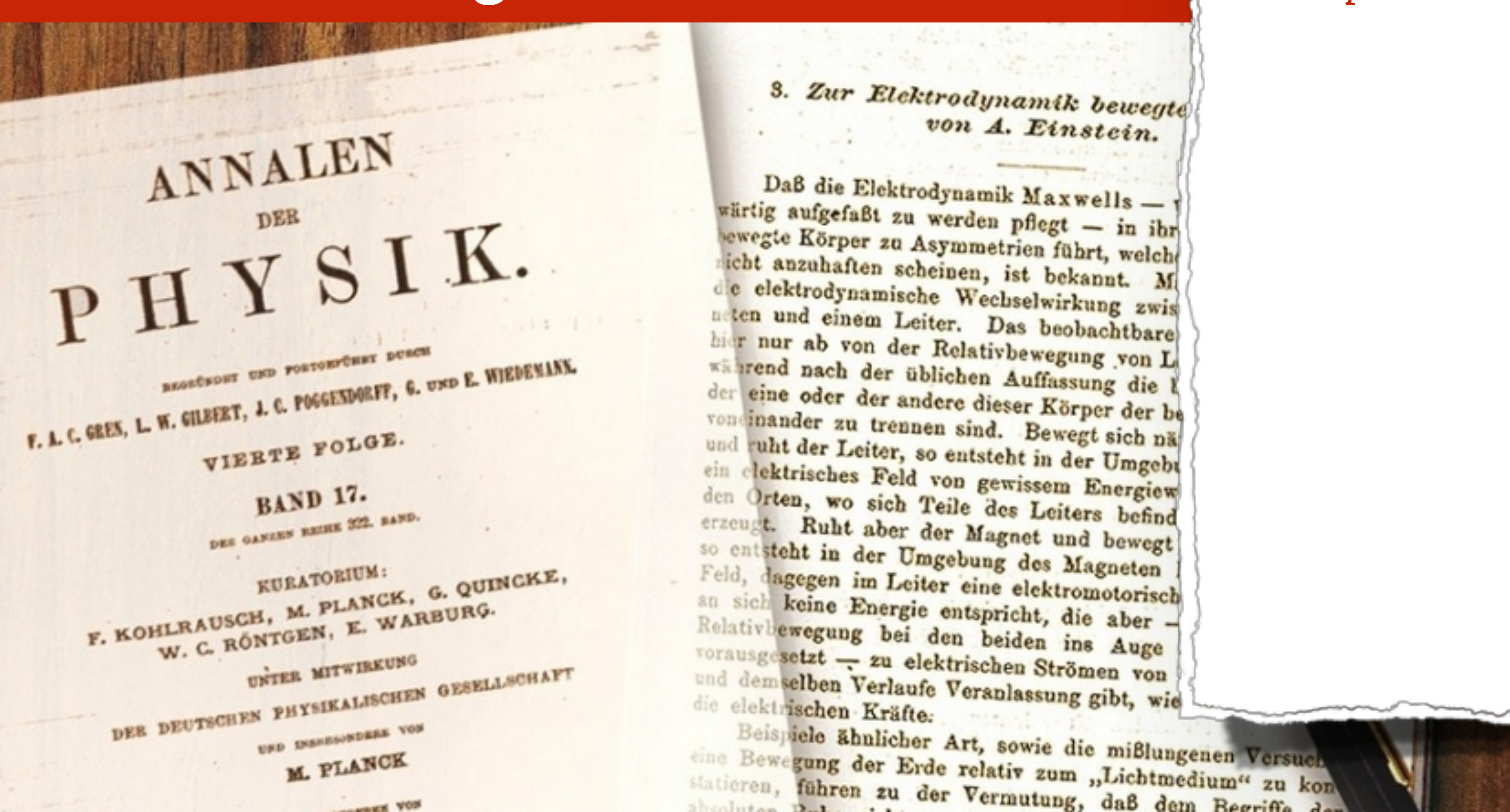


not your standard physics journal writing

Einstein writes very simply

His 1905 Relativity paper:

“On the Electrodynamics of Moving Bodies”



It is known that Maxwell's electrodynamics—as usually understood at the present time—when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena. Take, for example, the reciprocal electrodynamic action of a magnet and a conductor. The observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary view draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion.

For if the magnet is in motion and the conductor at rest, there arises in the neighbourhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are situated.

But if the magnet is stationary and the conductor in motion, no electric field arises in the neighbourhood of the magnet. In the conductor, however, we find an electromotive force…which gives rise…to electric currents of the same path and intensity as those produced by the electric forces in the former case.

Einstein writes very simply

His 1905 Relativity paper:

"On the Electrodynamics of Moving Bodies"

Let us take a system of co-ordinates in which the equations of Newtonian mechanics hold good. In order to render our presentation more precise and to distinguish this system of co-ordinates verbally from others which will be introduced hereafter, we call it the "stationary system."

If a material point is at rest relatively to this system of co-ordinates, its position can be defined relatively thereto by the employment of rigid standards of measurement and the methods of Euclidean geometry, and can be expressed in Cartesian co-ordinates.

If we wish to describe the motion of a material point, we give the values of its co-ordinates as functions of the time. Now we must bear carefully in mind that a mathematical description of this kind has no physical meaning unless we are quite clear as to what we understand by "time." We have to take into account that all our judgments in which time plays a part are always judgments of simultaneous events. If, for instance, I say, "That train arrives here at 7 o'clock," I mean something like this: "The pointing of the small hand of my watch to 7 and the arrival of the train are simultaneous events."

It might appear possible to overcome all the difficulties attending the definition of "time" by substituting "the position of the small hand of my watch" for "time." And in fact such a definition is satisfactory when we are concerned with defining a time exclusively for the place where the watch is located; but it is no longer satisfactory when we have to connect in time series of events occurring at different places, or—what comes to the same thing—to evaluate the times of events occurring at places remote from the watch.

and then

he played the two postulates out

to see what would result

“A storm broke loose in my mind.”

the 2nd postulate

makes things strange

suggests that c

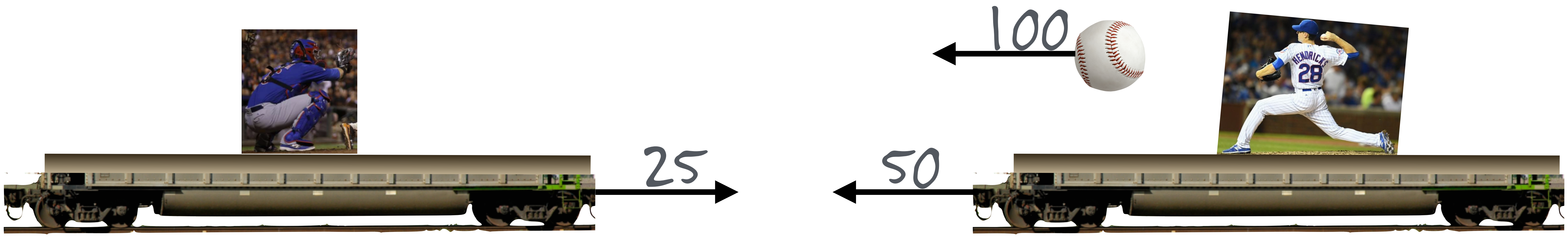
the speed of light is constant in all inertial frames:

$c = 3 \times 10^8$ m/s = 300 million m/s = 1,080 million km/h

c = 671 million mph

this seems reasonable:

a trap.

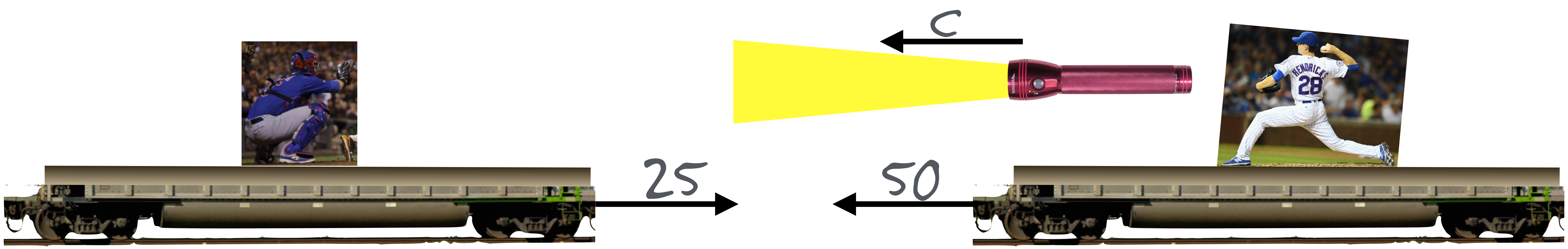


case 1: v(catcher)=0 v(ball)=100 v(pitcher)=0

what's v(ball) that catcher experiences: v(caught)=100

this seems strange:

light’s different.



case 1: v(catcher)=0 v(light)=c v(pitcher)=0

what’s v(light) that catcher experiences: v(caught)=c

---

case 2: v(catcher)=0 v(light)=c v(pitcher)=50

what’s v(light) that catcher experiences: v(caught)=c

---

case 3: v(catcher)=25 v(light)=c v(pitcher)=50

what’s v(light) that catcher experiences: v(caught)=c

his concern:

synchronizing clocks

on a train

she arranges for light detectors to be equidistant from light source

train lady sees:

simultaneous hits

on a train

she arranges for light detectors to be equidistant from light source

train lady sees:

still: simultaneous hits

her motion doesn't matter to her

beside the tracks

he arranges for light detectors to be equidistant from light source

track man sees:

simultaneous hits

`but`

what does he see on the train

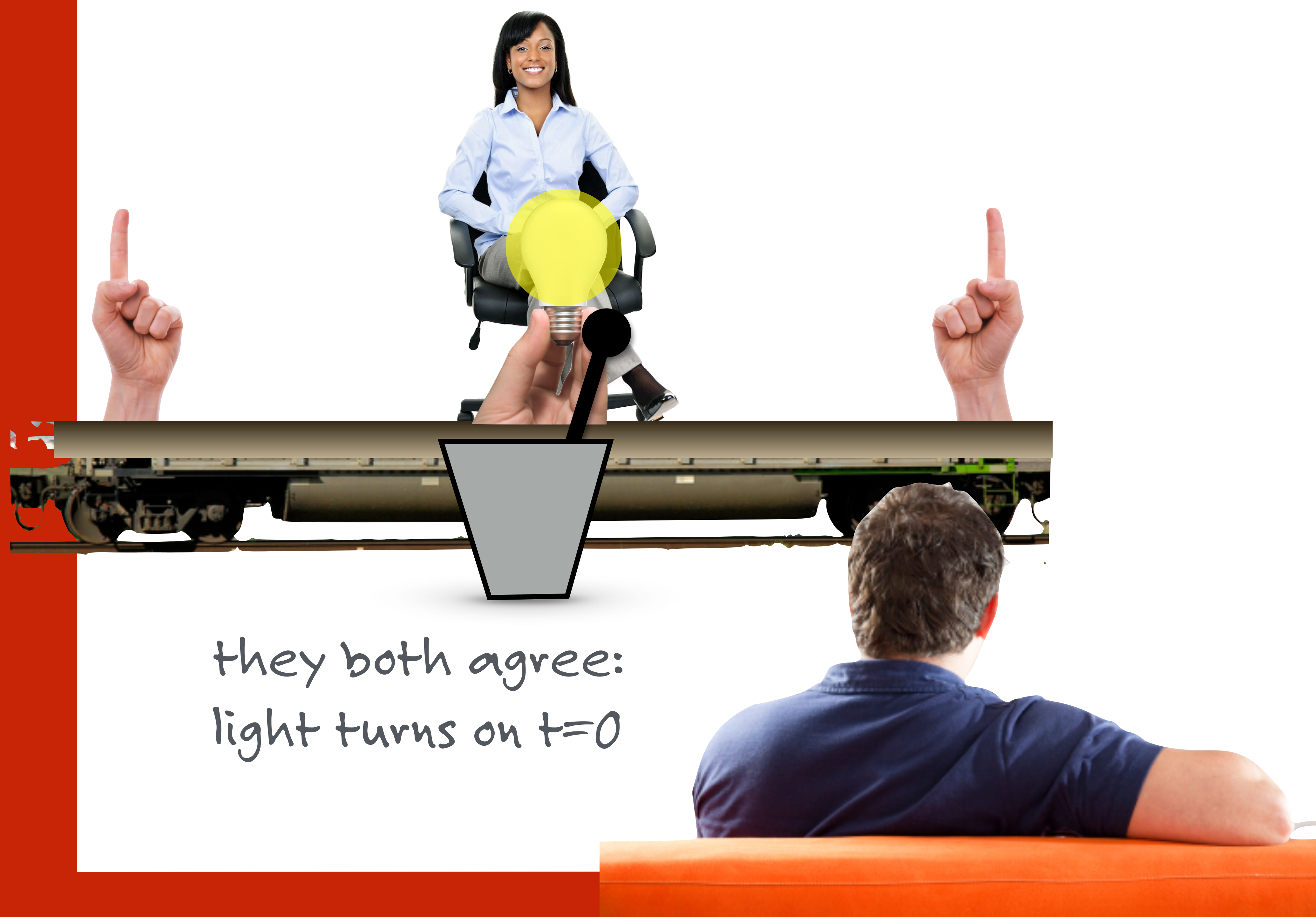
if the light source goes by him?

beside the tracks

track man sees:

beside the tracks

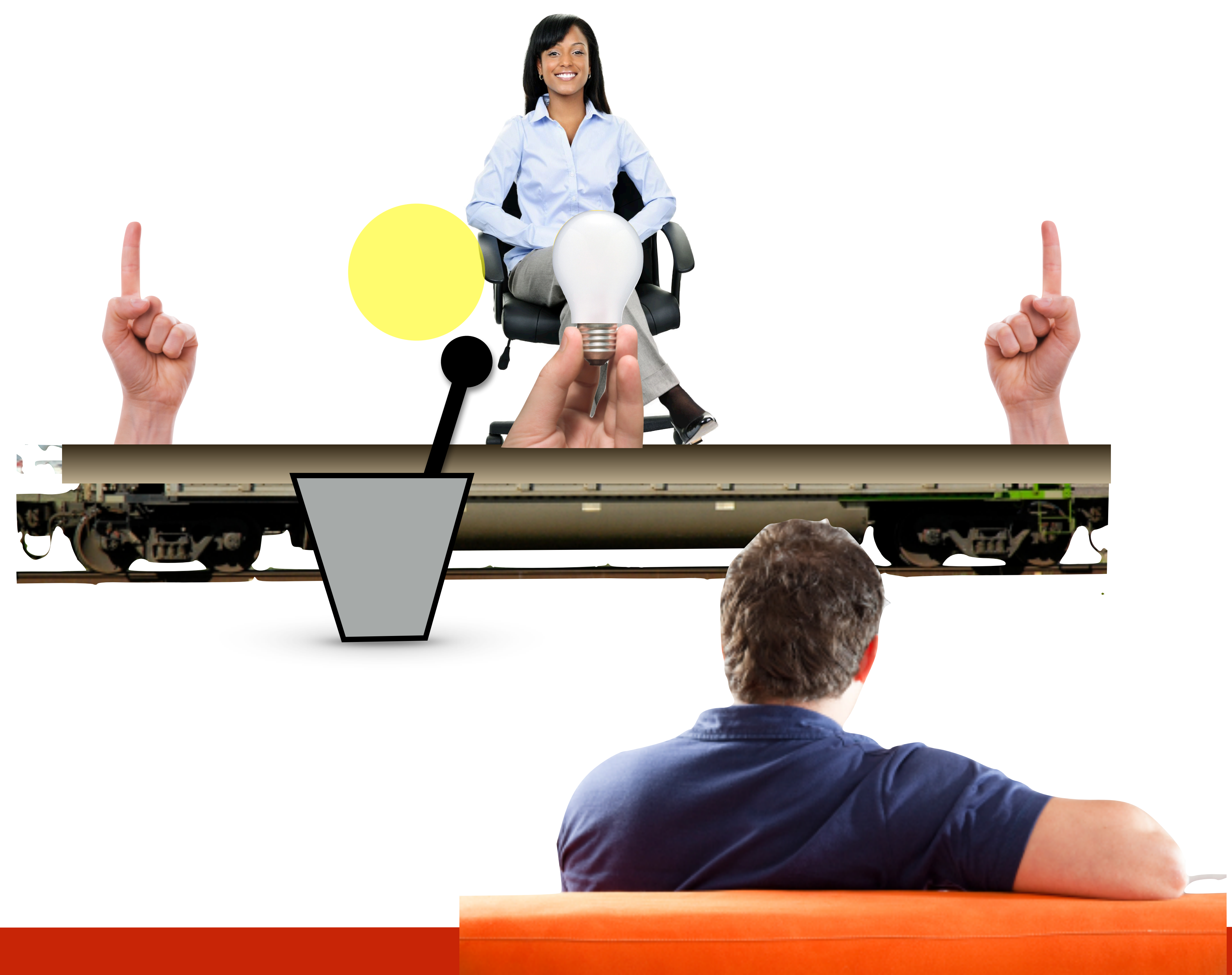
track man sees:



they both agree:
light turns on t=0

beside the tracks

track man sees:



beside the tracks

track man sees:

back finger catches up
front finger runs away

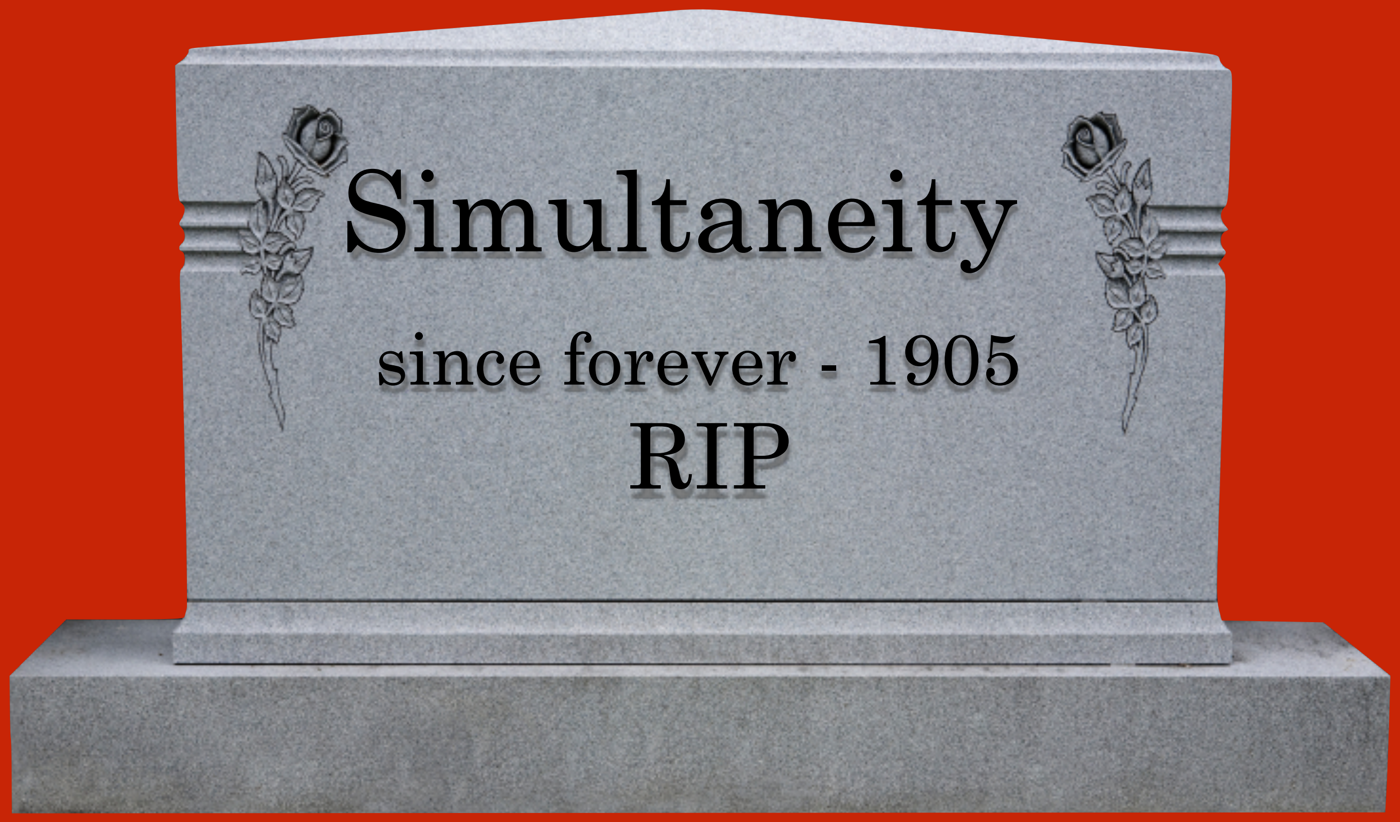
a consequence

of the second postulate:

if two events are simultaneous in one frame

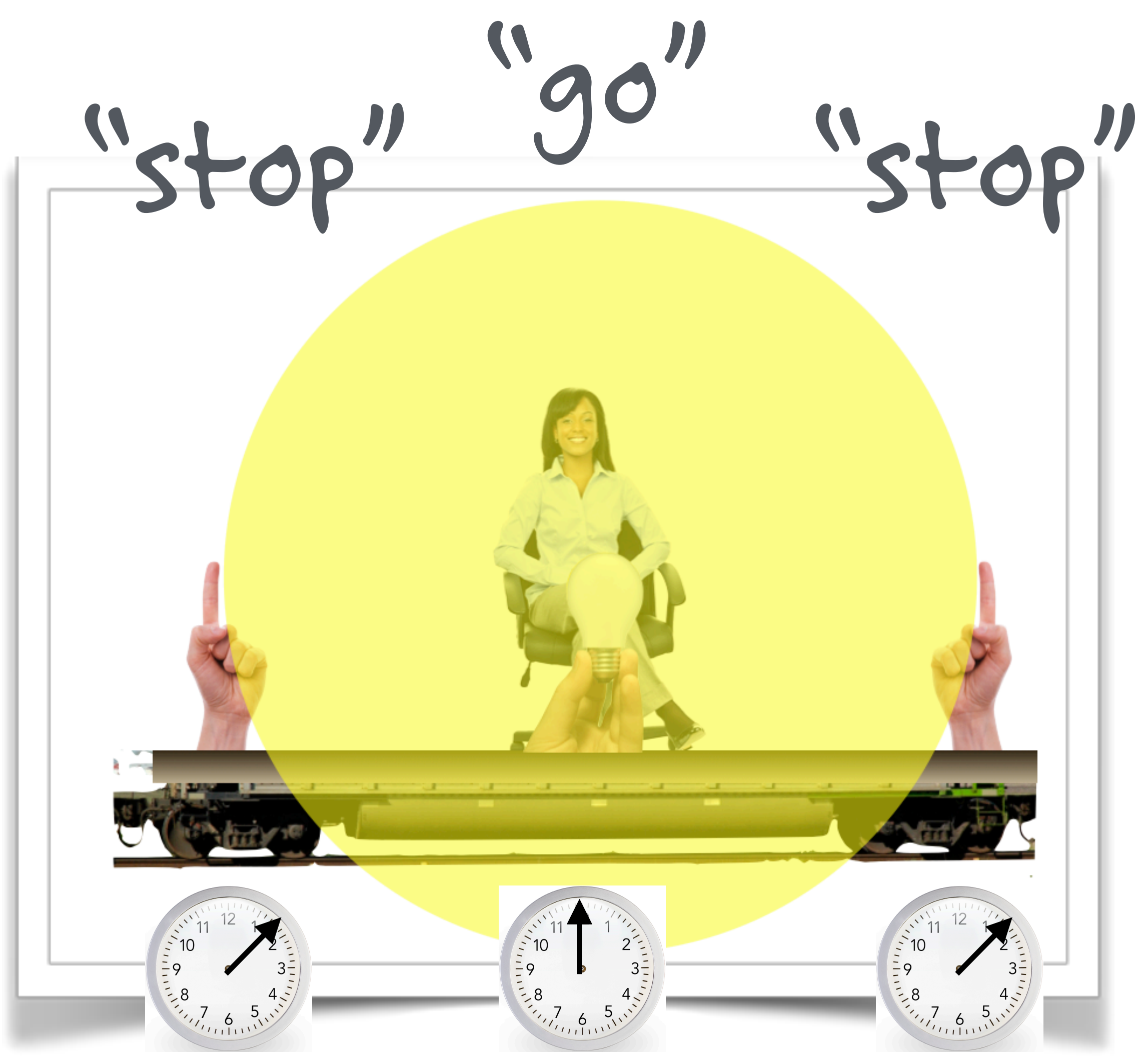
they are not for a co-moving inertial frame

There is no such thing as the *concept of* simultaneous events



this bothered Einstein

how would you synchronize two clocks?



"stop" "go" "not yet"

without "simultaneity"...you can't

two problems with this:

1. Since there is no way to determine that something is simultaneous in one frame and also in another

one can never synchronize clocks between co-moving frames of reference

so one can never confirm or disconfirm the reality of a special frame of reference*

2. The notion that a *cause* always precedes an *effect* seems threatened.

*critical.... queue soapbox:

to the logic of science: disconfirmation

not “proof”

not “belief”

Unsure about someone’s “scientific” assertion?

Ask what it would take to change their mind.

So.

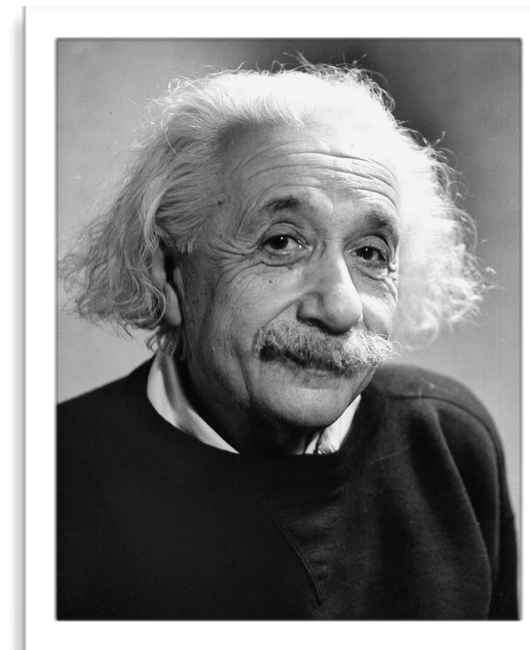
No inertial frame is special.

All are equivalent.

Why?

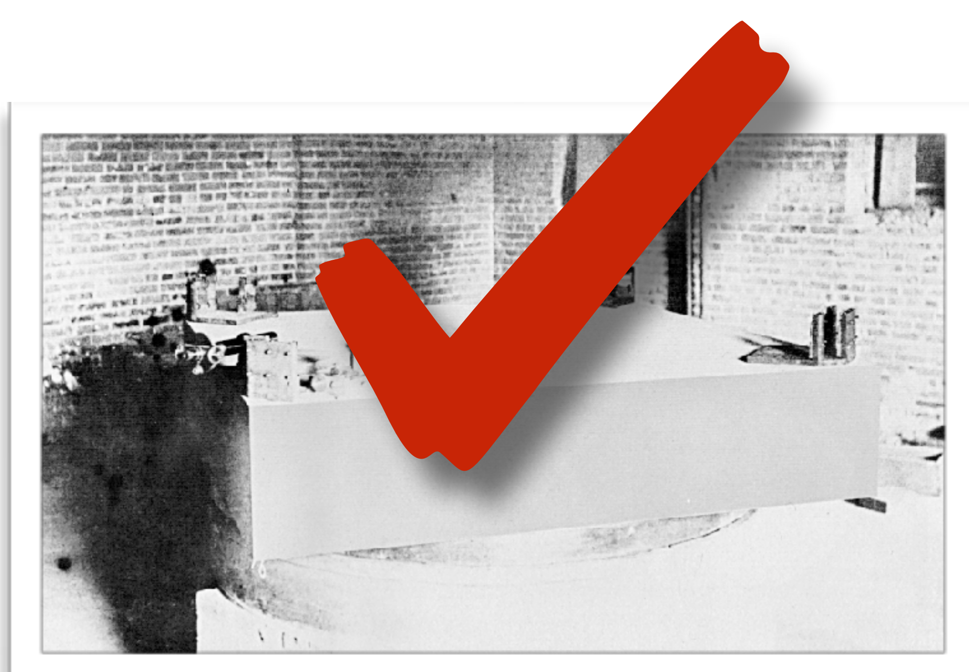
because disconfirmation of a state of absolute rest or absolute constant motion is impossible

new criterion for physical reality:



If it can’t be measured it can’t be real

The ether can’t be measured, so it cannot be real…



26 yo Einstein:

“‘The introduction of a ‘‘luminiferous ether’’ will prove to be superfluous inasmuch as the view here to be developed will not require an ‘absolutely stationary space’ provided with special properties…’’

2. "Causality" requires care

is CAUSALITY a casualty!?

Two observers disagree about when events happen

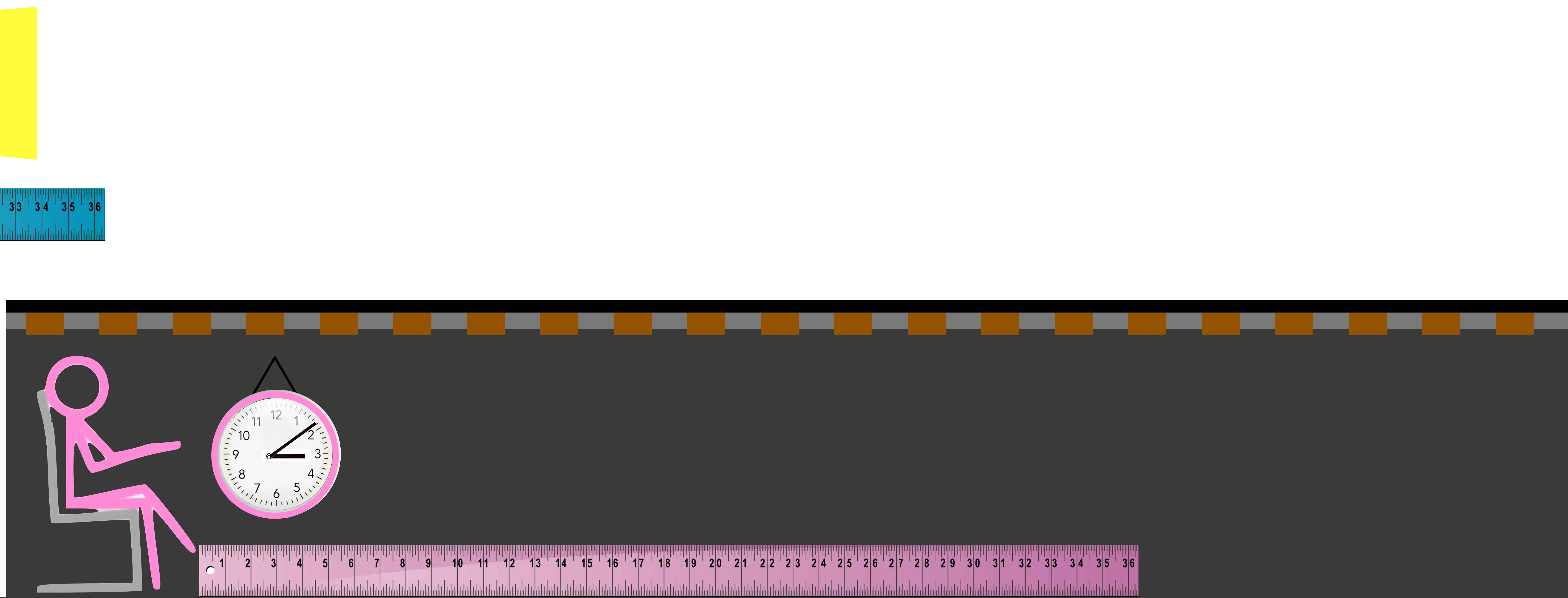
the same time? at different times?

Suppose the hospital order is: first I'm born, then I cry

would a moving observer believe that first I cry, then I'm born?

light is constant speed everywhere

$v_A = c$

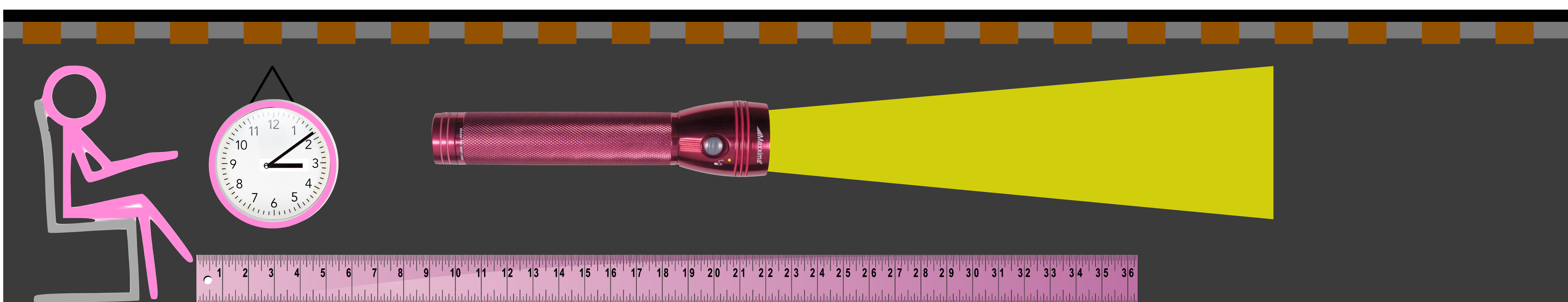


$v_H = c!!$

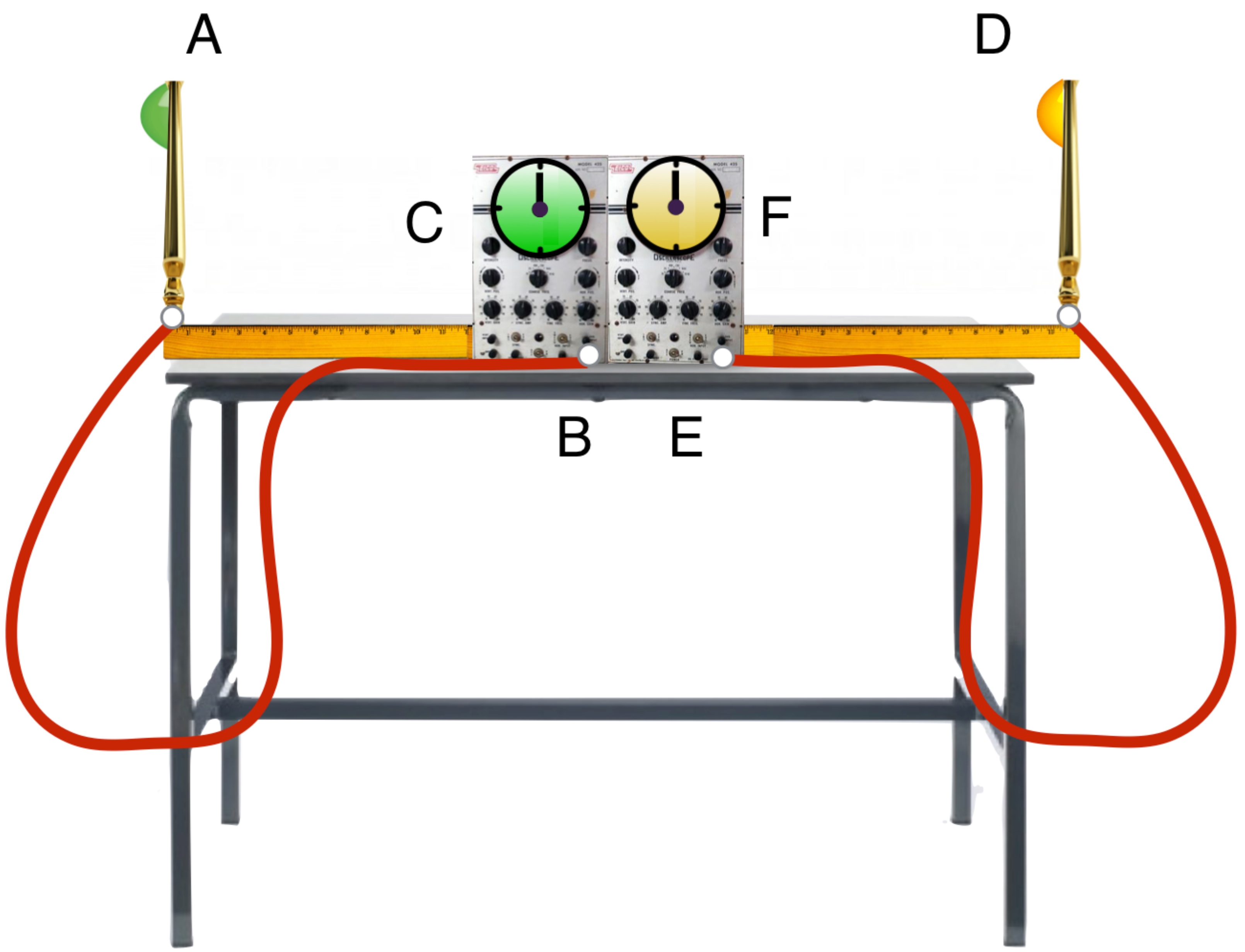
and the other way as well.

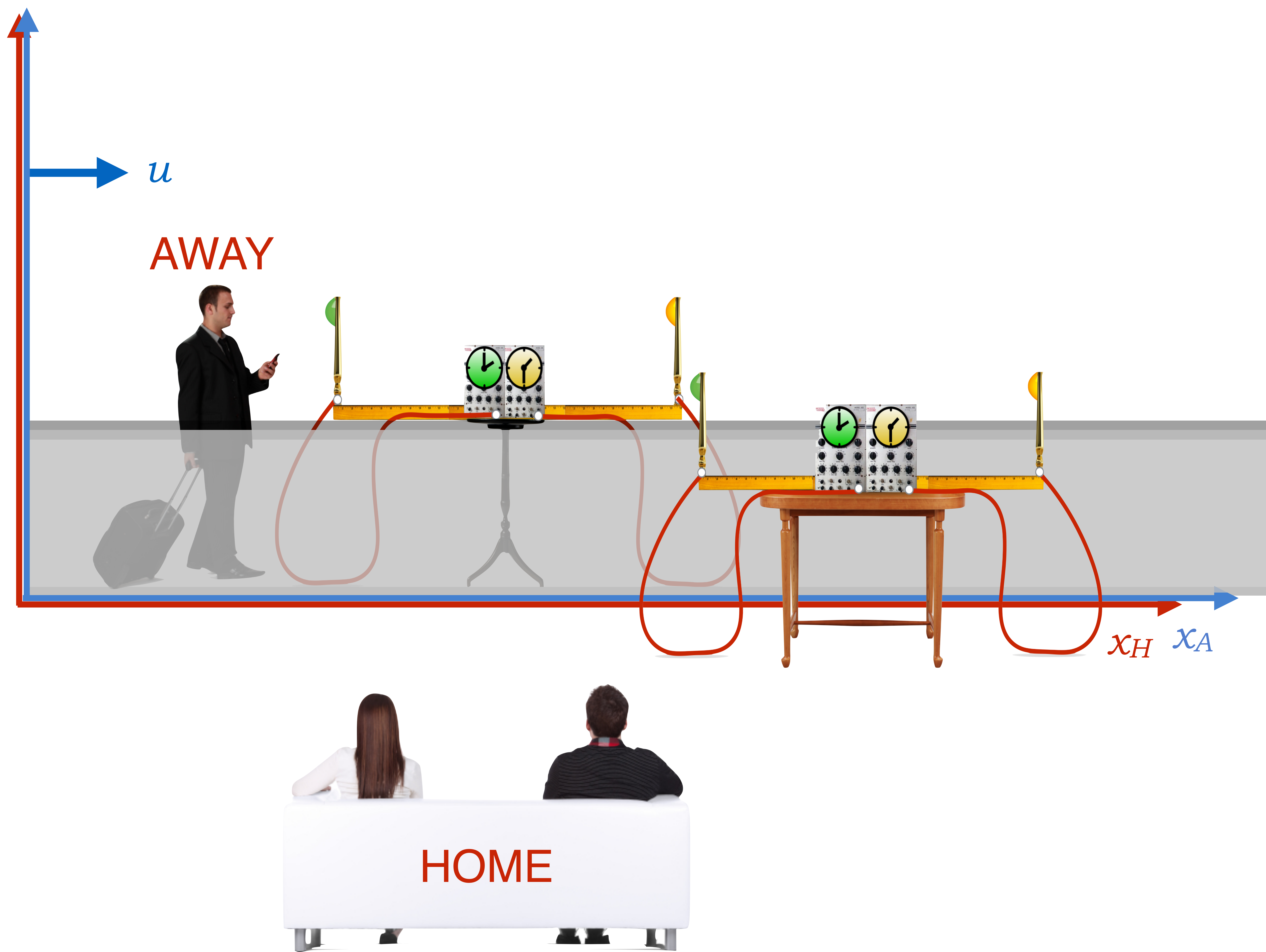
$v_T = c!$

can't catch up!

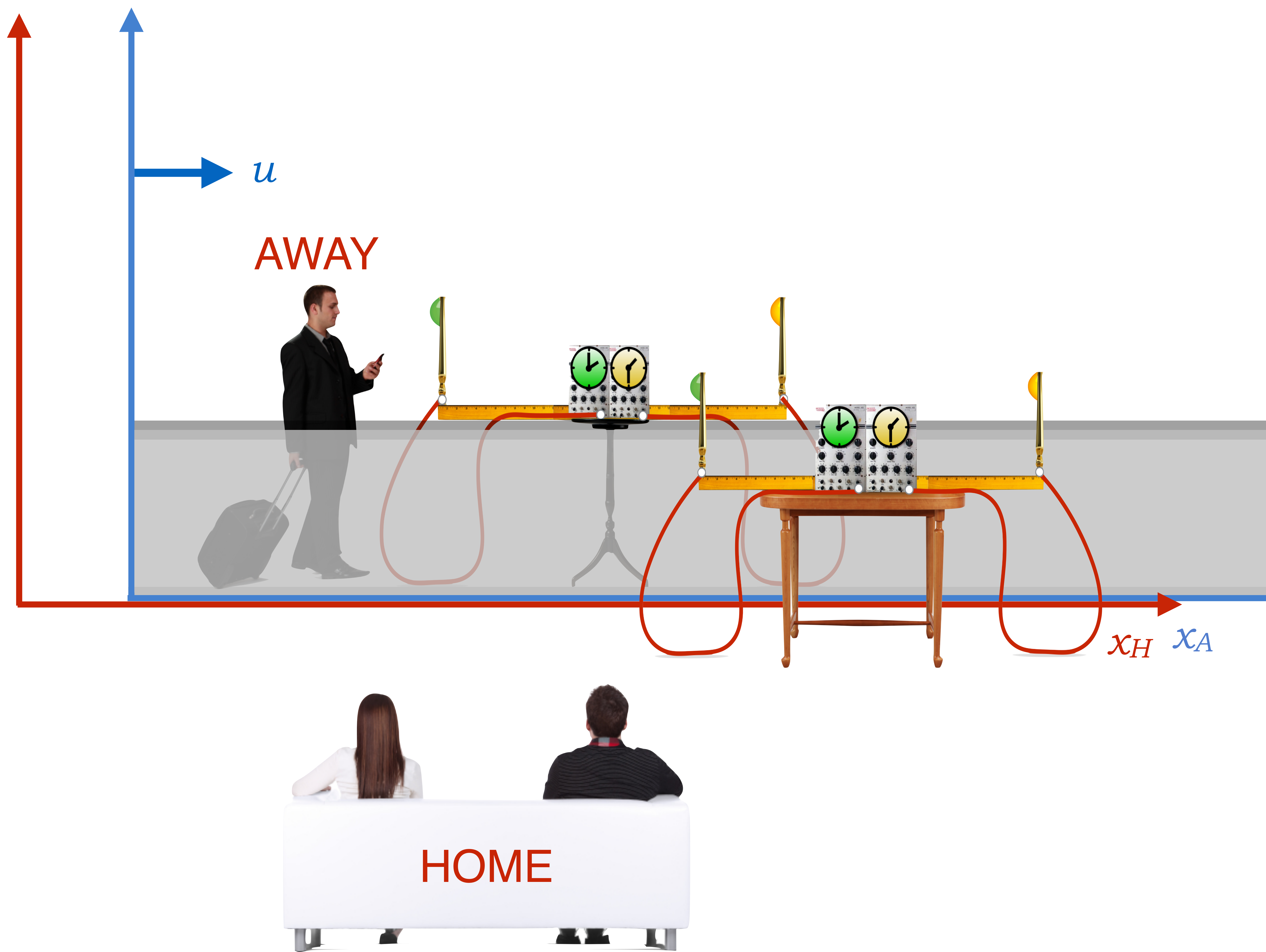


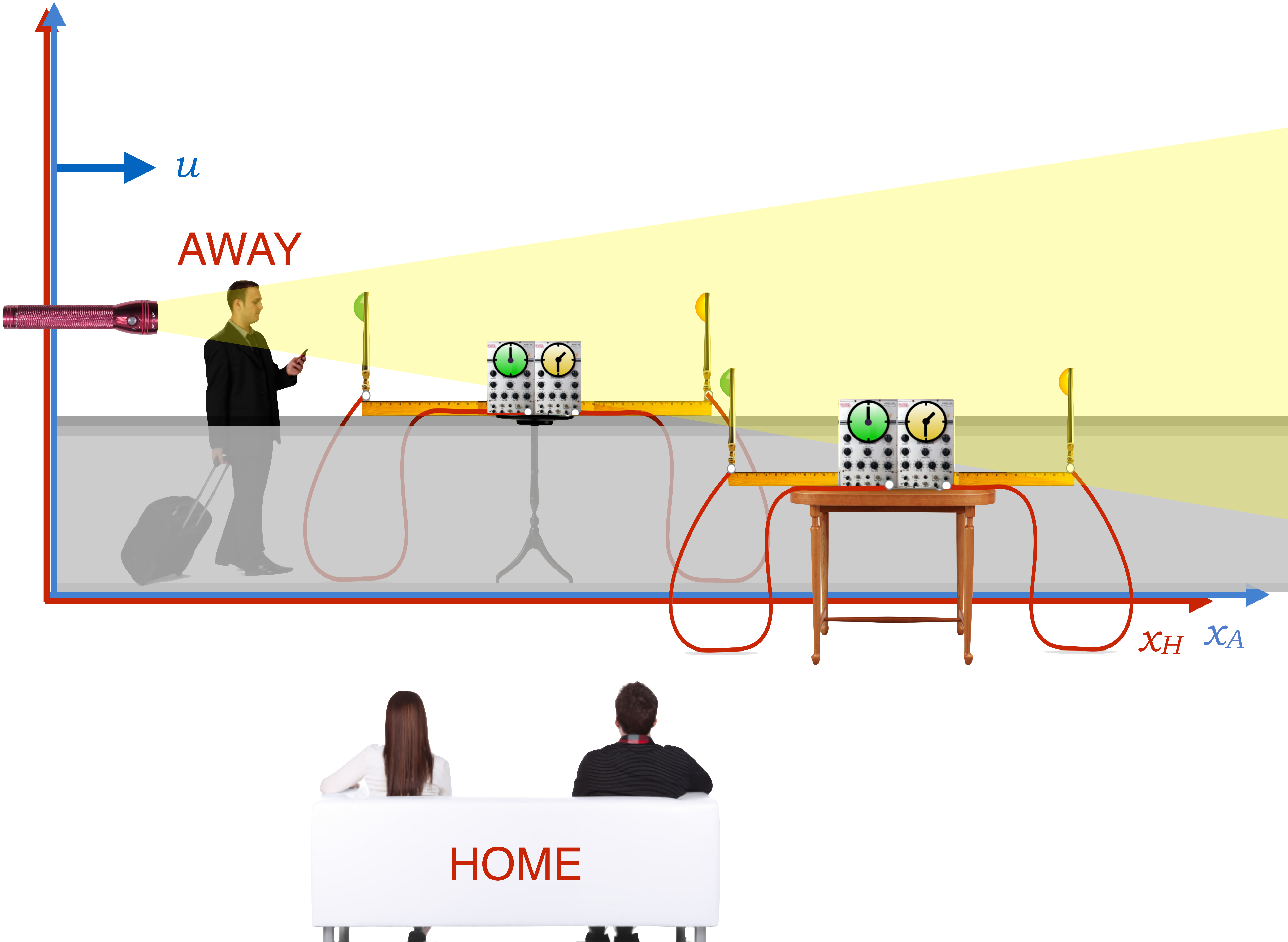
$v_G = c$

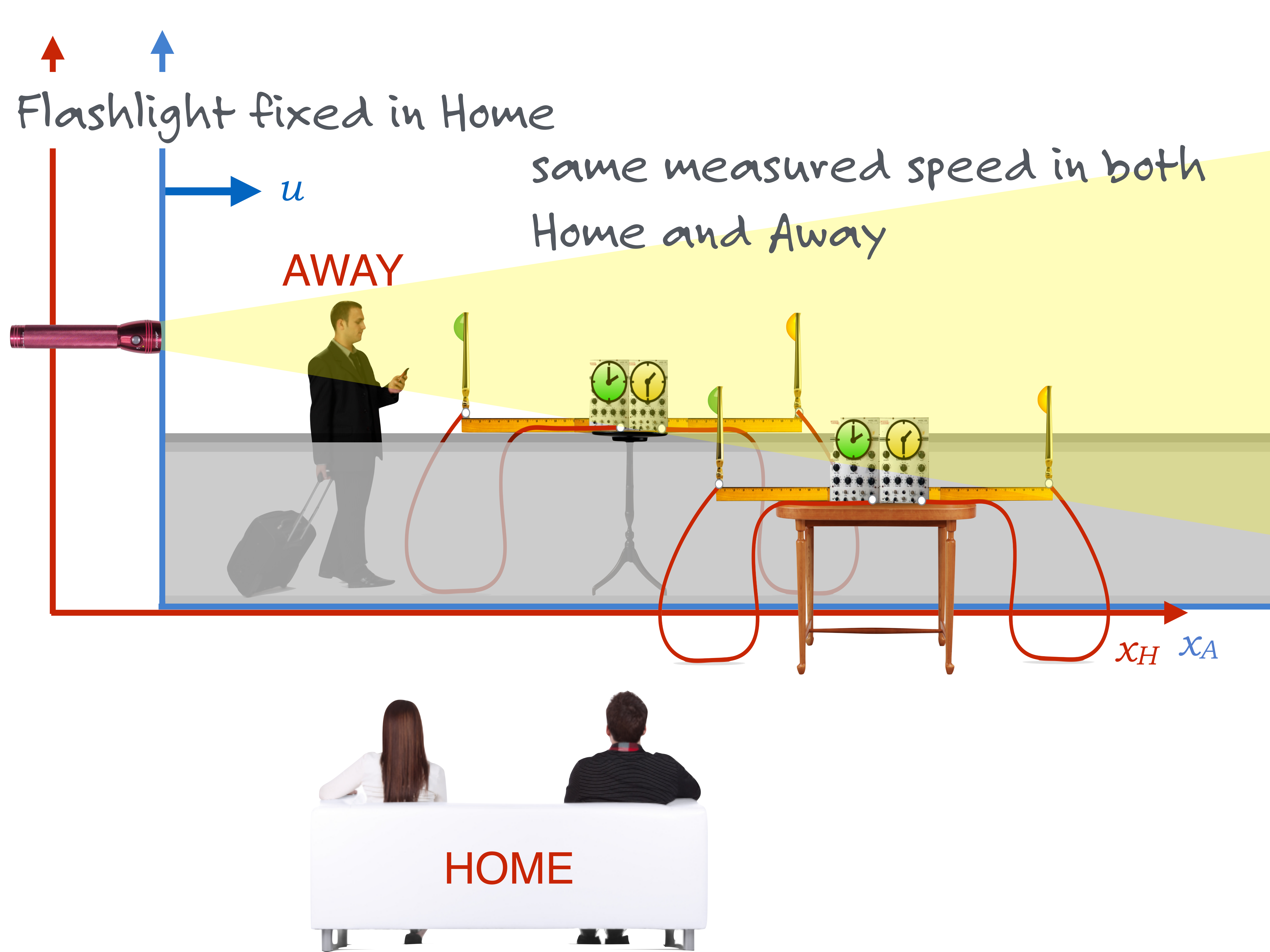

A
D
C
F
B
E



u
AWAY
x_H
x_A
HOME


u
AWAY
x_H
x_A
HOME


u
AWAY
x_H
x_A
HOME

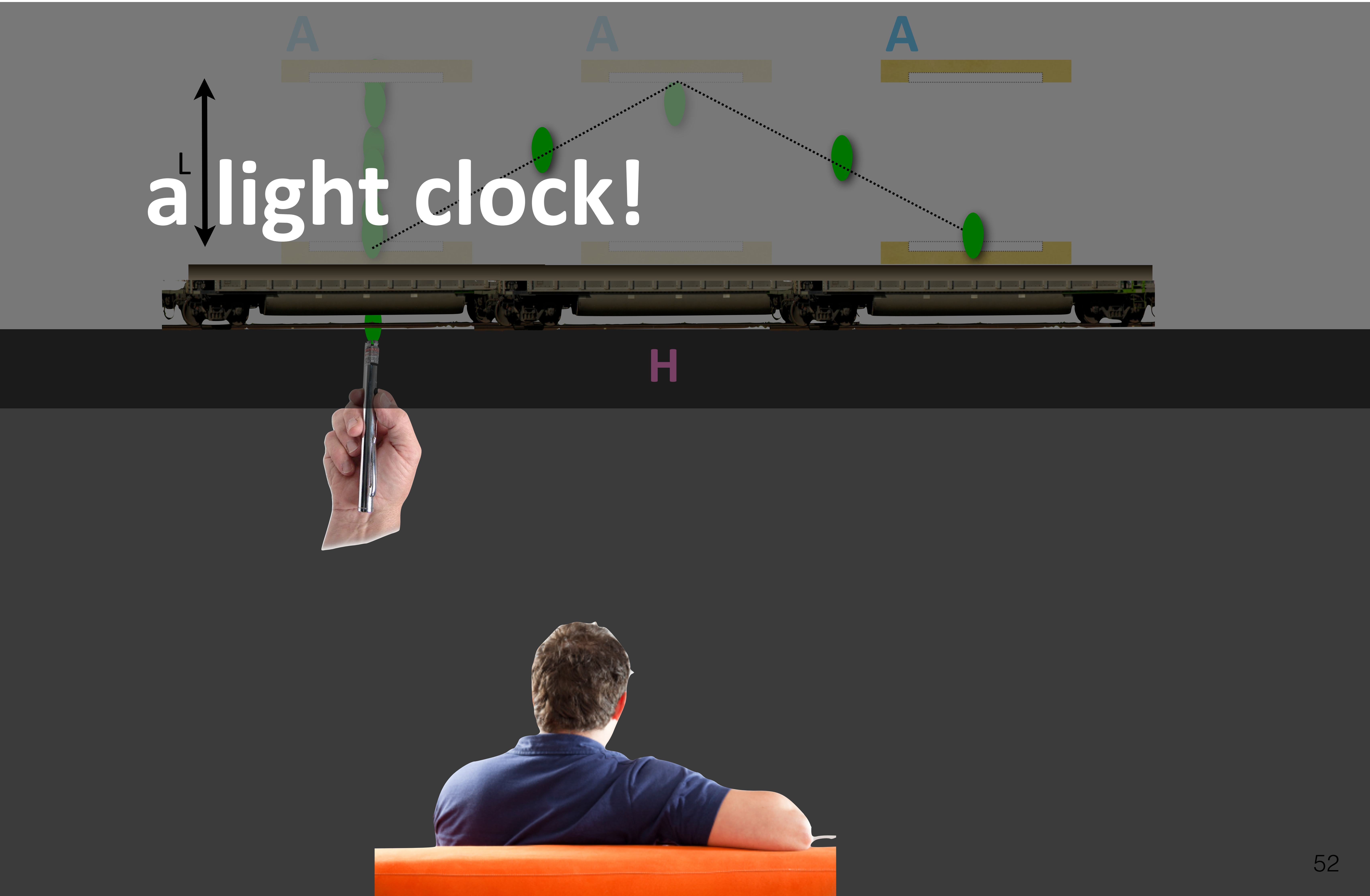


Flashlight fixed in Home
same measured speed in both
Home and Away
u
AWAY
x_H
x_A
HOME

there are consequences to this

let's make a light clock

and follow the mathematics story


A
A
A
L
a light clock!
H

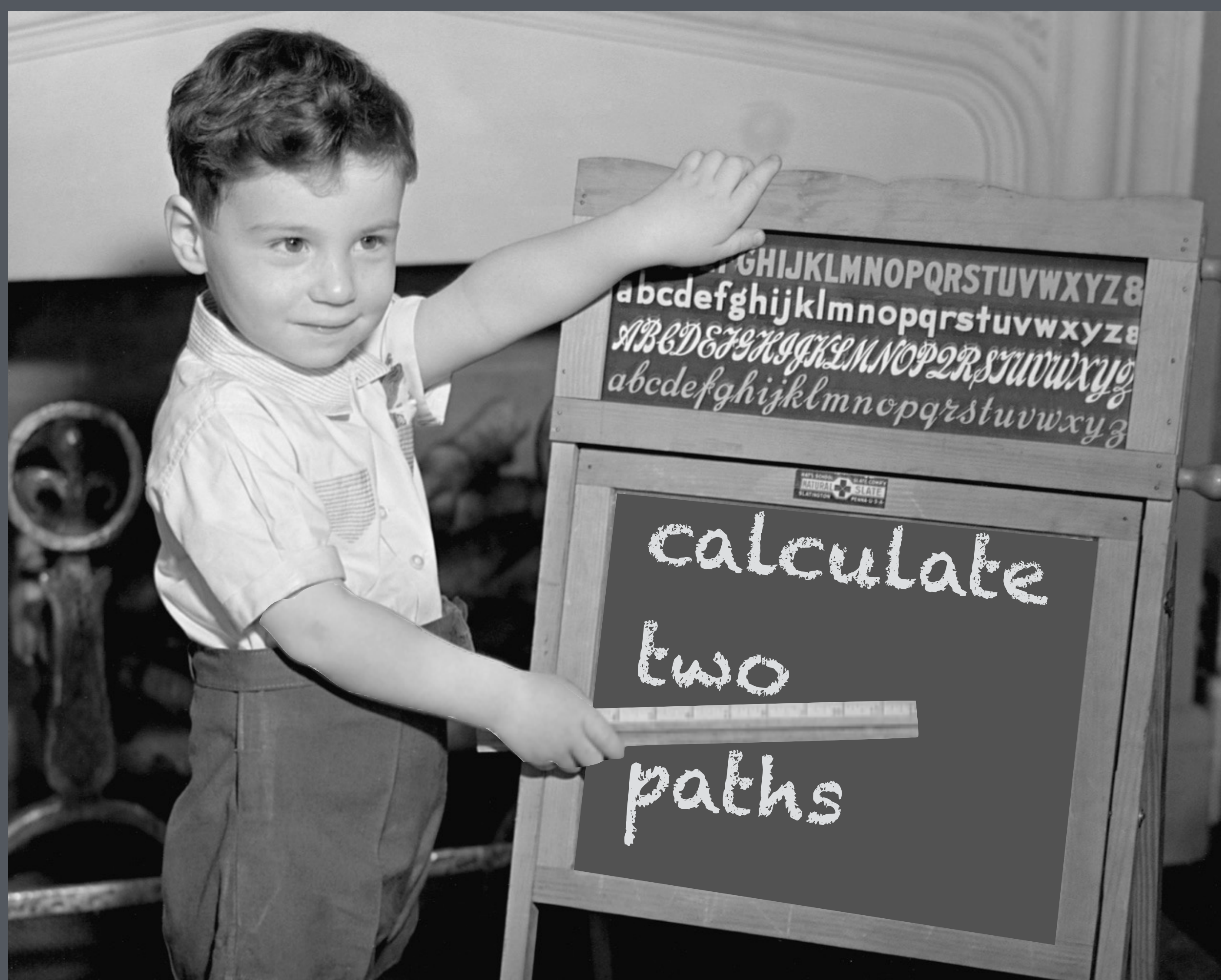
Compare time

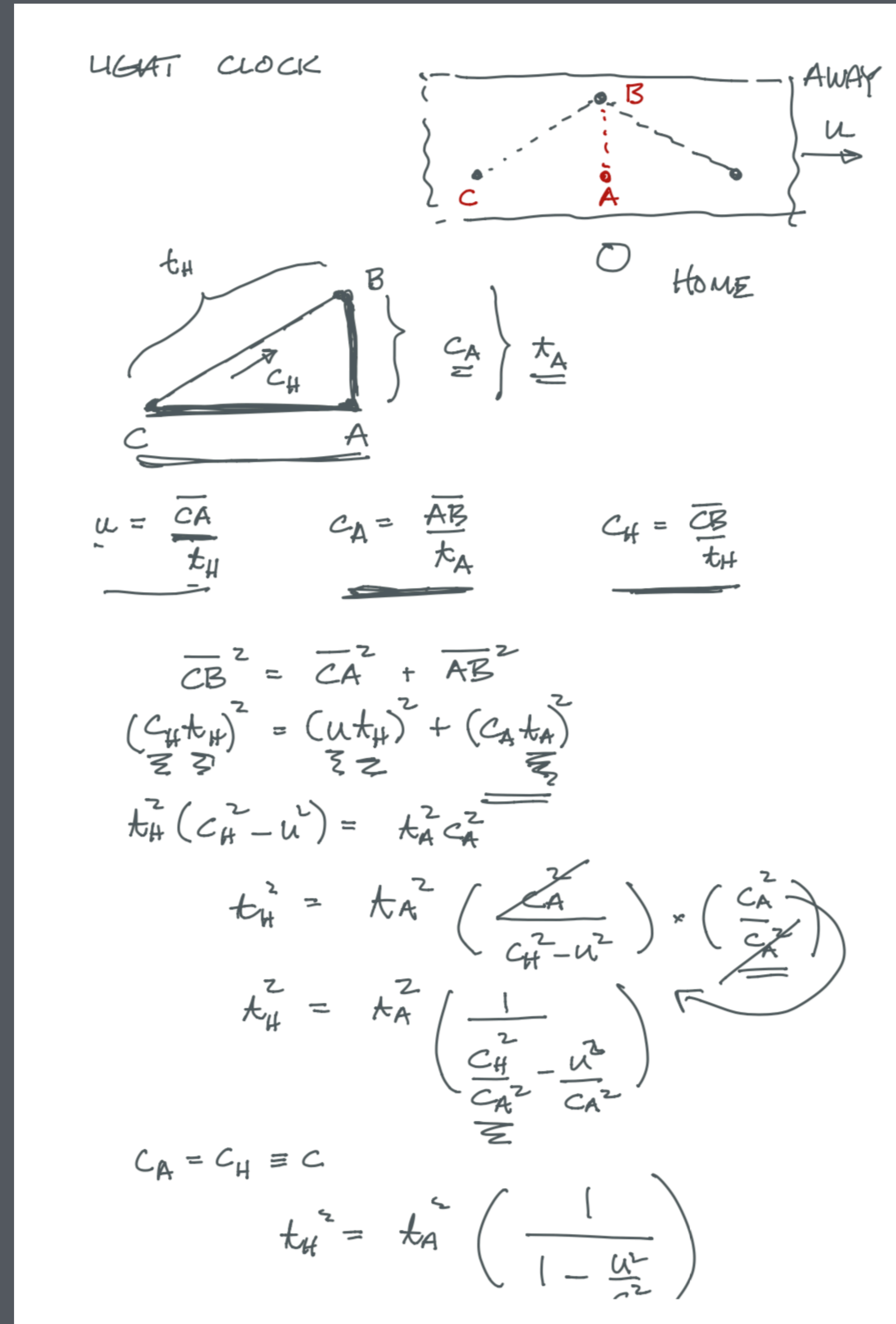
for tick-tock in train frame

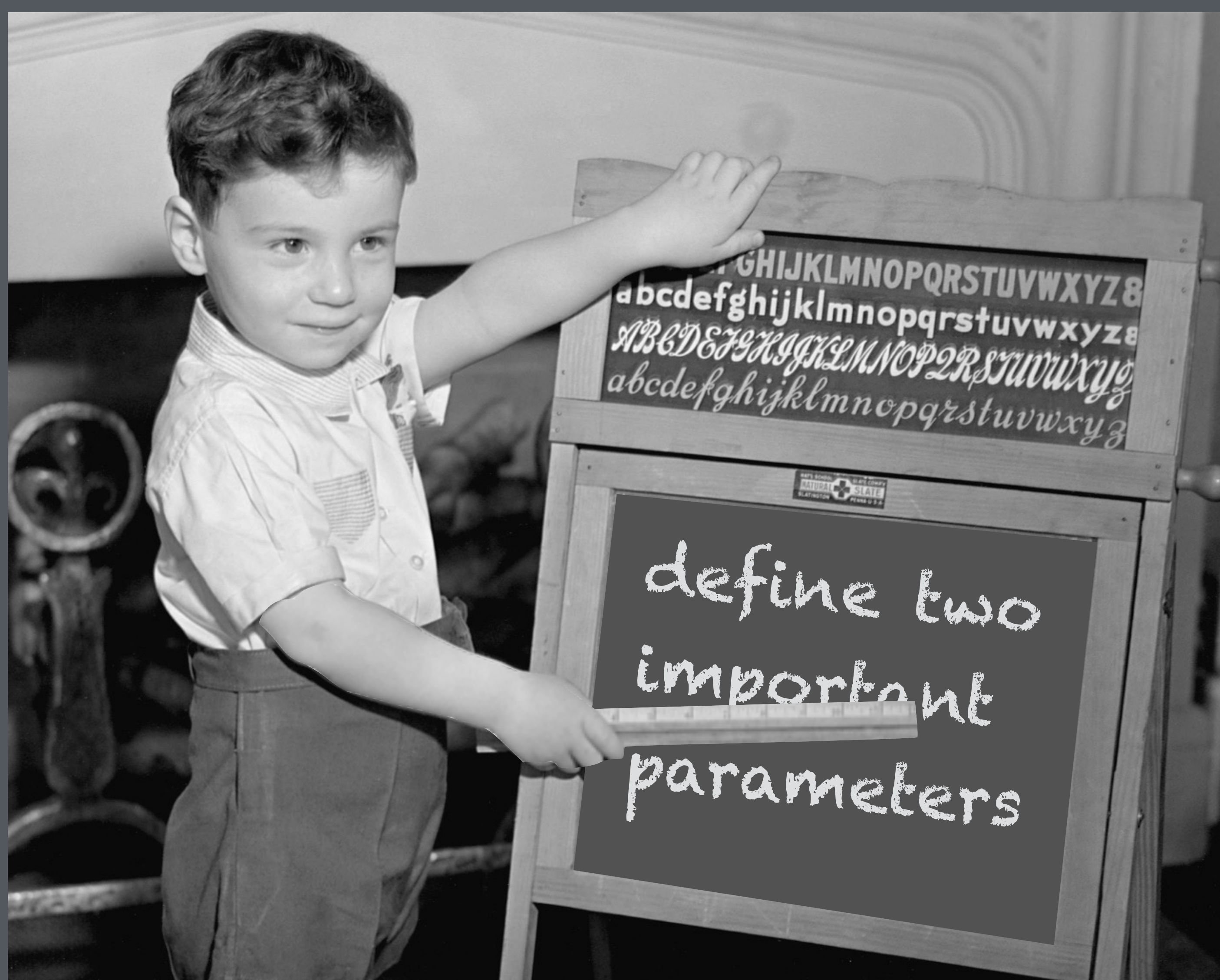
with

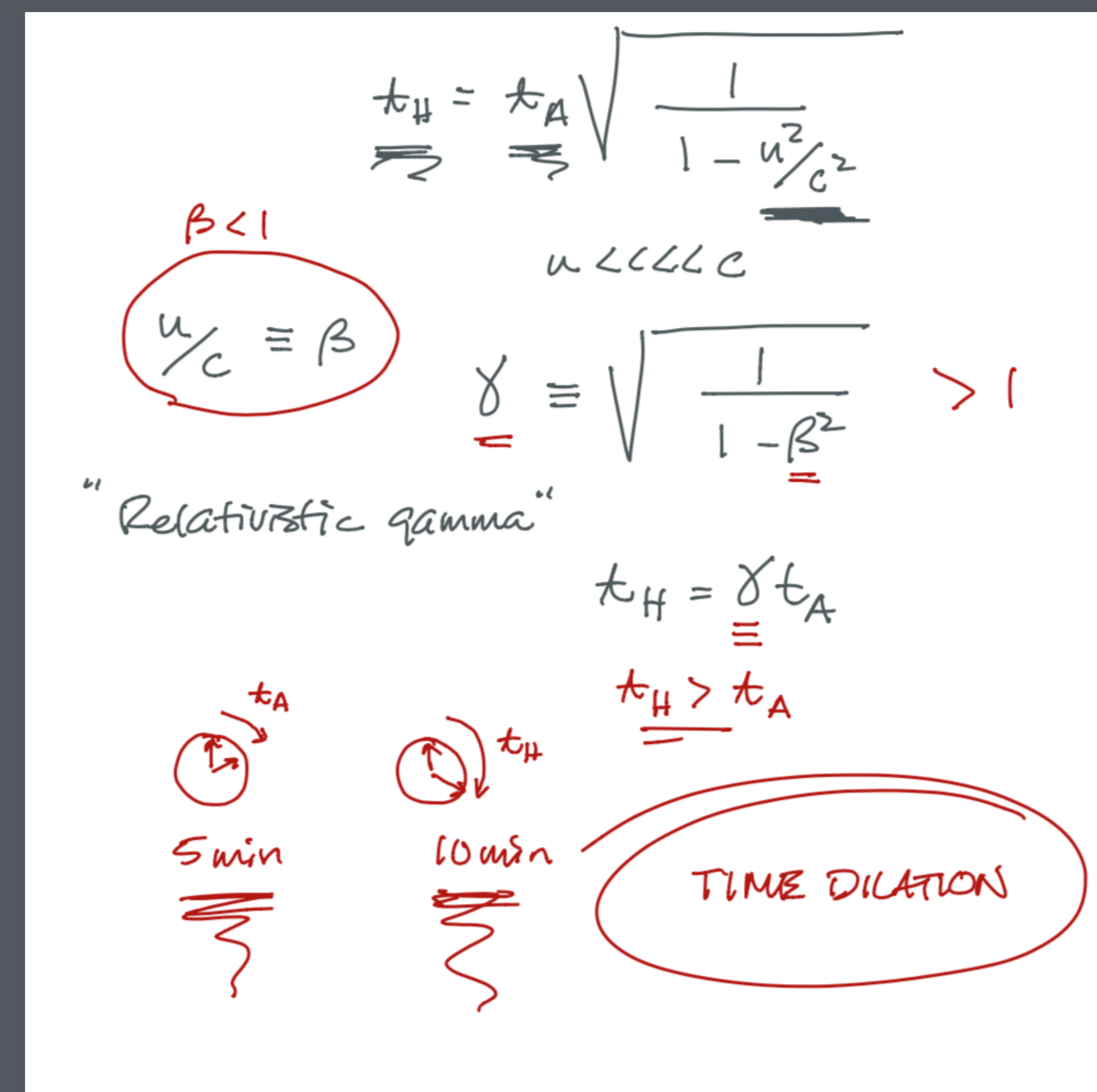
tick-tock in couch-guy's frame

done in class






define two
important
parameters


$t_H = t_A \sqrt{\frac{1}{1 - u^2/c^2}}$
$\beta < 1$
$u \ll\ll c$
$u/c \equiv \beta$
$\gamma \equiv \sqrt{\frac{1}{1-\beta^2}} > 1$
"Relativistic gamma"
$t_H = \gamma t_A$
$t_H > t_A$
t_A
t_H
5 min
10 min
TIME DILATION

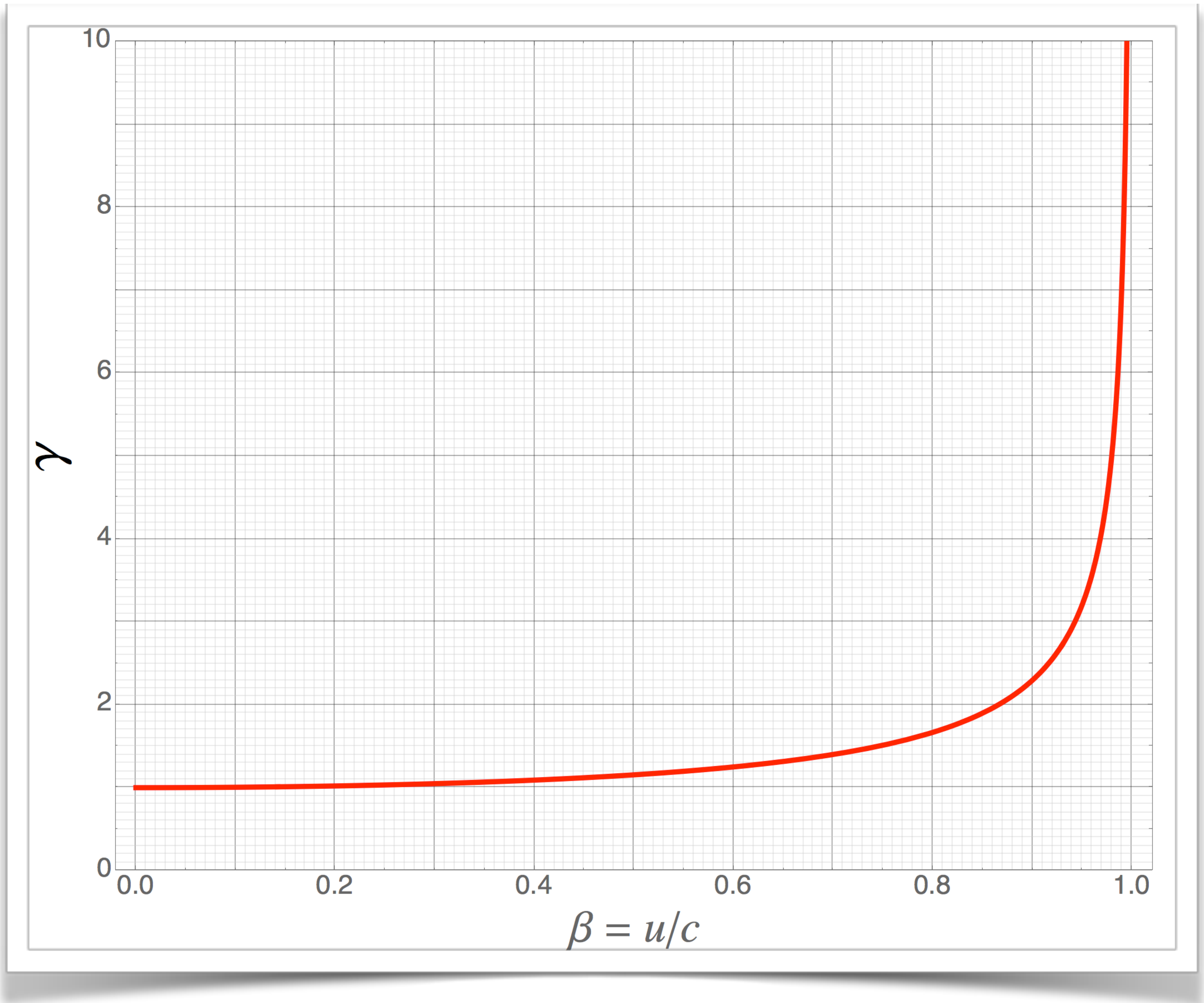
Moving clocks appear to run slower as seen by a relatively stationary observer

$$t_H = \frac{t_A}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$

$$t_H = \gamma t_A$$

time dilation

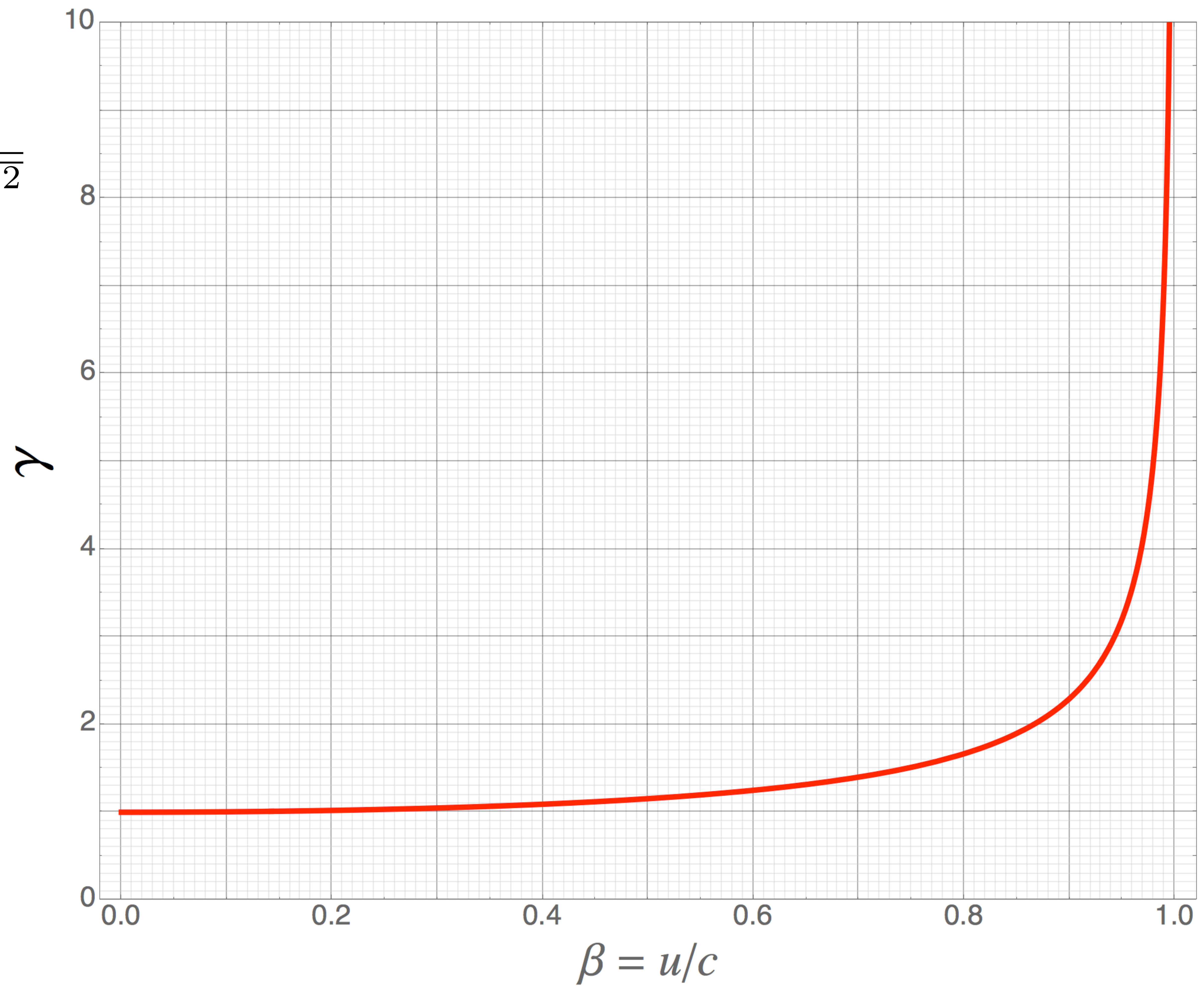
the second of 3 strange things about space and time



"relativistic gamma"

$$\gamma = \frac{1}{\sqrt{1-\left(\frac{u}{c}\right)^2}}$$

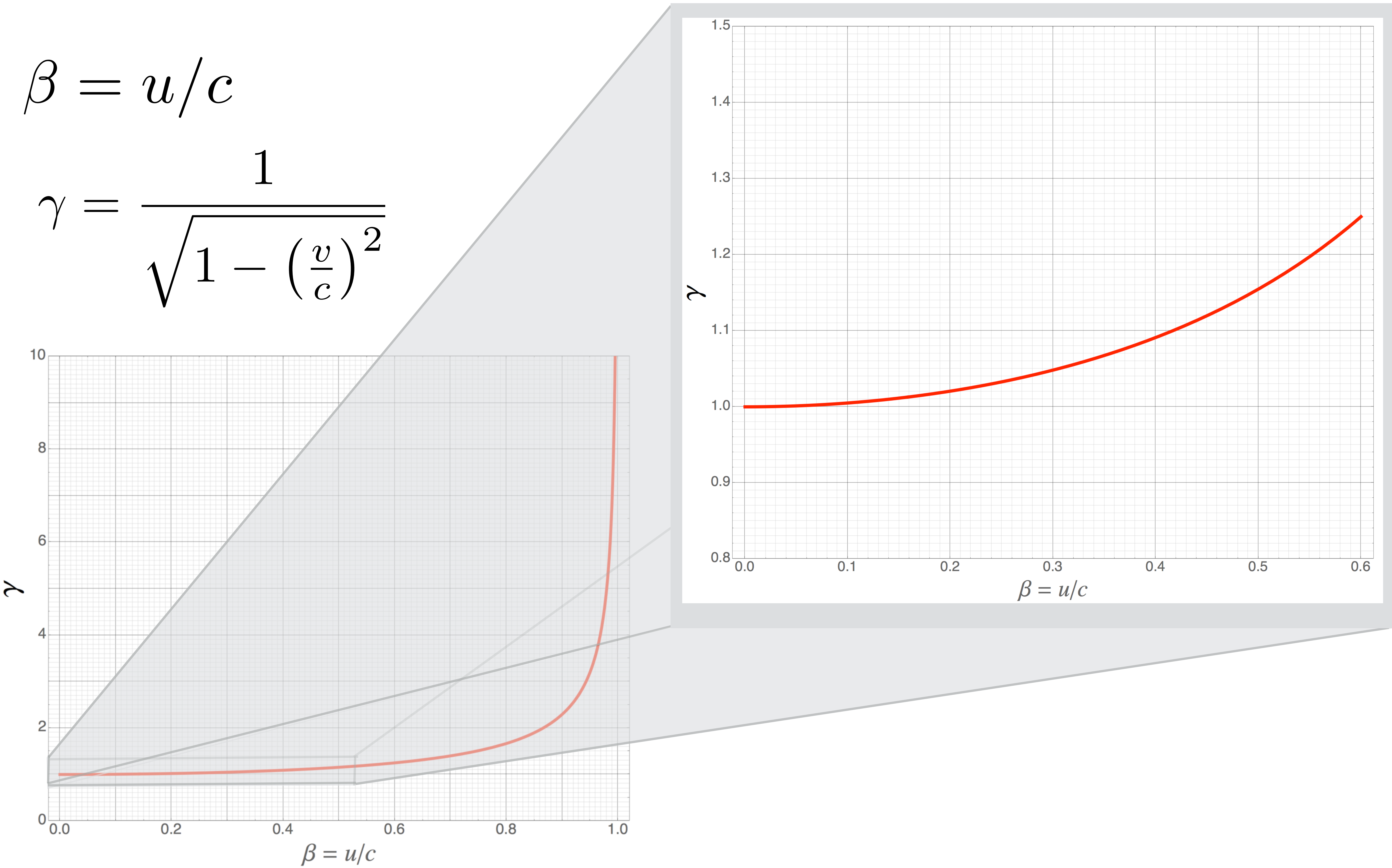
$$\beta = u/c$$



‘‘relativistic gamma’’

$$\beta = u/c$$

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



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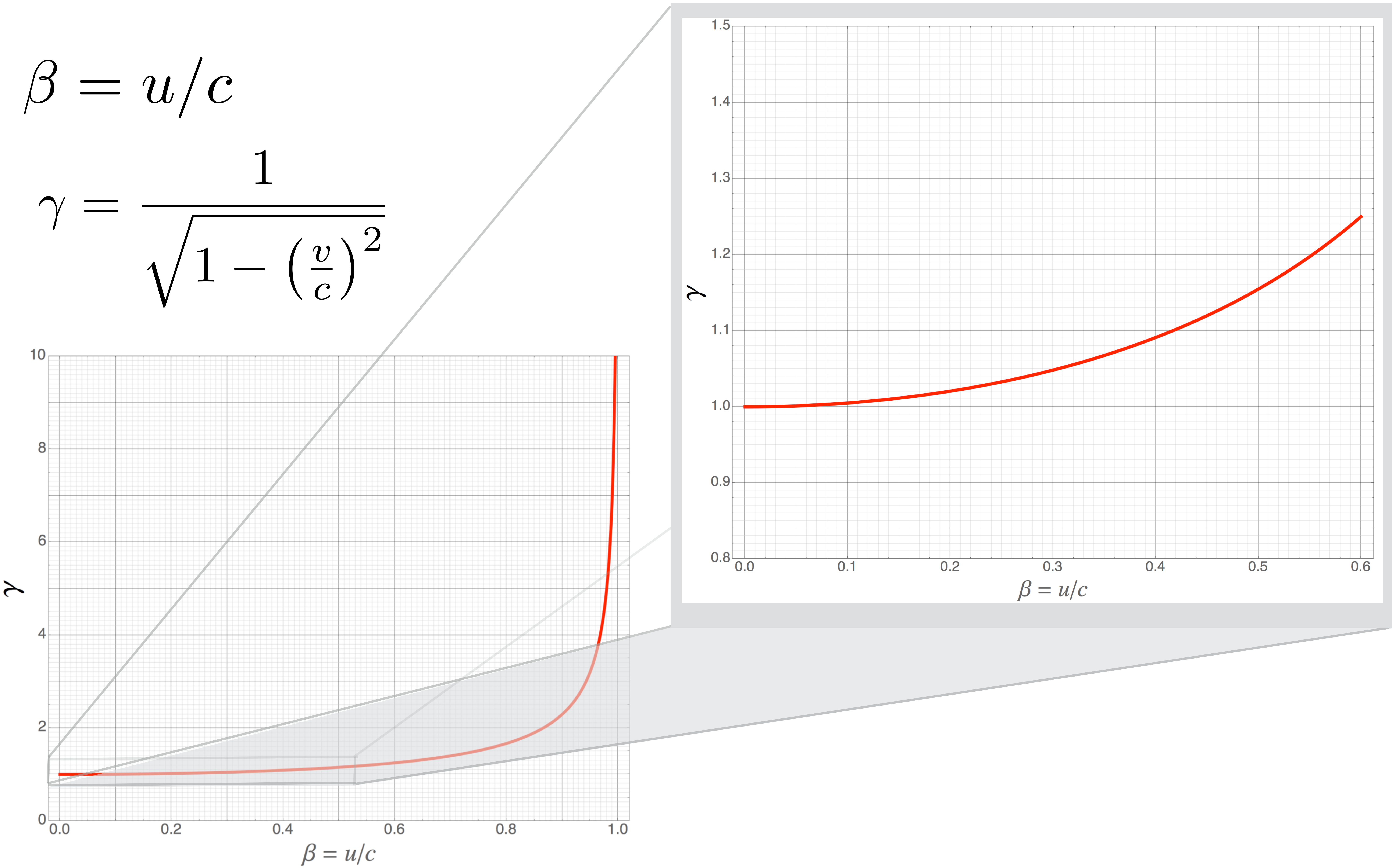
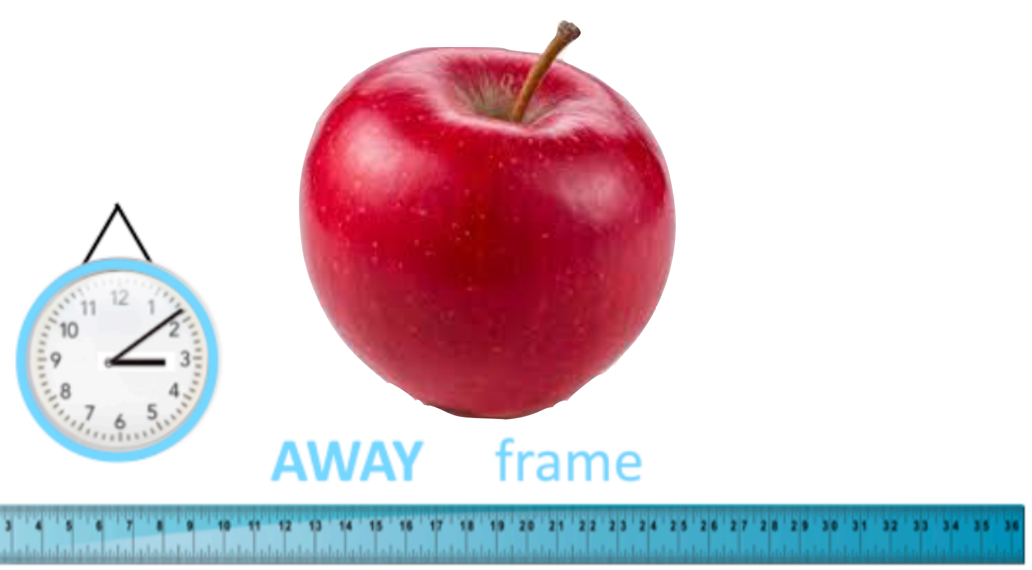
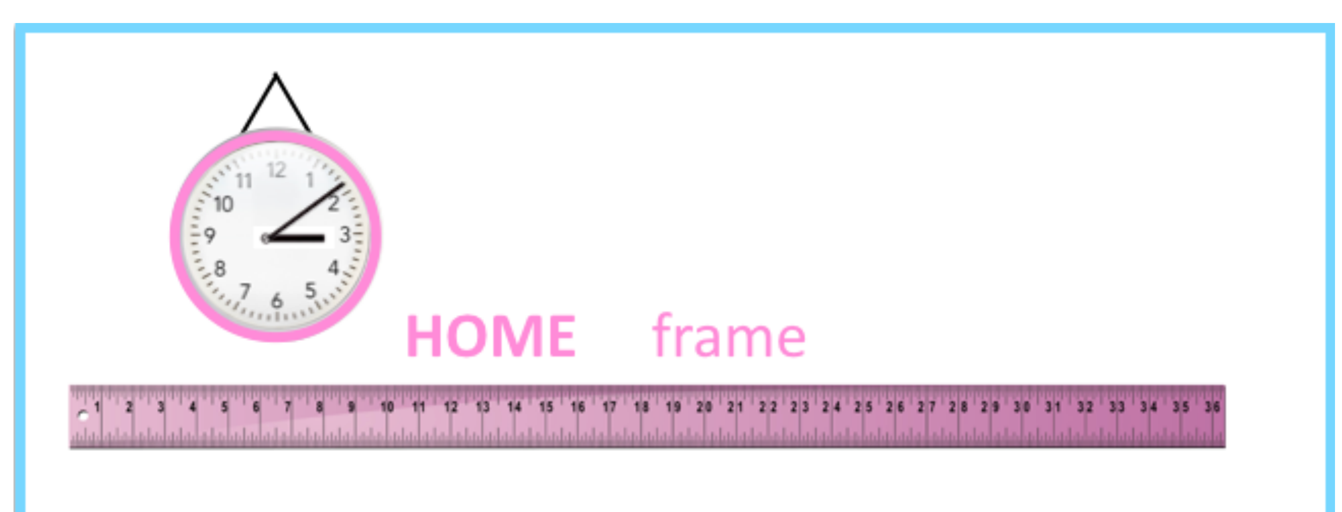


events and intervals

events happen once at 1 space and 1 time location

intervals happen once at 2 space and/or 2 time locations





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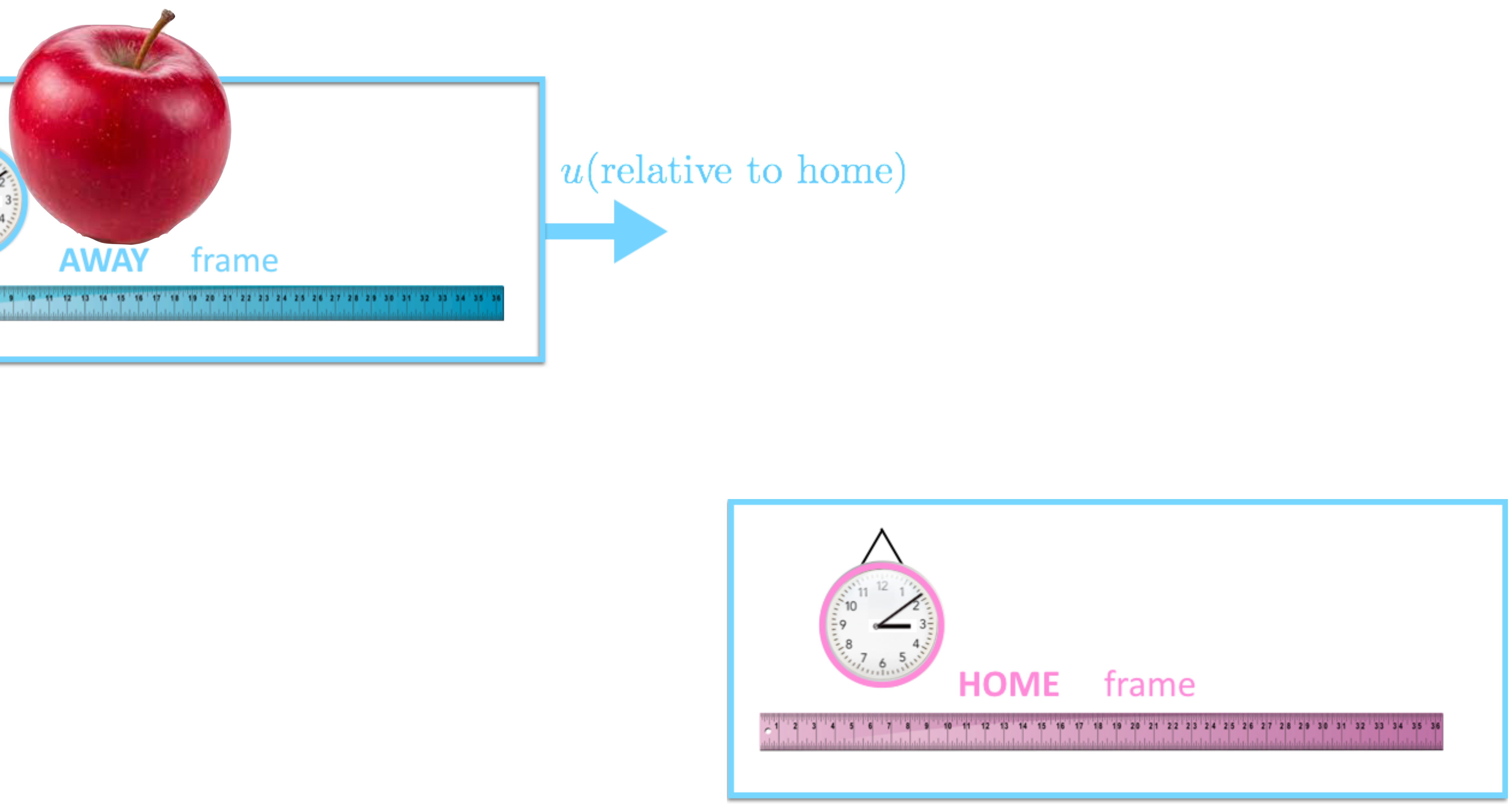

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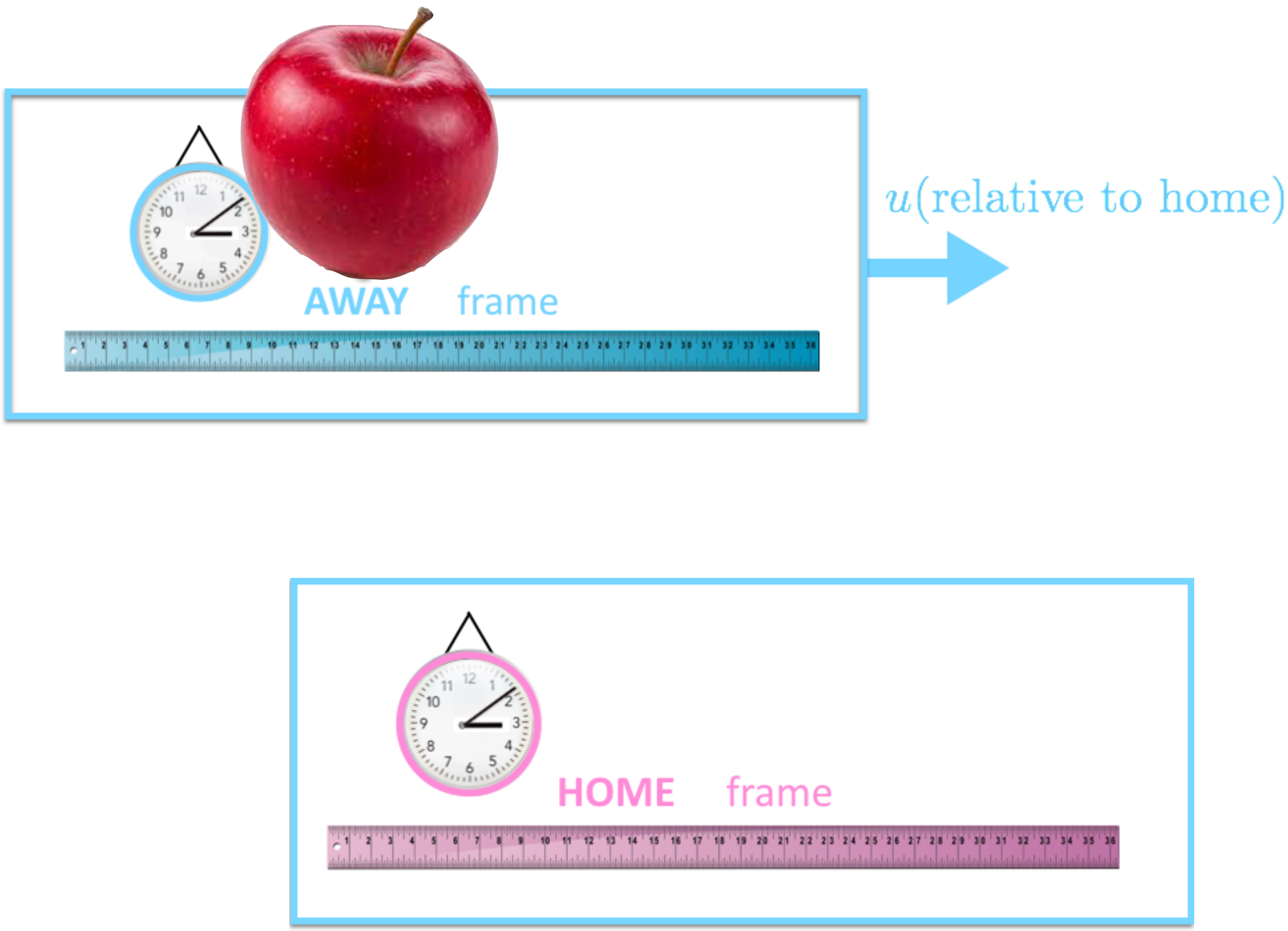

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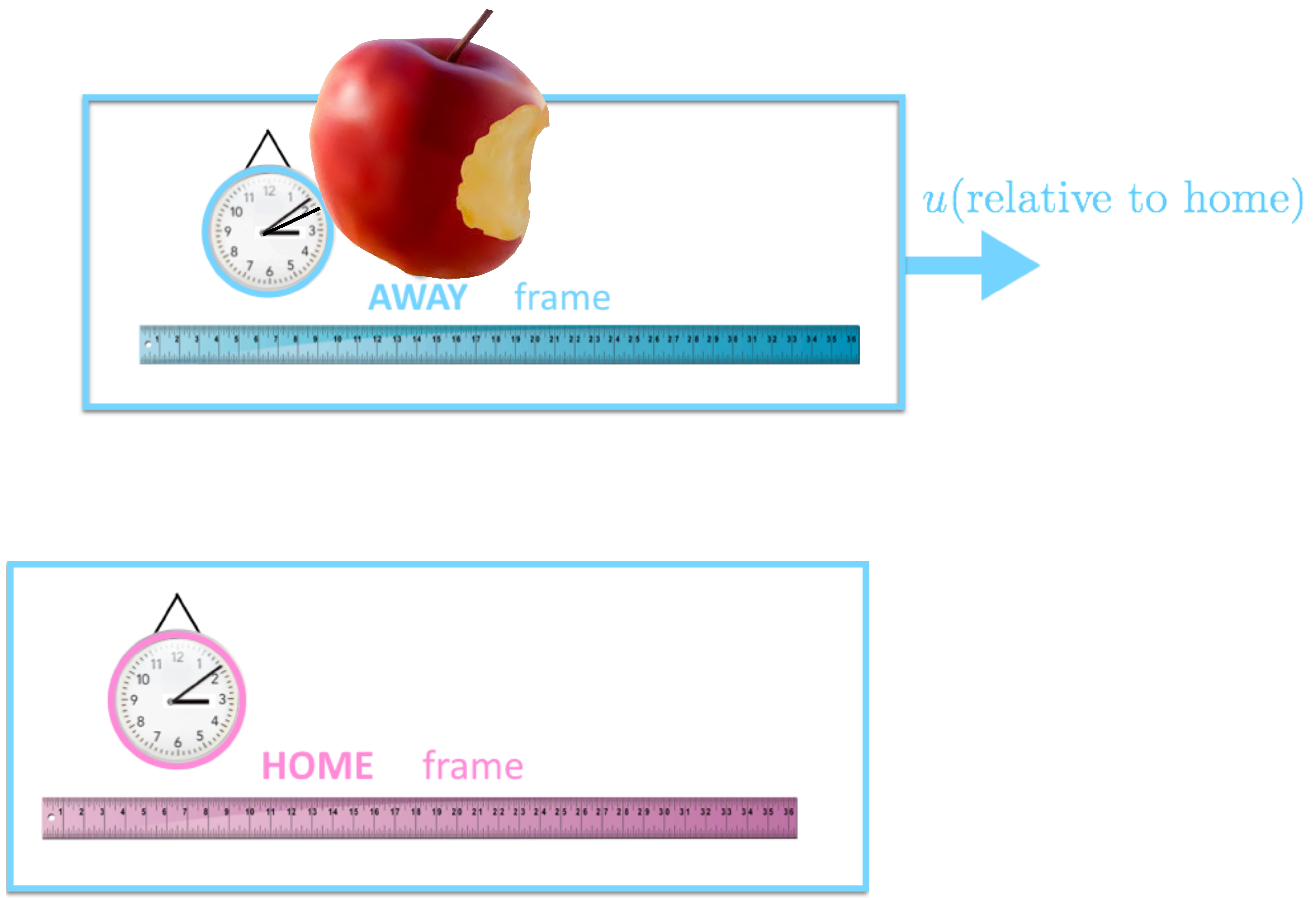

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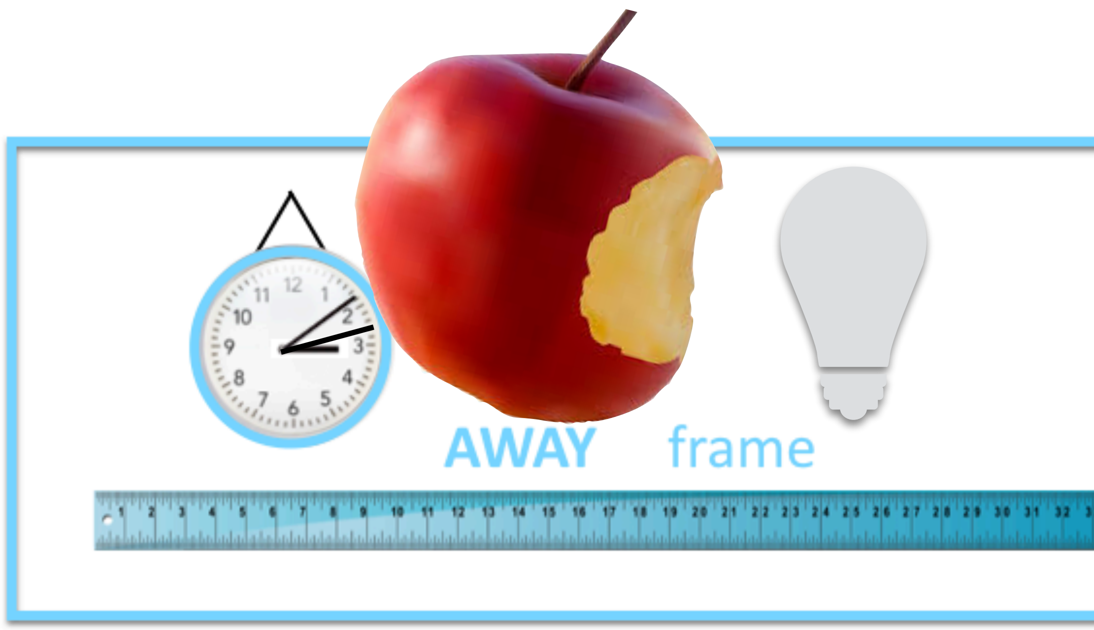
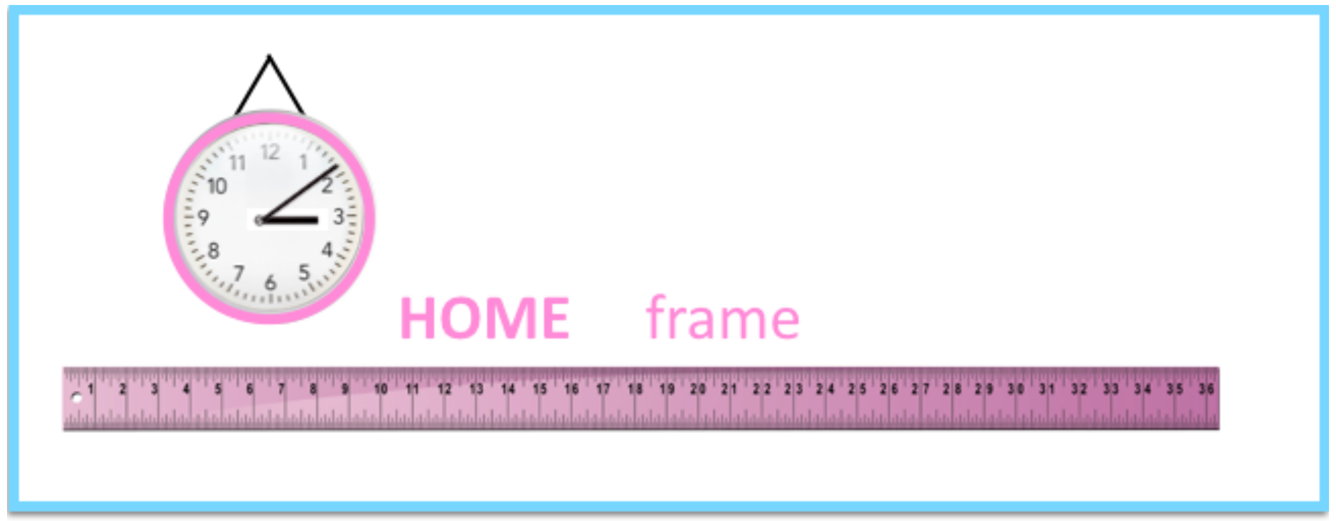
events happen once at 1 space and 1 time location

intervals happen once at 2 space and/or 2 time locations



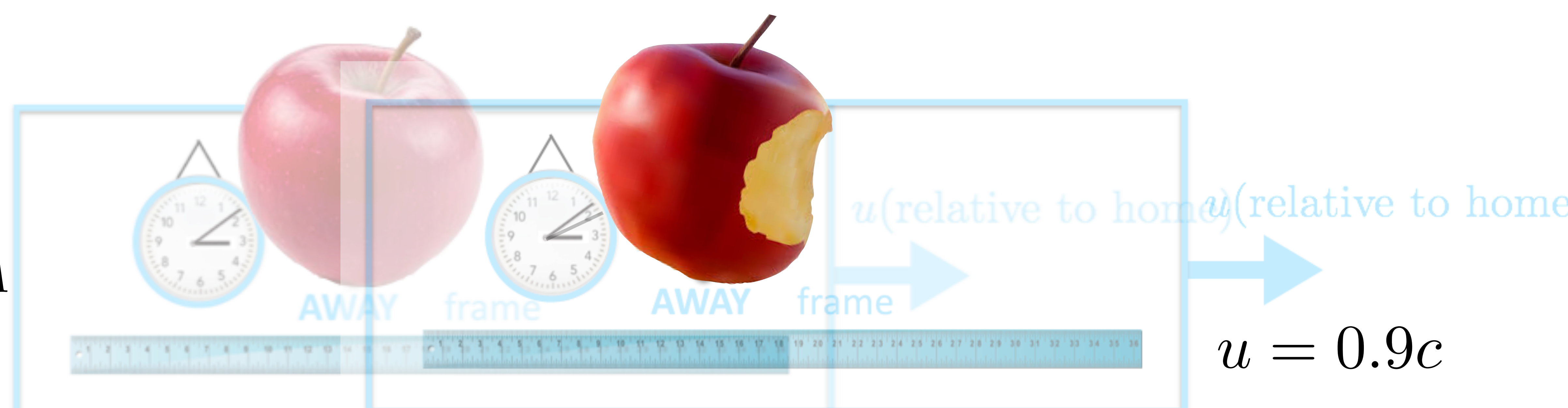


events and intervals

events happen once at 1 space and 1 time location

intervals happen once at 2 space and/or 2 time locations

$$\Delta t(\text{in Away}) \equiv t_A$$



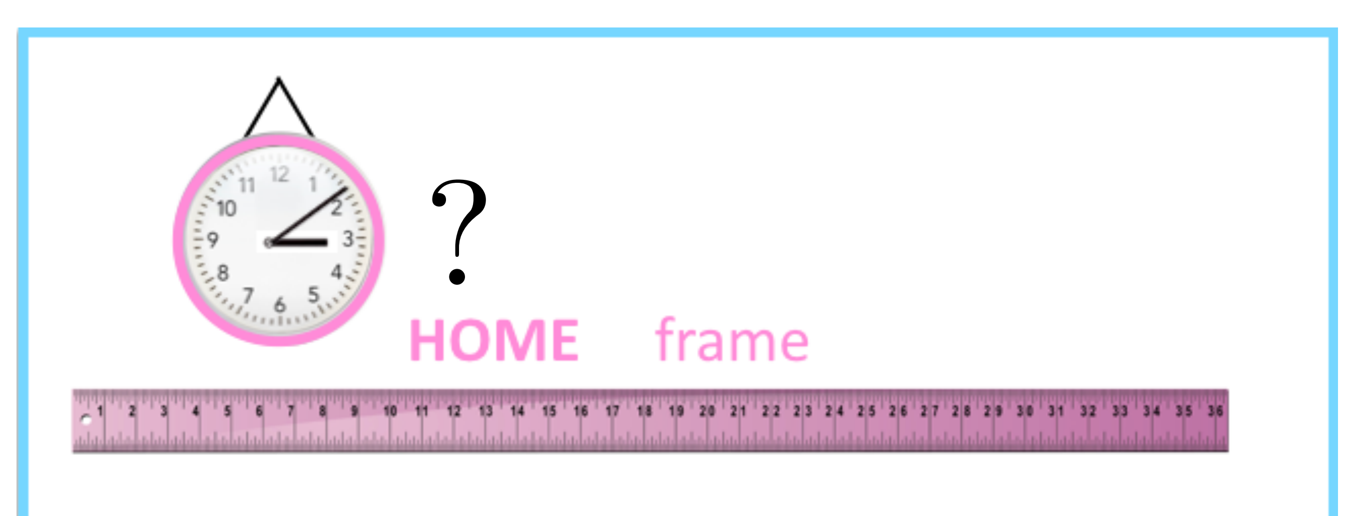
$$u = 0.9c$$

$$t_A = 1 \text{ second}$$

$$t_H = ?$$

$$t_H = \gamma t_A$$

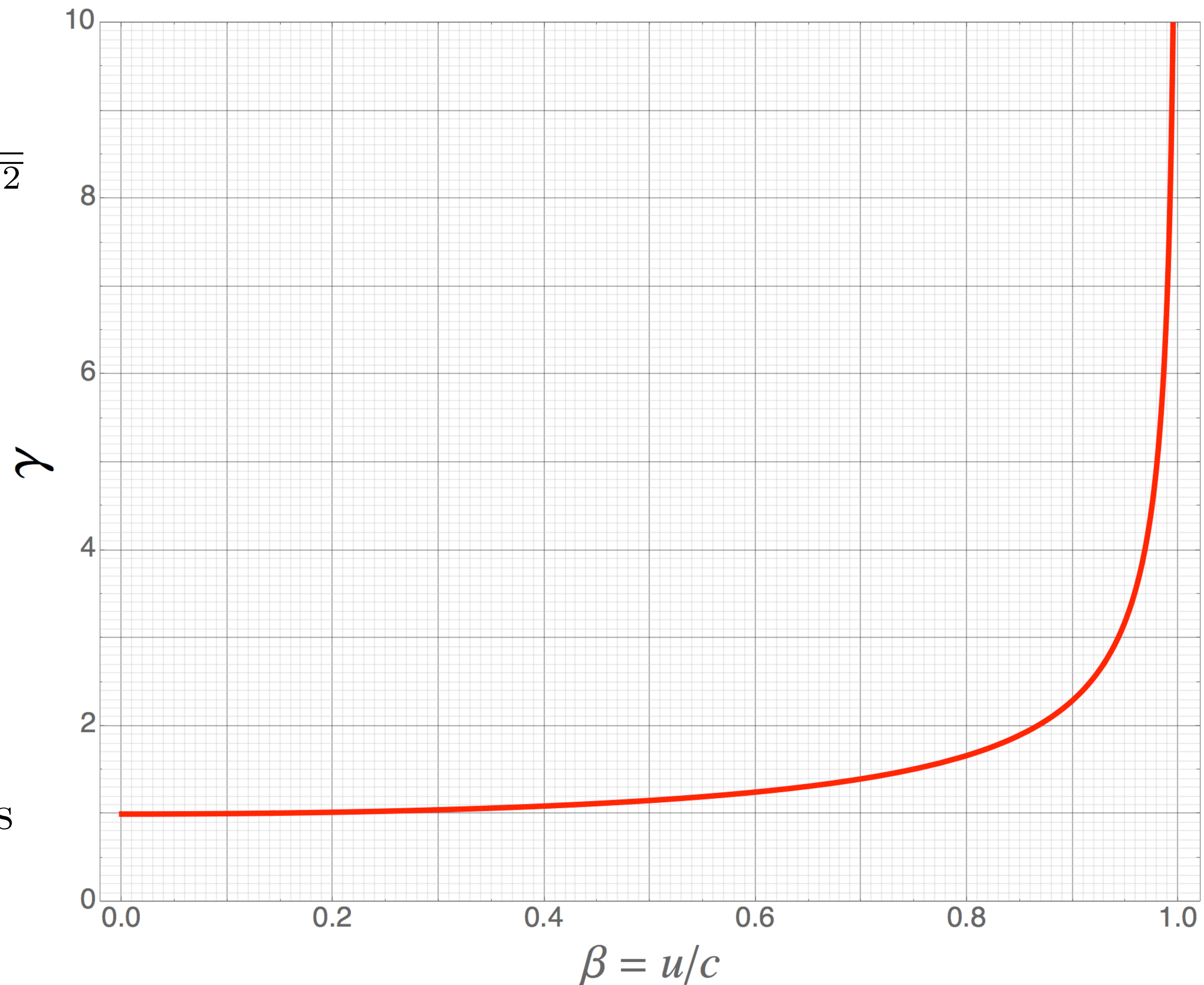
$$\Delta t(\text{as seen by Home}) \equiv t_H$$



relativistic gamma

$$\gamma = \frac{1}{\sqrt{1 - (\frac{u}{c})^2}}$$

$$\beta = u/c$$



$$u = 0.9c$$

$$t_A = 1 \text{ second}$$

$$t_H = 2.3 \text{ seconds}$$

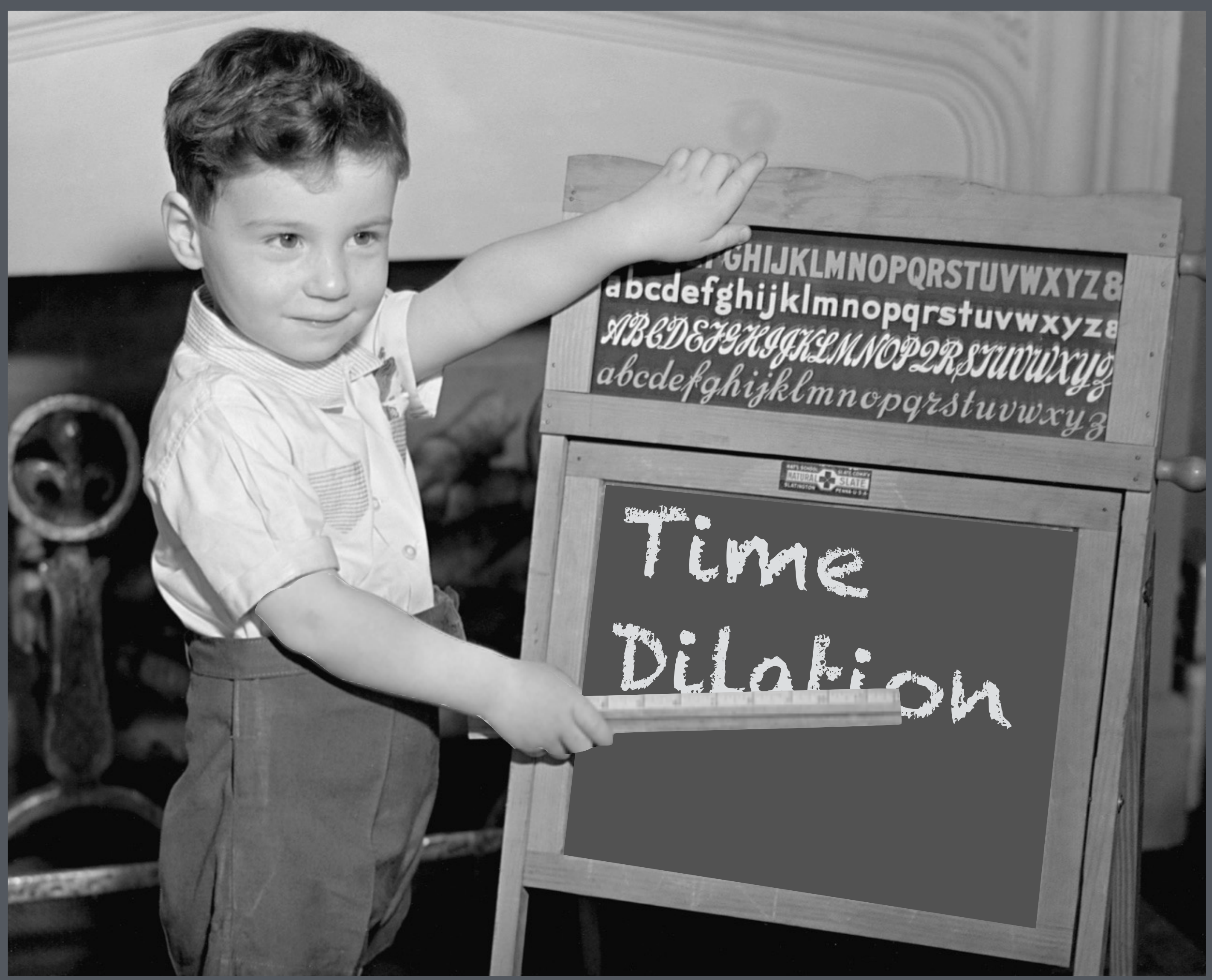
1 second is slower than 2.3 seconds

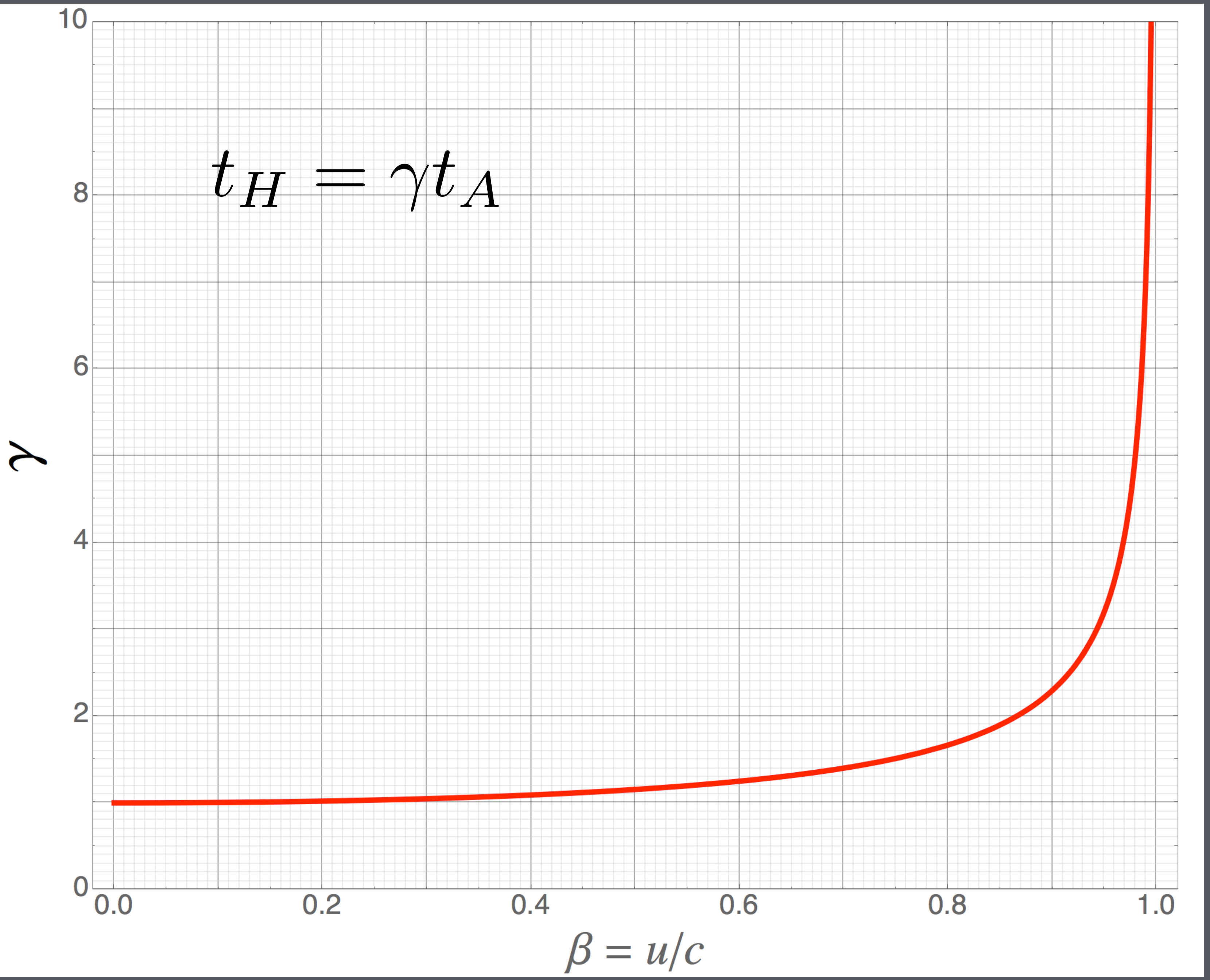
You have a clock and I have a clock and they are identical. I observe yours is in an inertial frame of reference moving past my frame of reference.

I also observe that 1 hour on your clock seems to take 2 hours on my clock.

Yours appears to be slower or faster than mine?

How fast is your frame moving relative to mine?





this works for any clocks

actual clocks

atomic transitions

elementary particle lifetimes

biological clocks

remember what's constant...

The speed of light, c. ...a speed.

$$c = \frac{\text{distance interval}}{\text{time interval}}$$

If clocks are messed with Δt depends on the frame...

and the velocity of light is constant,...

Doesn't it stand to reason that lengths are also messed with...

ΔL depends on the frame...?

...shorter as viewed from the home frame:

$$L_H = \frac{L_A}{\gamma}$$

a length in the away frame will seem...

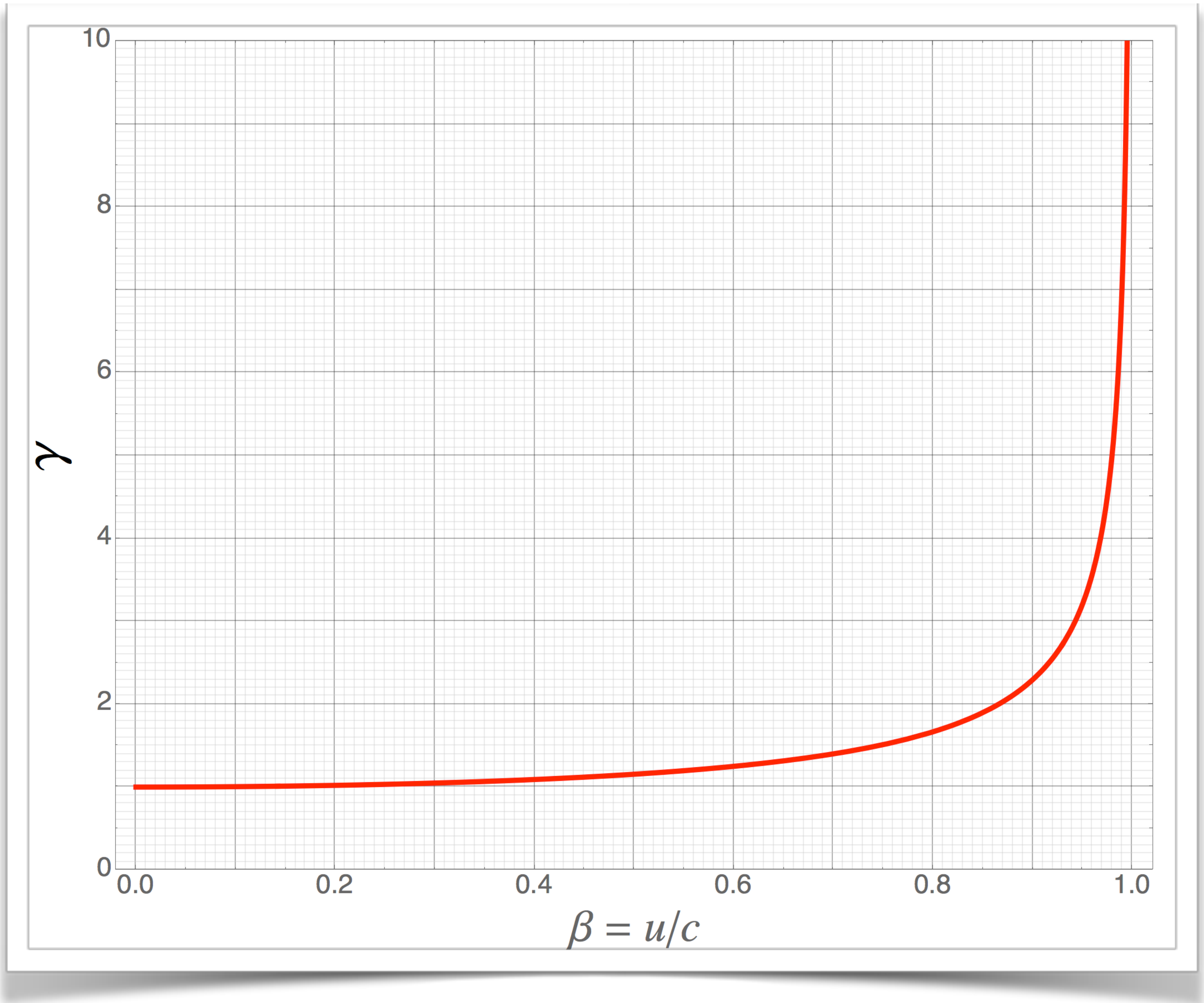
> 1

Moving lengths appear shorter to a relatively stationary observer

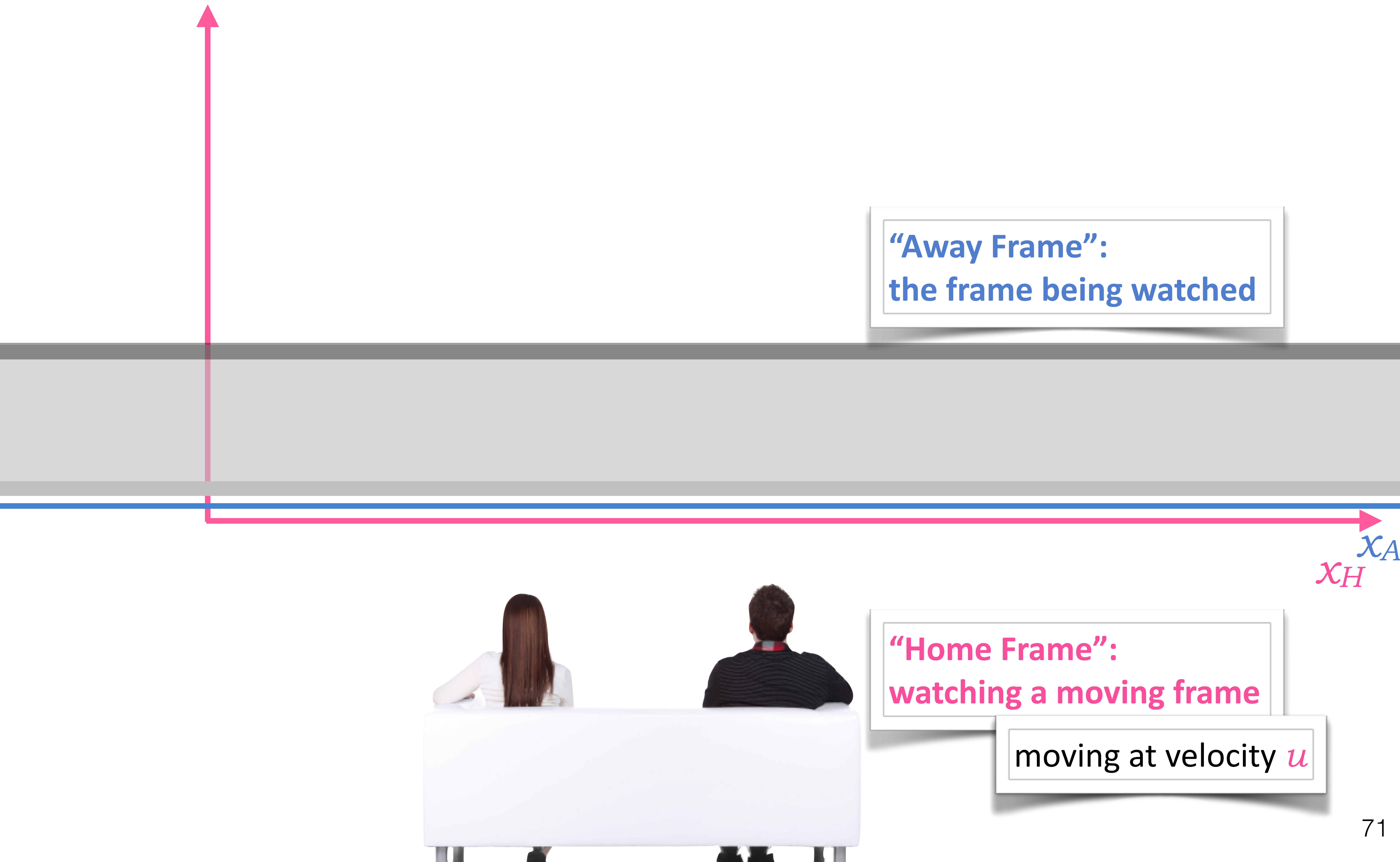
$$L_H = \frac{L_A}{\gamma}$$

length contraction

the third of 3 strange things about space and time



the airport

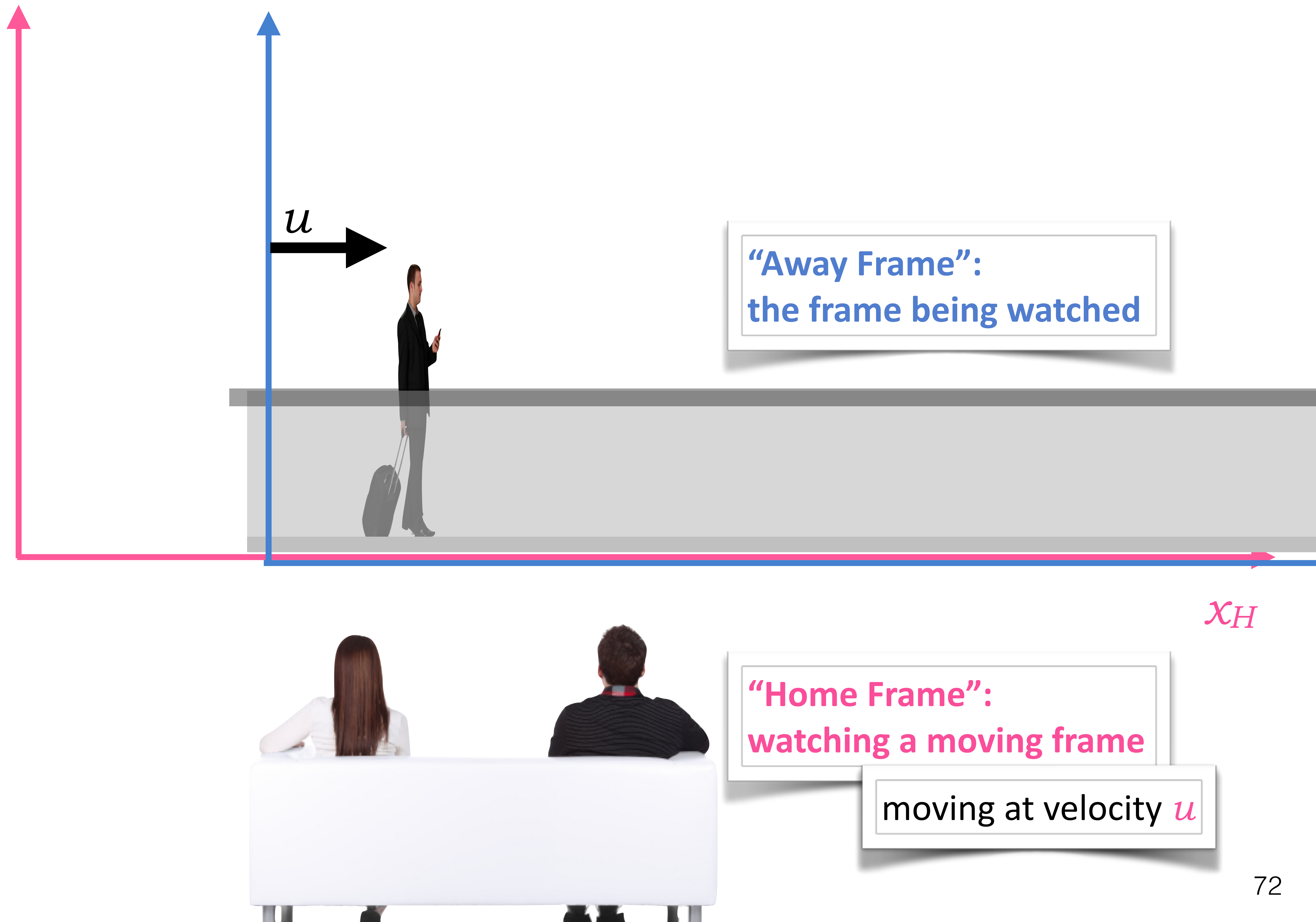


"Away Frame":
the frame being watched

"Home Frame":
watching a moving frame

moving at velocity u

the airport

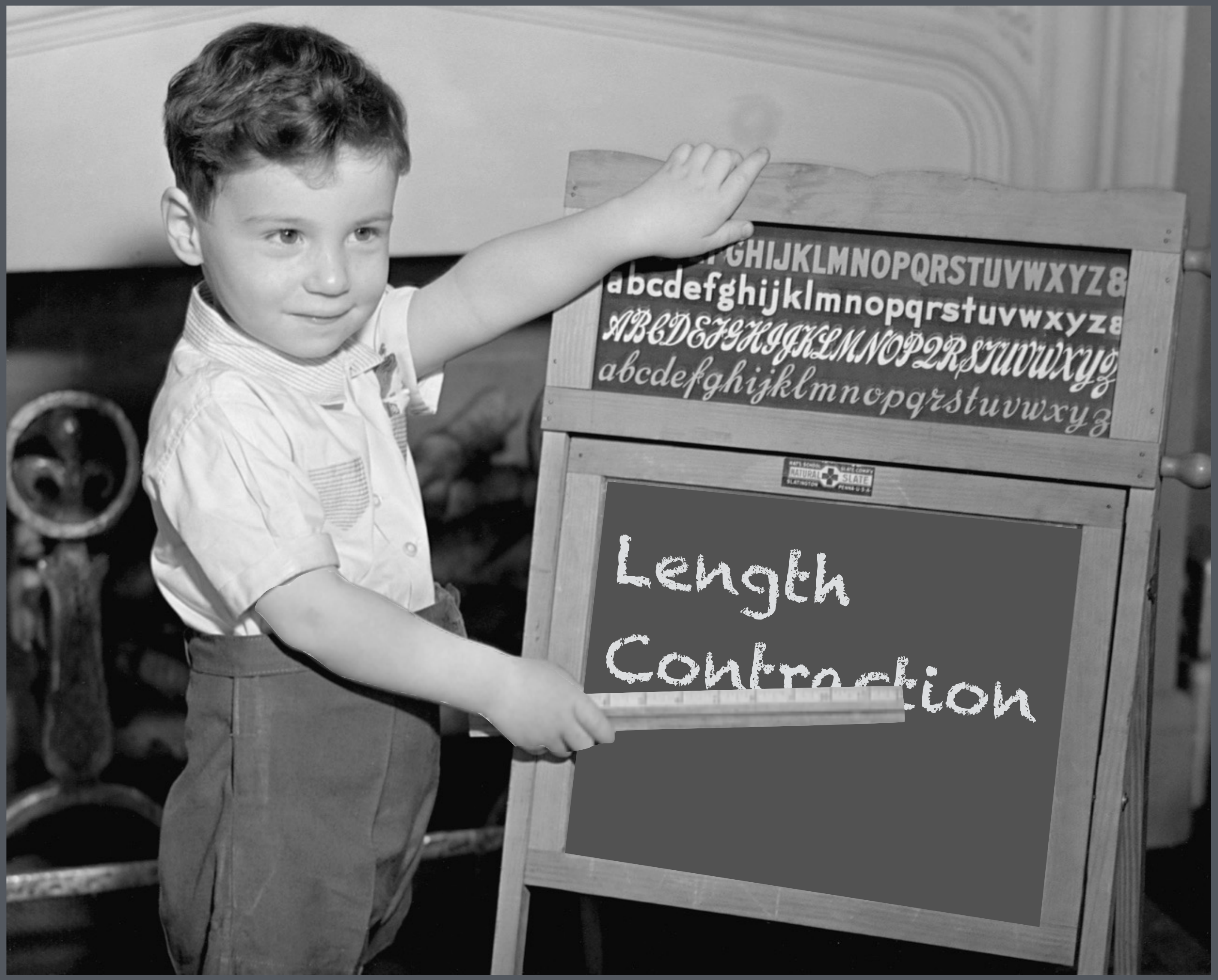


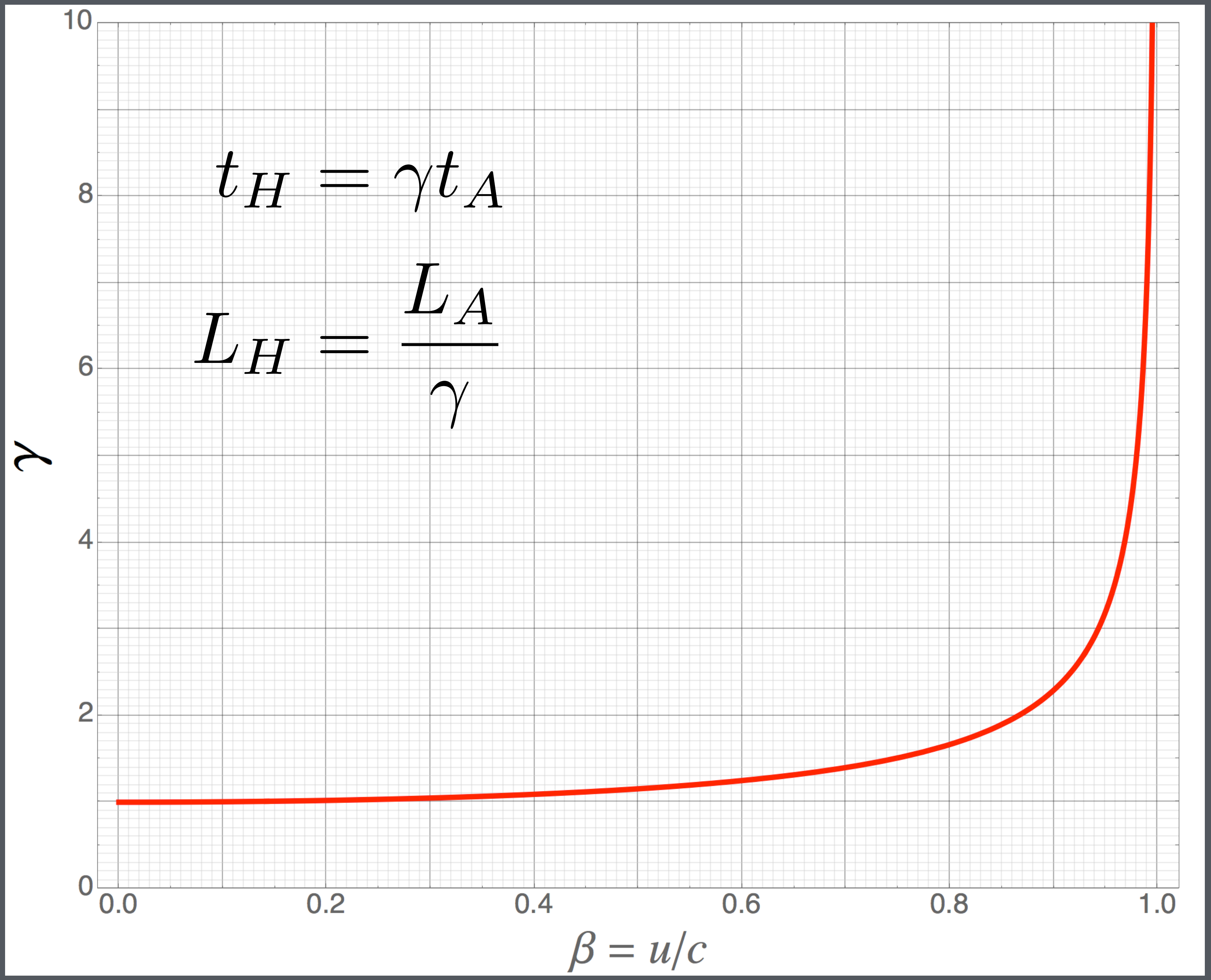
u
"Away Frame":
the frame being watched
x_H
"Home Frame":
watching a moving frame
moving at velocity u

what's he see?

what's he see?

How fast must a meter stick be traveling relative to you in order for its length to appear to be 25 cm as measured by you?





collecting these two consequences

of the two simple postulates

"Time Dilation":

$$t_H = \gamma t_A$$

Moving clocks appear to run slower as seen by a relatively stationary observer

"Length Contraction":

$$L_H = \frac{L_A}{\gamma}$$

Moving lengths appear shorter to a relatively stationary observer

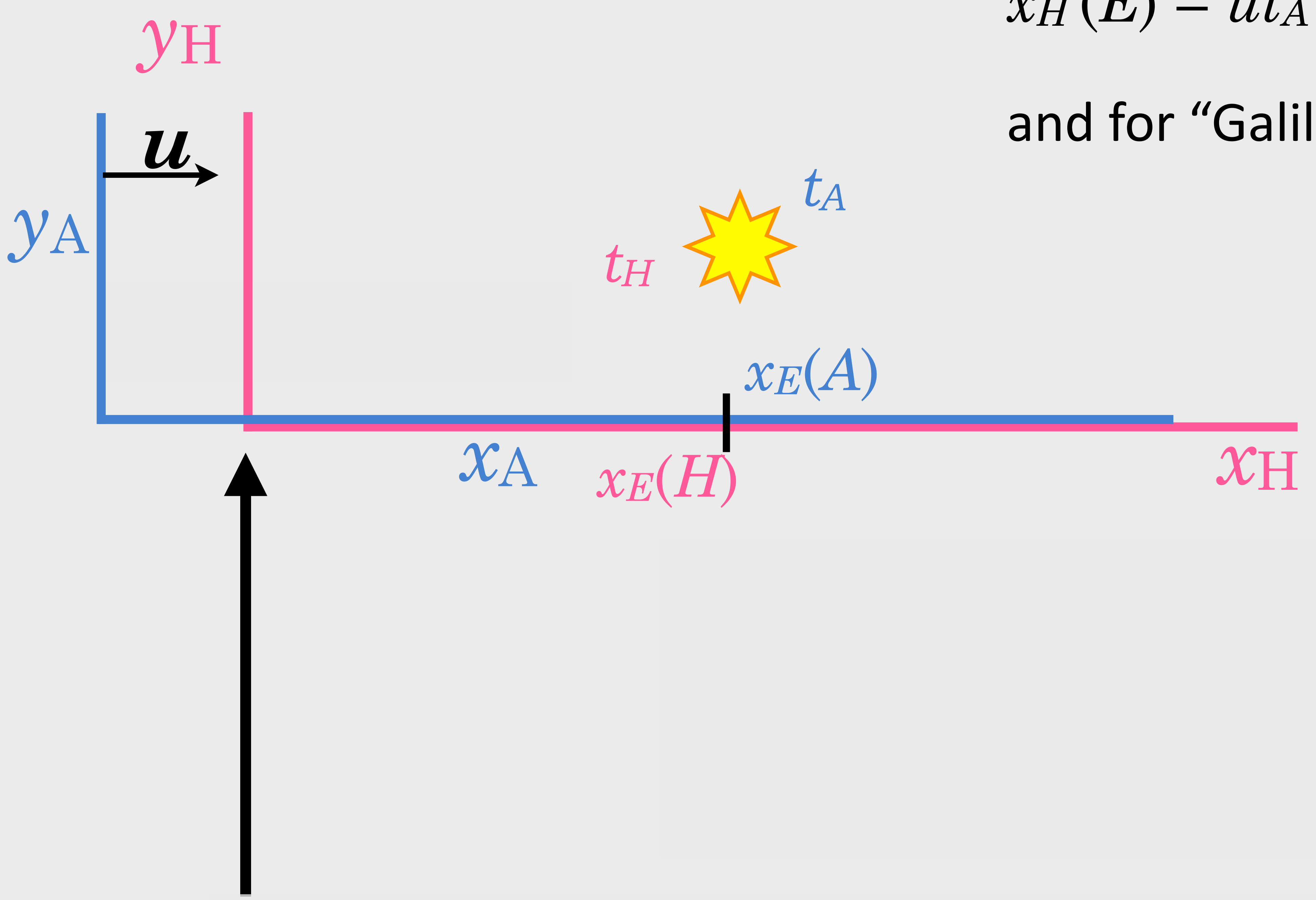
Newton/Galileo?

mixes space coordinates

The Galilean Transformation:

$$x_H(E) = ut_A + x_A(E)$$

and for "Galilean transformations": $t_H = t_A$

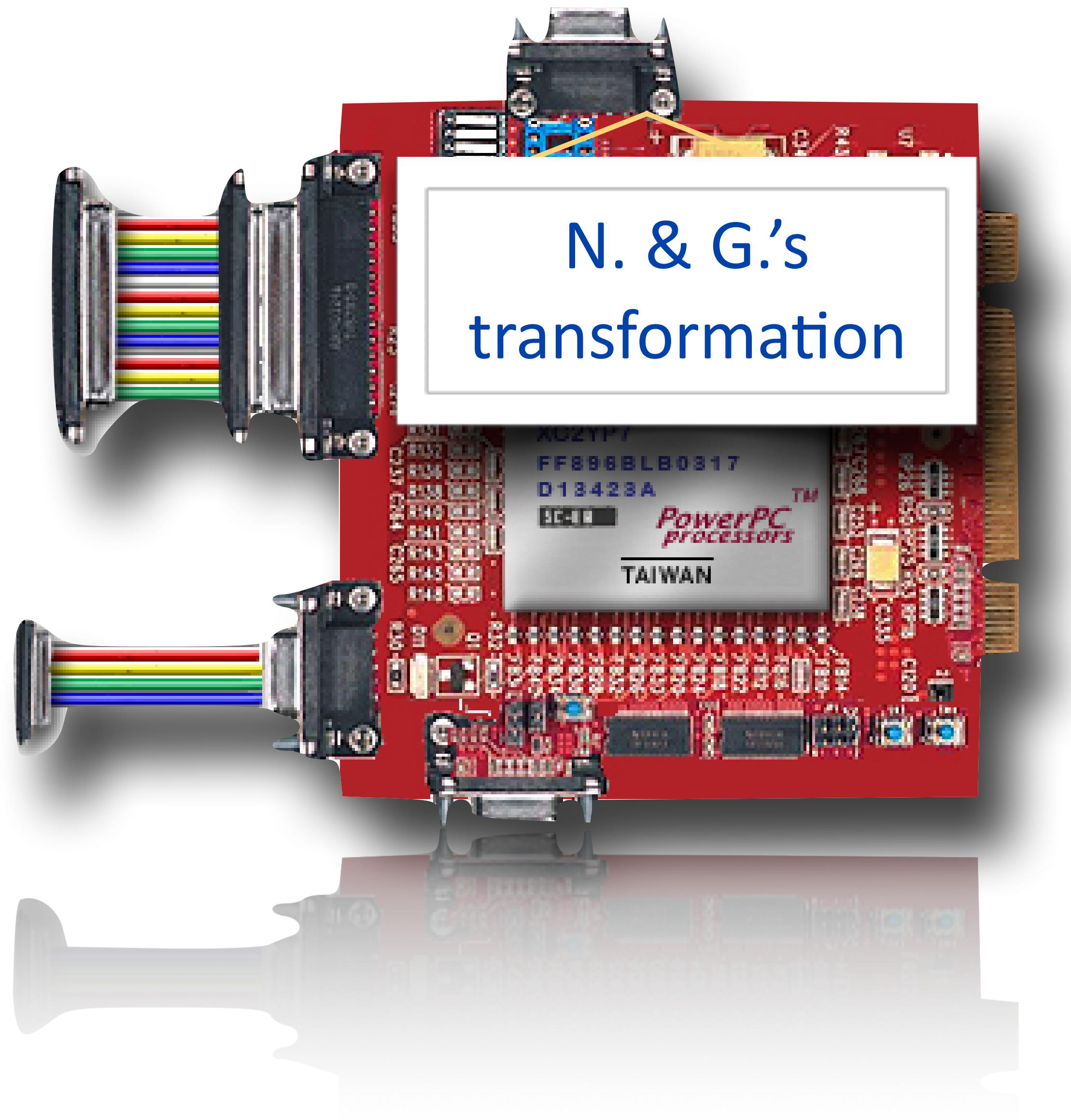


when A's and H's origins cross: start clocks in both.

$t_A(E) = 0$ & $t_H(E) = 0$ when $x_A(E) = 0$ & $x_H(E) = 0$.

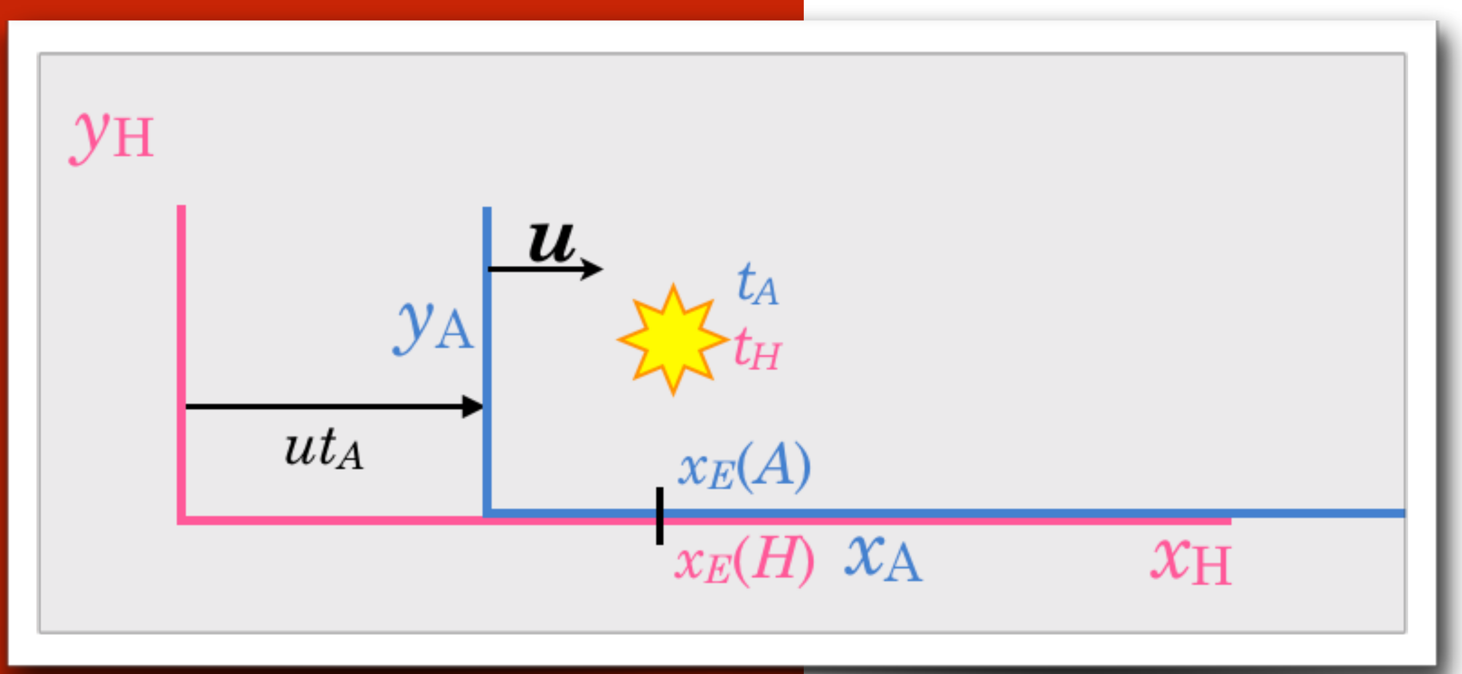
Newton/ Galileo?

x_A, t_A



Galilean Transformations

mixes space coordinates

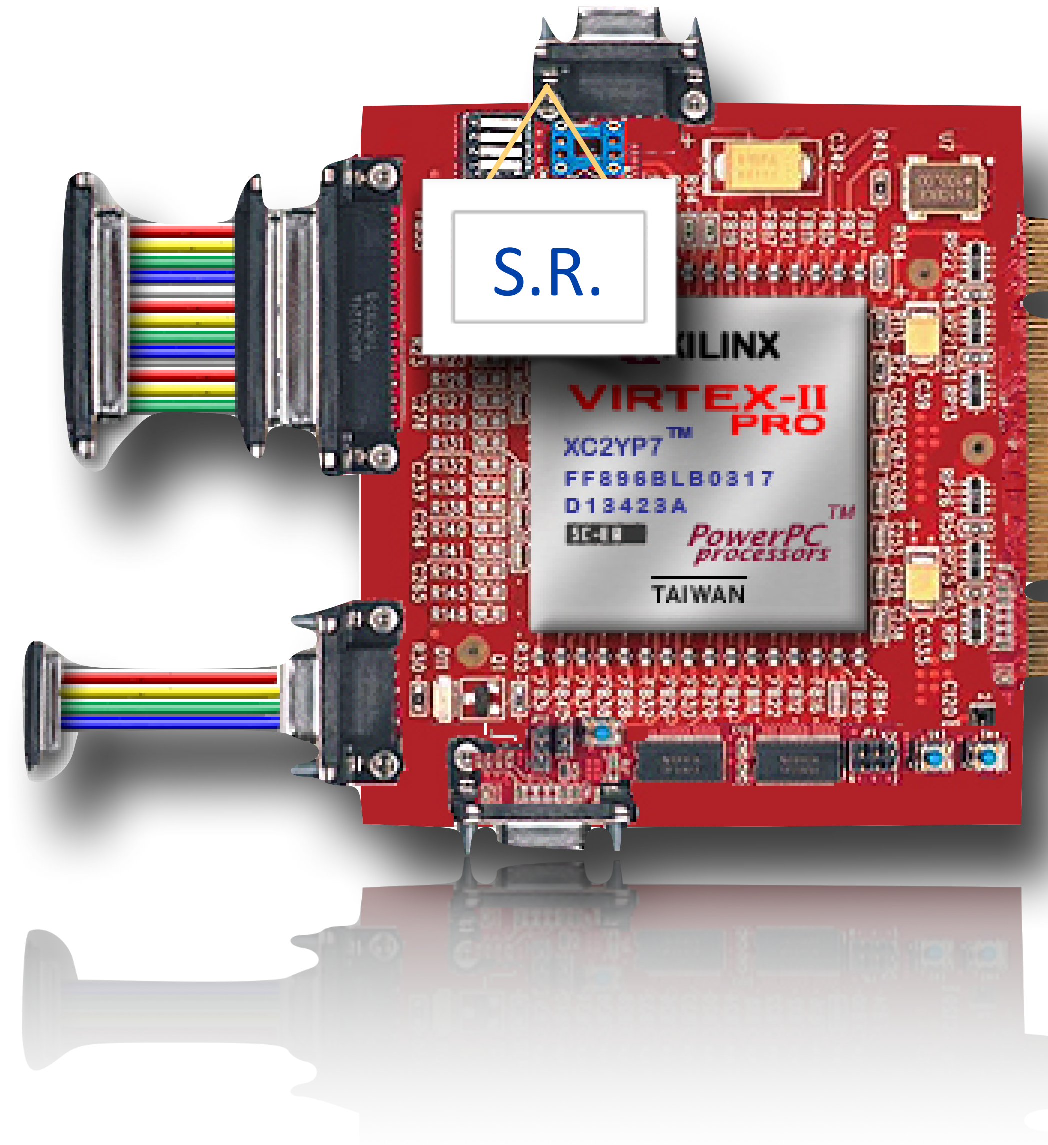


$$x_H = x_A + ut$$

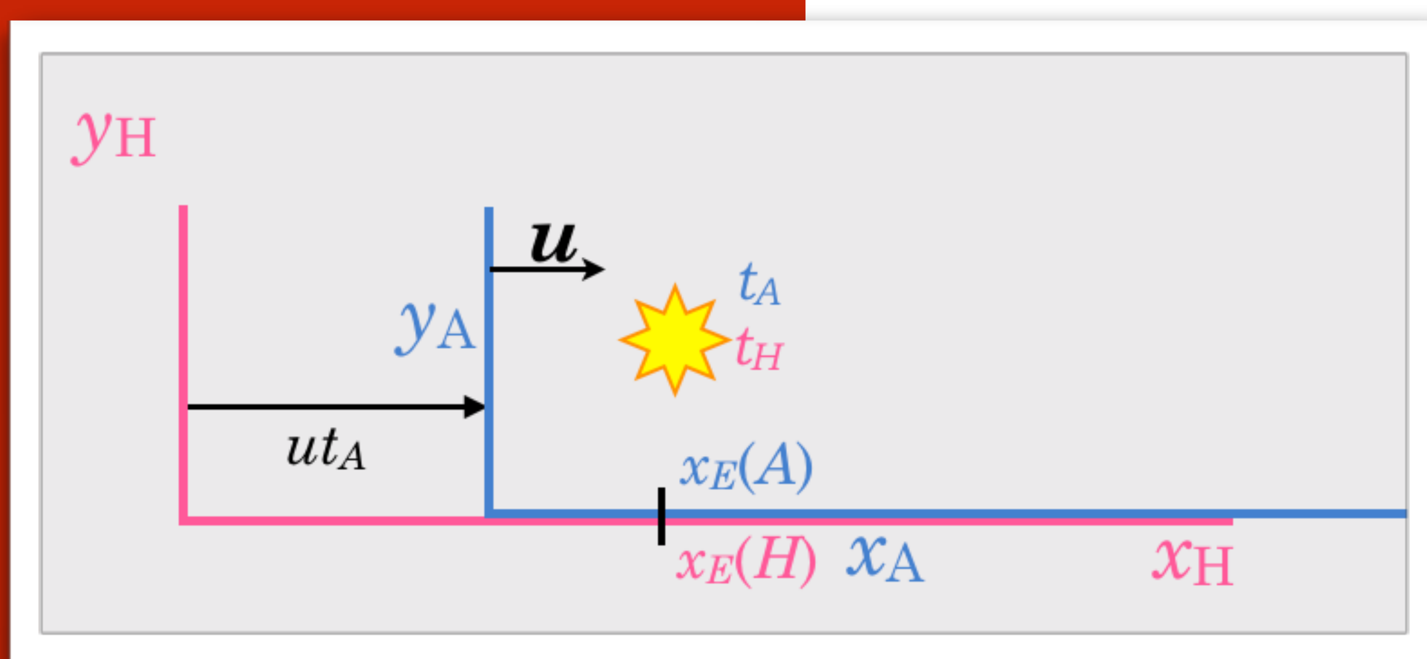
$$t_H = t_A = t$$

Einstein?

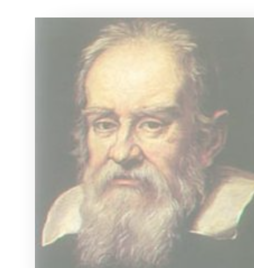
x_A, t_A



mixes space and time coordinates



The prescription is called the **Lorentz Transformations**



$$x_H = \gamma(x_A + ut_A) \qquad x_H = x_A + ut$$

$$t_H = \gamma(t_A + \frac{u}{c^2}x_A) \qquad t_H = t_A = t$$

$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{u}{c}\right)^2}}$$

Let your fingers do this...and show me: 1.

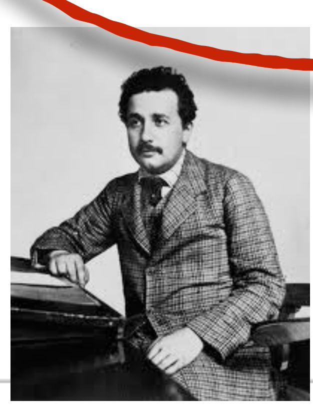
at the top of your board, write the equation for γ

what value does γ approach as $u << c$?

$$x_H = \gamma(x_A + ut_A)$$

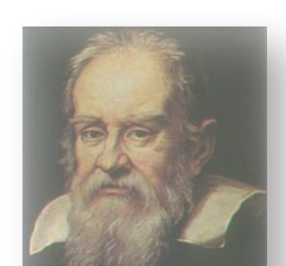
$$t_H = \gamma(t_A + \frac{u}{c^2}x_A)$$

$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{u}{c}\right)^2}}$$



$$x_H = x_A + ut$$

$$t_H = t_A = t$$

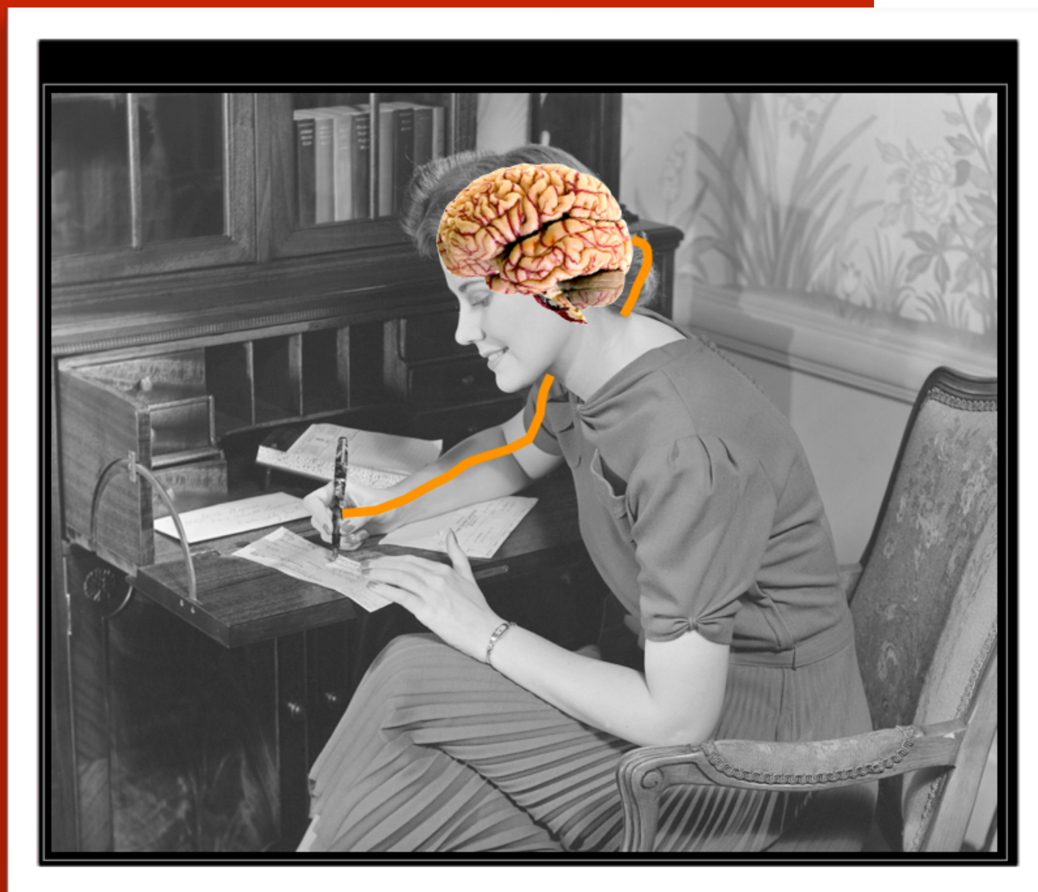


Let your fingers do this...and show me, 2.

NOW write the equation for x_H

what value it look like if $u << c$?

$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{u}{c}\right)^2}}$$



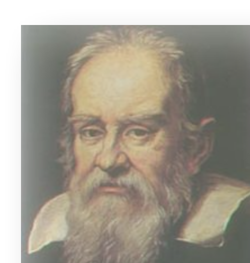
$$x_H = \gamma(x_A + ut_A)$$

$$t_H = \gamma(t_A + \frac{u}{c^2}x_A)$$

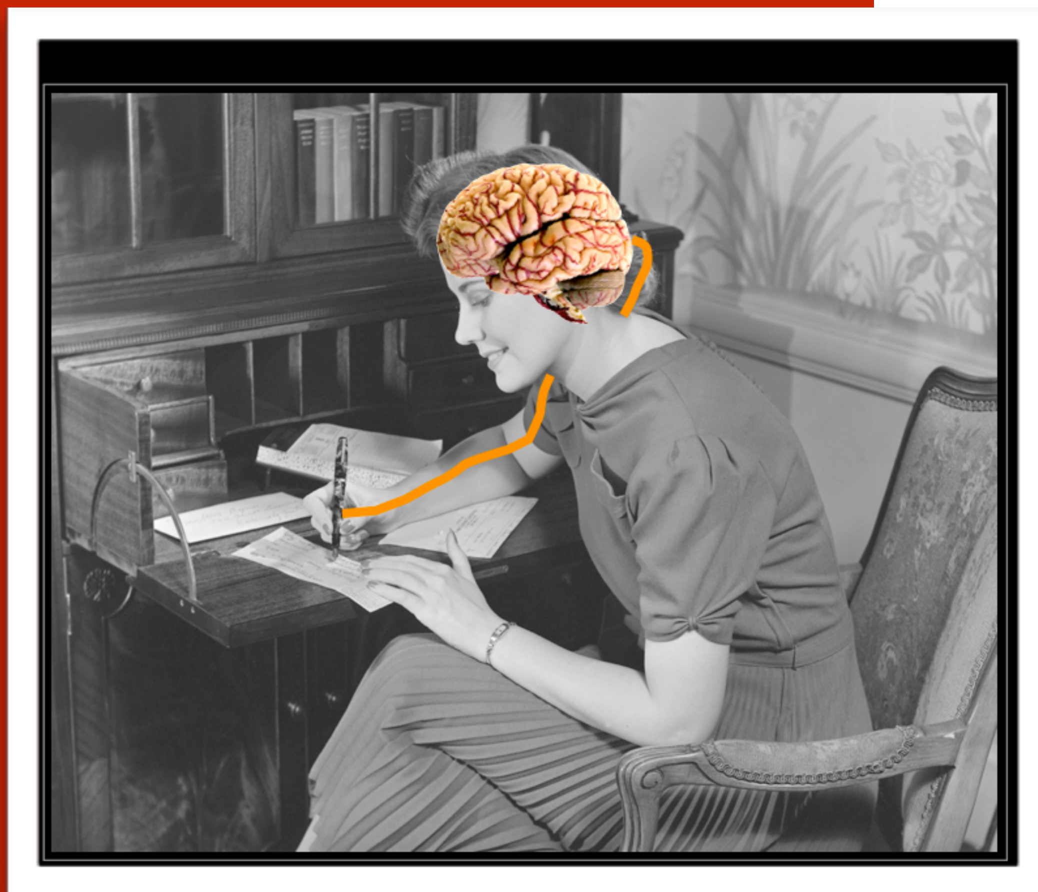
$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{u}{c}\right)^2}}$$

$$x_H = x_A + ut$$

$$t_H = t_A = t$$



Let your fingers do this...and show me, 3.



NOW write the equation for t_H

what value it look like if $u << c$?

$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{u}{c}\right)^2}}$$

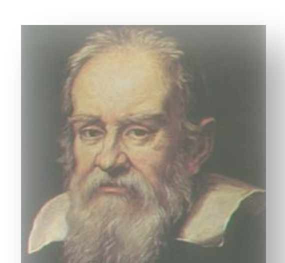
$$x_H = \gamma(x_A + ut_A)$$

$$t_H = \gamma(t_A + \frac{u}{c^2} x_A)$$

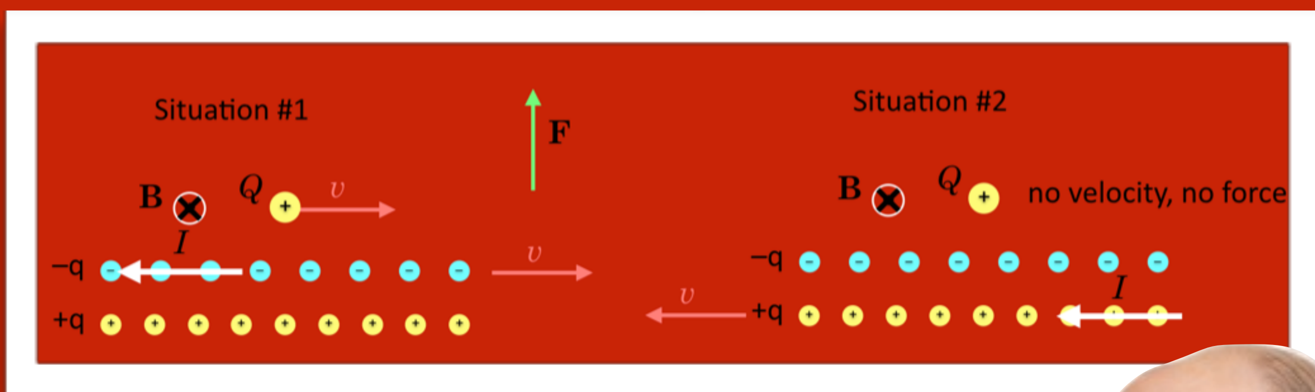
$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{u}{c}\right)^2}}$$

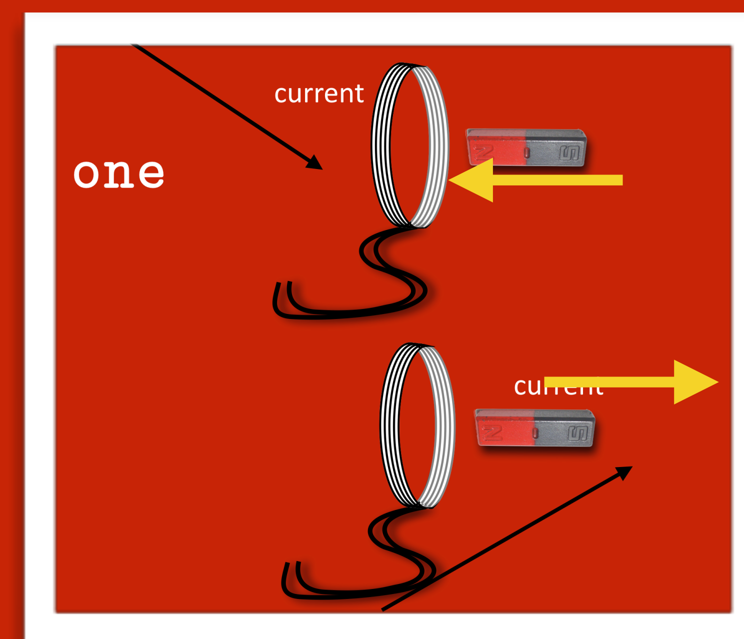
$$x_H = x_A + ut$$

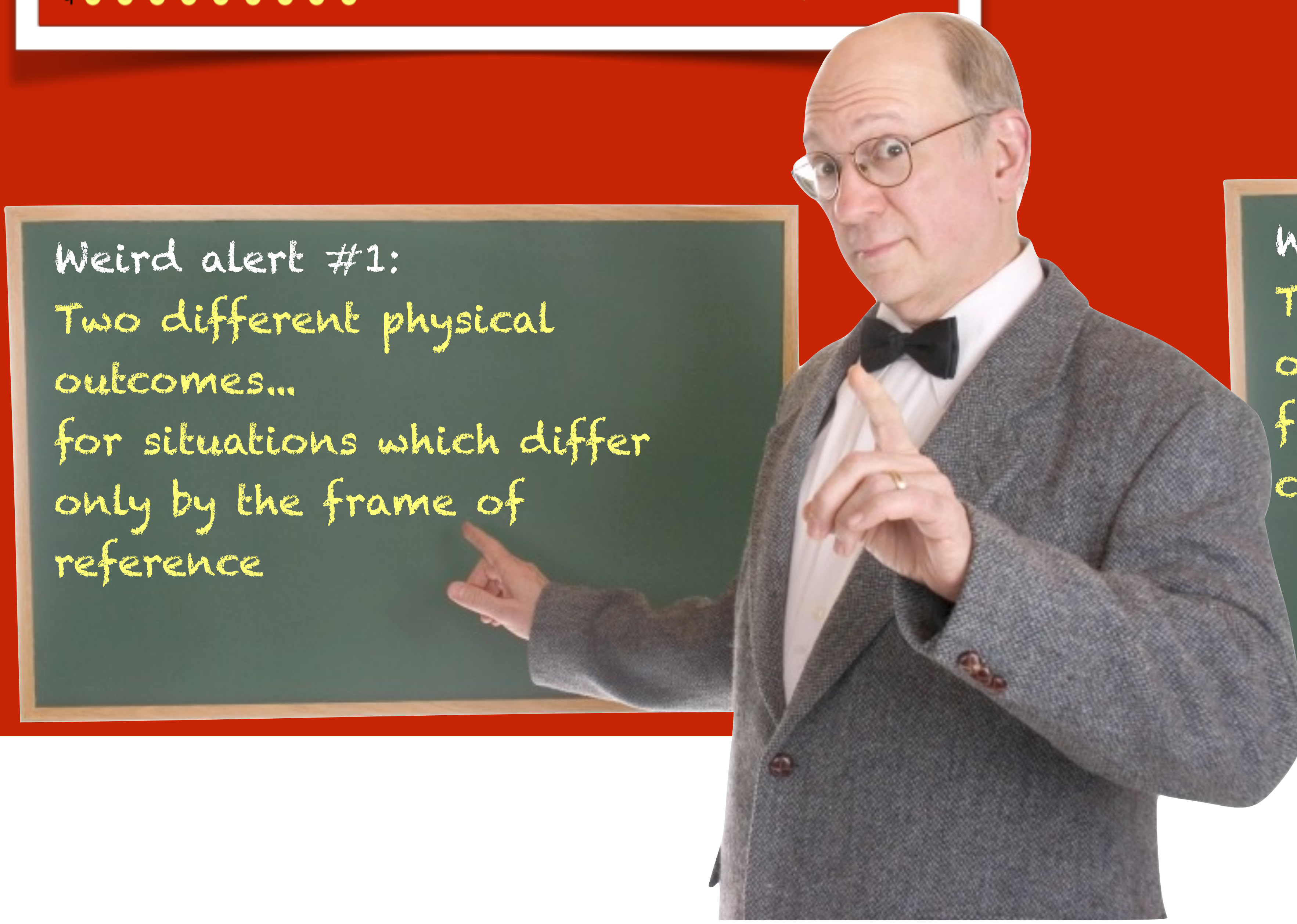
$$t_H = t_A = t$$

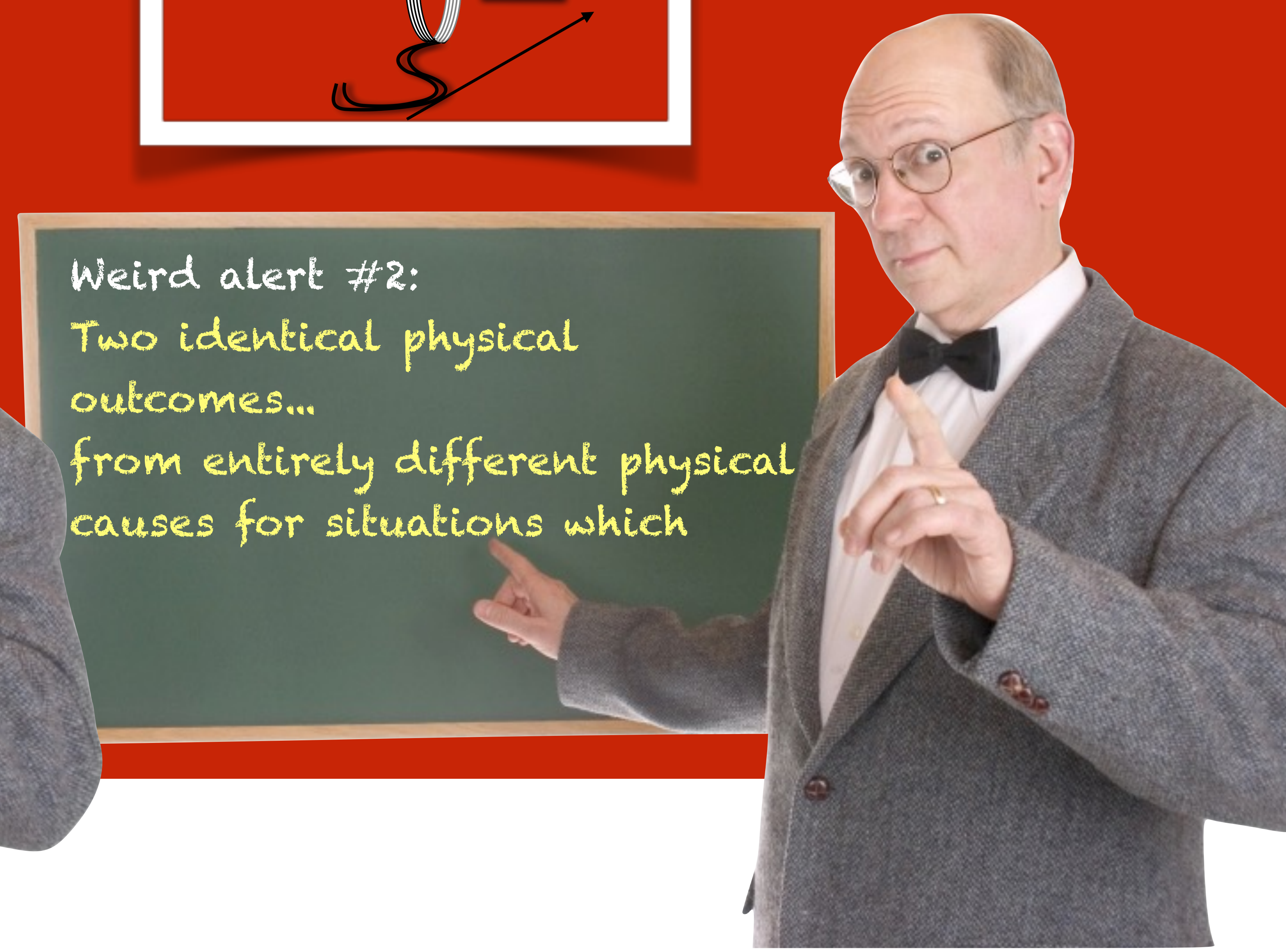


remember?

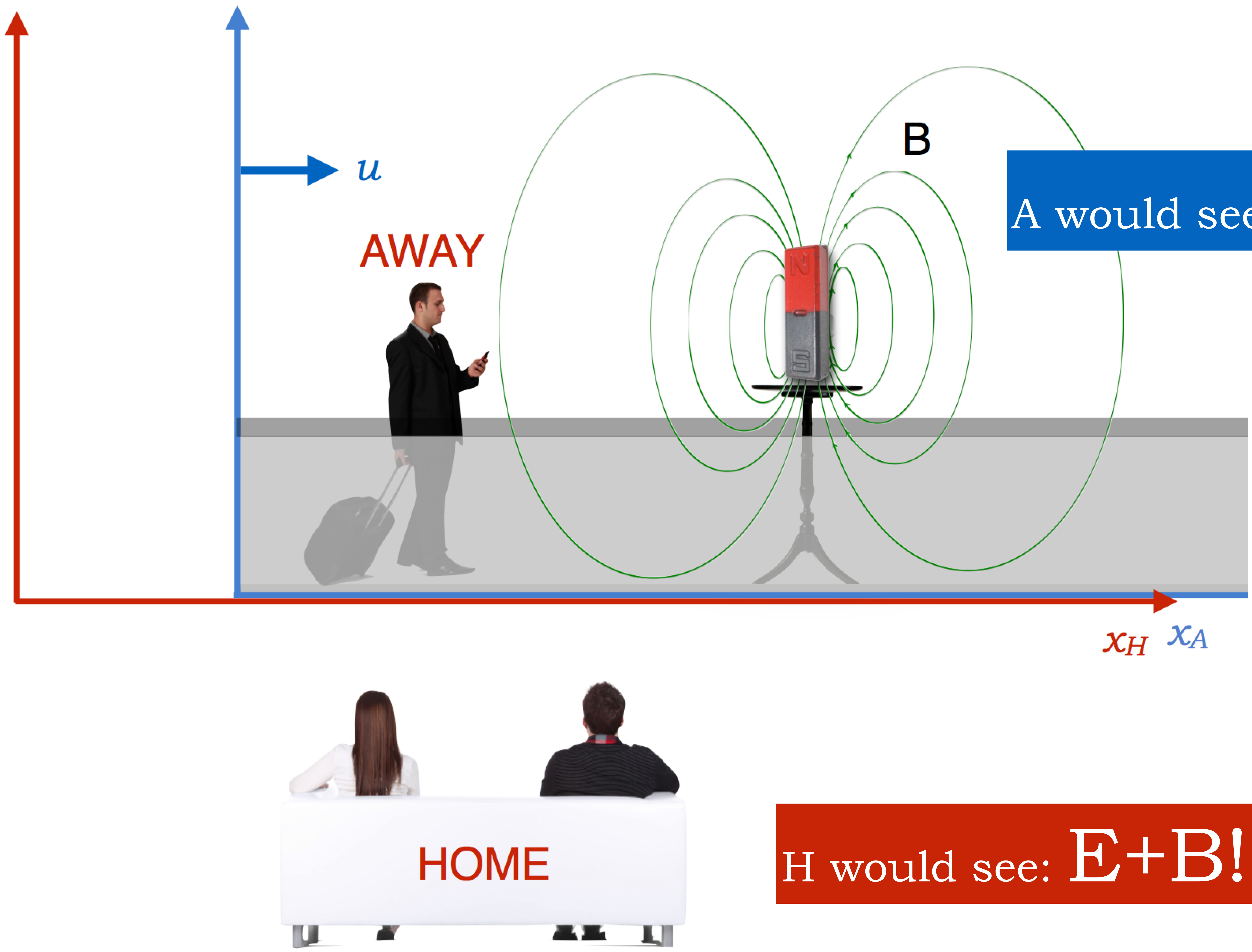

Situation #1
F
B
Q
v
I
−q
+q
v
Situation #2
B
Q
no velocity, no force
−q
+q
v
I


current
one
current


Weird alert #1:
Two different physical outcomes...
for situations which differ only by the frame of reference


Weird alert #2:
Two identical physical outcomes...
from entirely different physical causes for situations which

back to the airport



A would see: B

H would see: E+B!

so the original problems are solved by:

the Lorentz transformations in *x* and *t*

actually **mix** electric and magnetic fields

so

A **magnetic field** in one frame

is a **mixture of magnetic and electric fields** in another frame

An **electric field** in one frame

is a **mixture of electric and magnetic fields** in another frame so the original problems are solved by:

E and B are two manifestations of one thing:

the Electromagnetic Field

the Lorentz transformations in *x* and *t*

is a mixture of magnetic and electric fields in another frame

An electric field in one frame

is a mixture of electric and magnetic fields in another frame