hi

Lecture 12, 16.02.2017

Einstein’s Theory of Special Relativity, 1

housekeeping

Lectures forever now.

Gotta come to class

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

Marie Curie movie anyone?

Next homework will require Tuesday's class content

so it will be due on Saturday midnight, not Thursday midnight.

Midterm...before or after Spring Break?

review

Accelerators

- You now know a lot about the LHC and the Fermilab collider

Theory and Experiment in particle physics

- Luminosity and cross section

more 1890s

- Discovery of Radioactivity
- Polonium and Radium

Detectors:

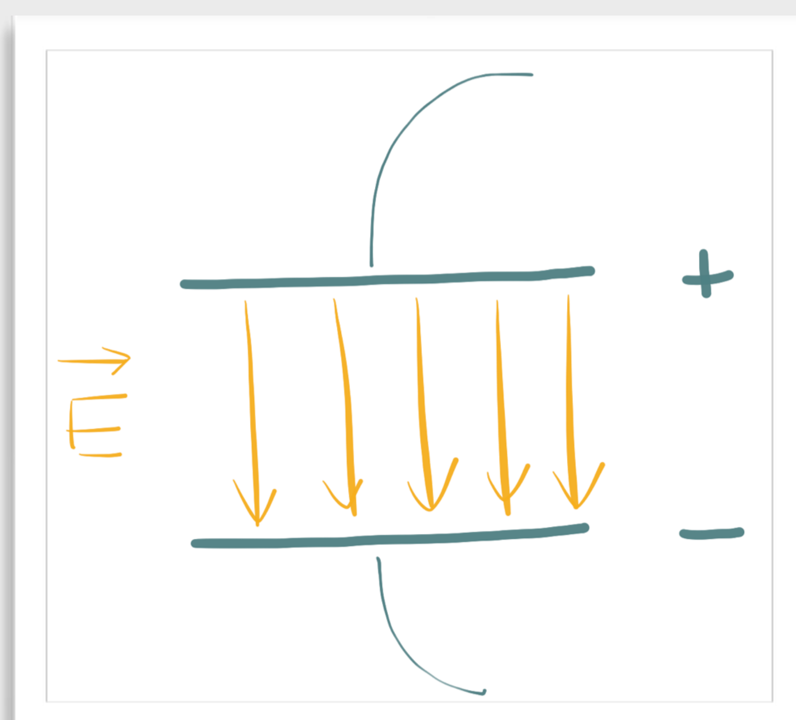
- Ionization Detectors
- electronic and visual

we did various configurations of fields

Electric Fields

electric “dipole” + and - charges

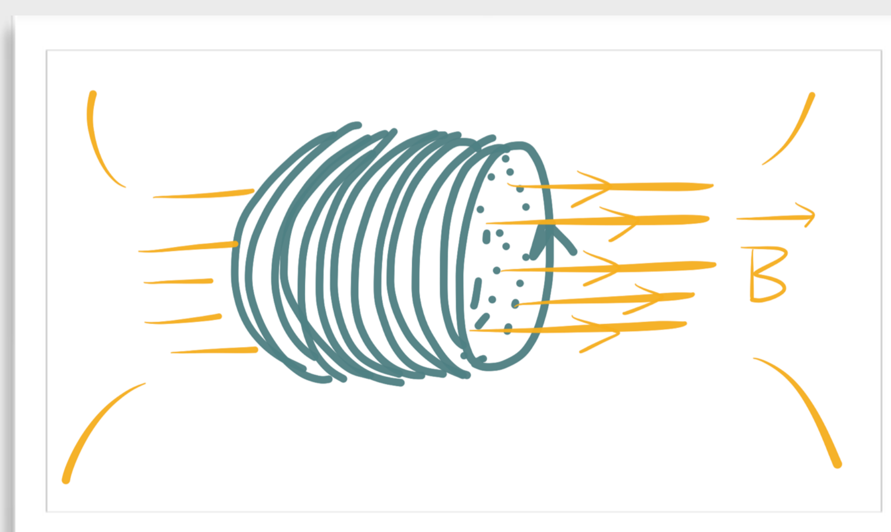
charged, metal parallel plates, “capacitor”



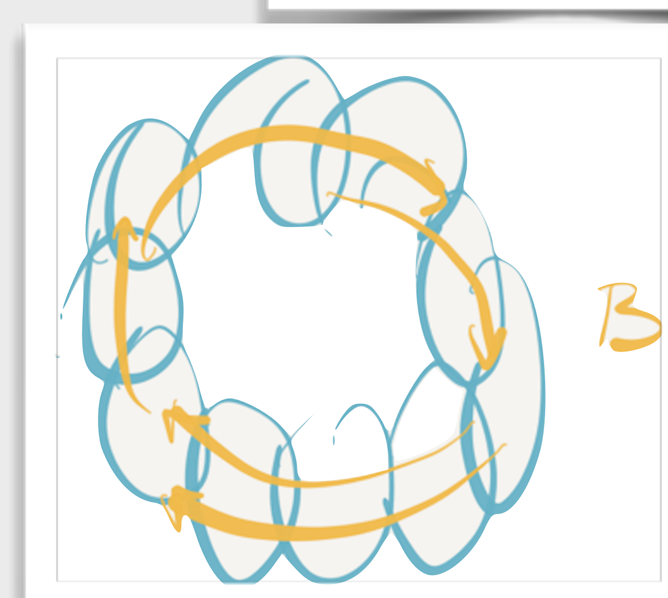
Magnetic Fields

single wire

current loop



“solenoid” - shaped like a spring

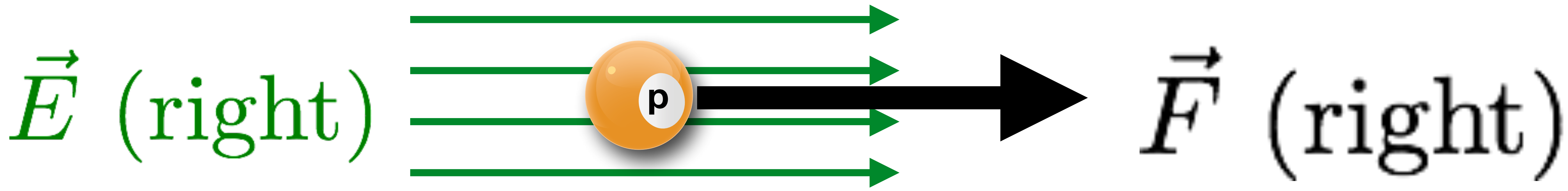


“toroid” - shaped like a donut with B inside

"Lorentz Force"

Electric fields accelerate + charged particles along the E field lines

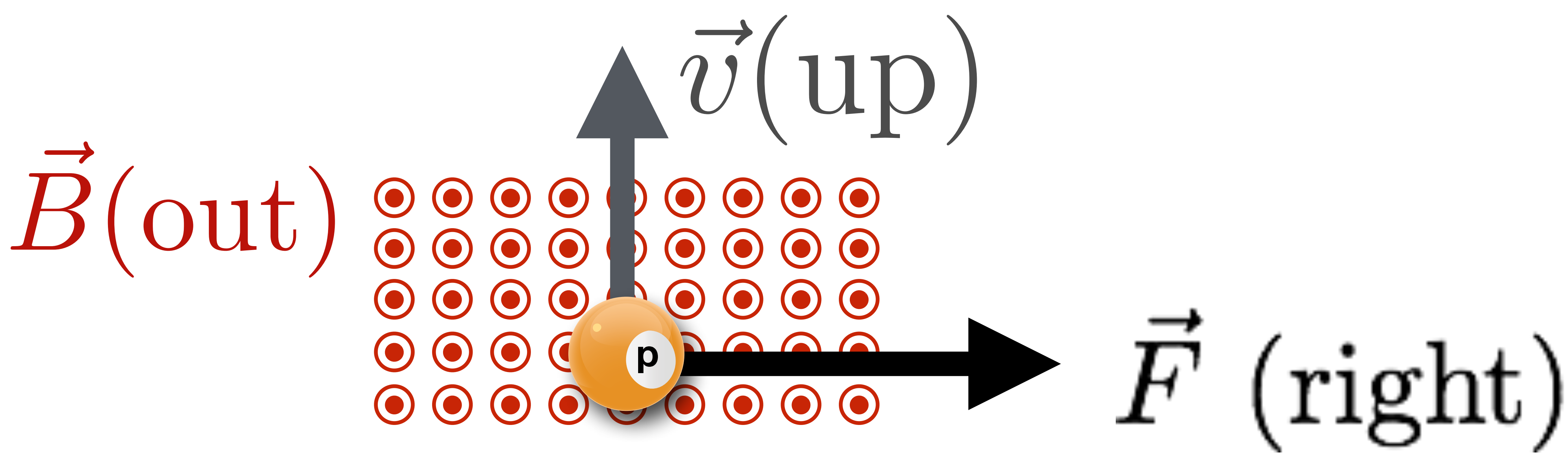
F = QE



Magnetic fields accelerate + charged particles toward a center of a circle - a centripetal force

considered as forces on particles, F = QvB

perpendicular to v and B, right hand pointing in F (for +Q)



Lorentz Force: **F** = Q**E** + QvB(**perpendicular**)

review, cont.

charges in motion

an electric charge at rest: what fields? electric

an accelerating electric charge: what fields? electric & magnetic

we say that an accelerating electric charge

___radiates___ an ___electromagnetic___ wave

a changing electric field creates: a changing magnetic field

a changing magnetic field creates: a changing electric field

"conservation law" means "before = after"

$K_0 + U_0 = K + P$ expresses ___energy___ conservation

$p_{A,i} + p_{B,i} = p_A + p_B$ expresses ___momentum___ conservation

detector:

emulsion detectors

type:	visual device, tracks as short as μm
measurement:	photons and charged particles
affect:	particles pass through or stop
recording:	photo. film - must be developed
size:	50 μm thick... magnifying glass
era:	1910’s - current with large sheets

Required looking at slices of small emulsions...with microscopes

detector:

cloud chambers

type:	visual
measurement:	individual tracks, momentum, ID
affect:	reusable - detector is the target
recording:	photographs, analyzed later
size:	cubic inches
era:	1940’s - 1950’s

detector: **bubble chamber**

type:	visual
measurement:	individual tracks, momentum, ID
affect:	destructive - detector is the target
recording:	photographs, analyzed later
size:	few feet diameter to 15’ diameter
era:	1950’s - 1970’s

detector:

gaseous ionization detectors

type:	digital
measurement:	individual tracks, momentum, ID
affect:	minimal - detector is gas
recording:	logical and analog, analyzed later
size:	feet long, large areas meters
era:	1940's - present

detector:

Silicon particle detector

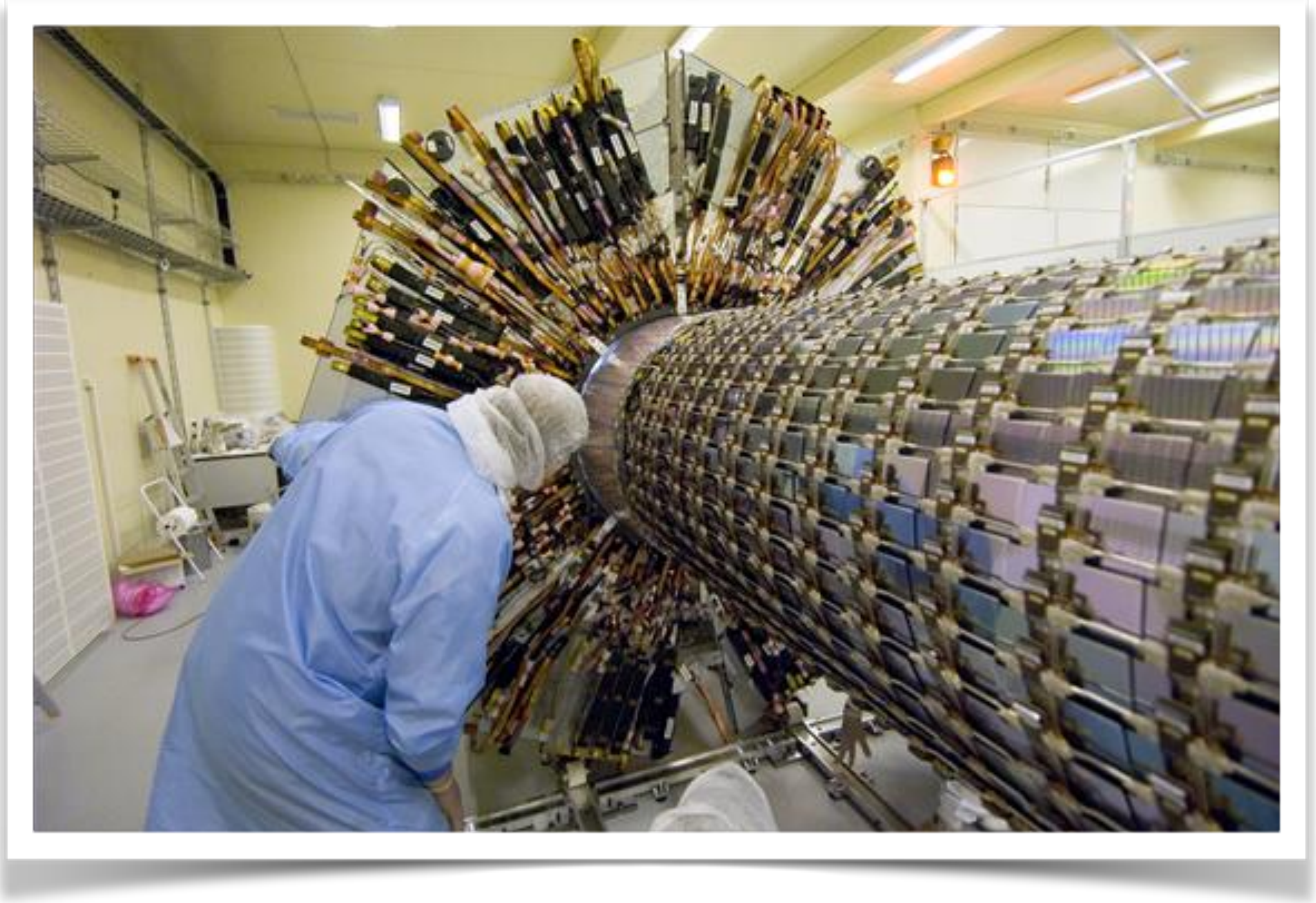
type:	logical
measurement:	individual tracks, momentum, ID
affect:	can be destructive - detector is solid
recording:	digital, analyzed later
size:	few 10’s of microns, but many millions
era:	2000 - present

the newest thing

silicon detectors

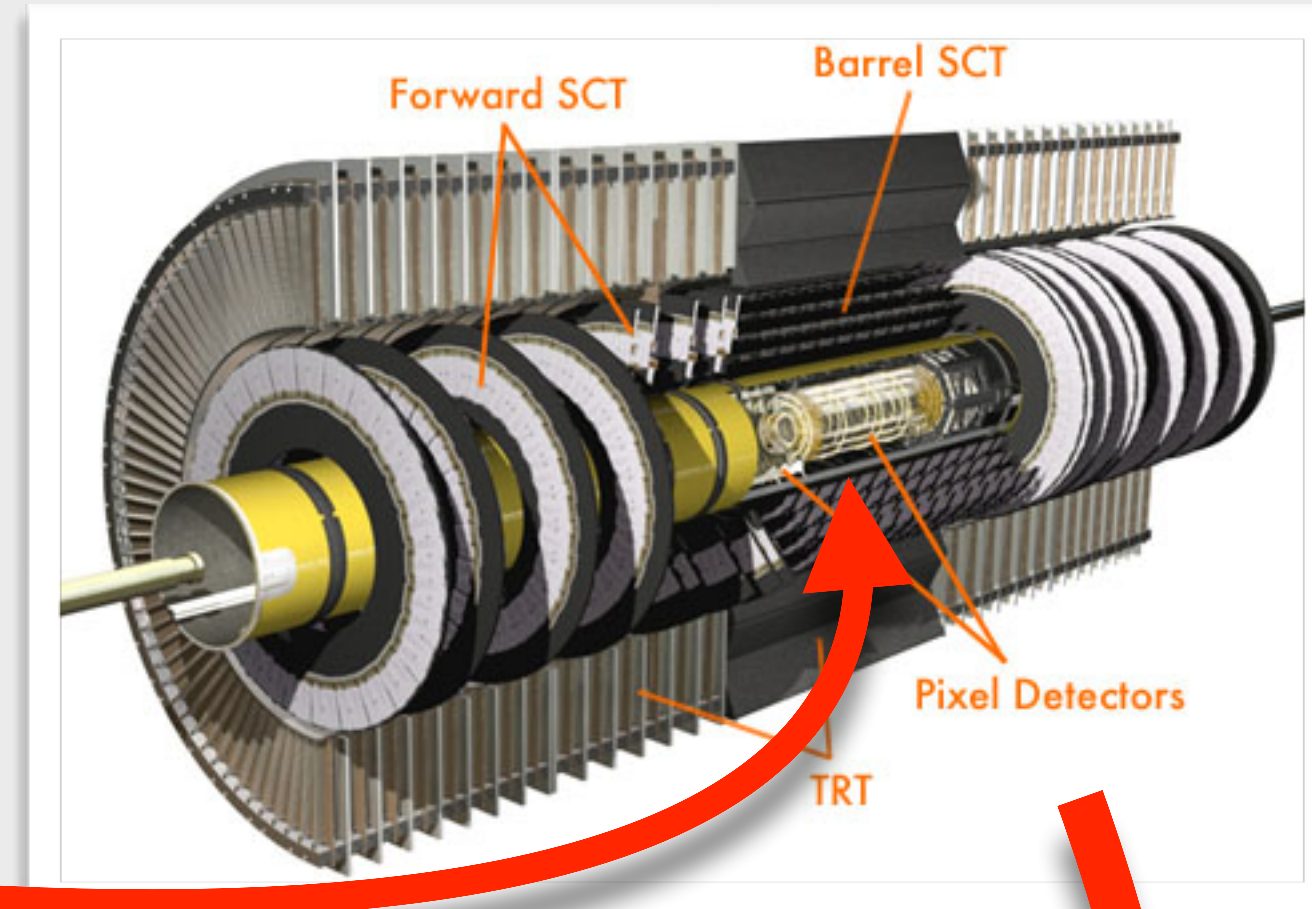
Can be very tiny!

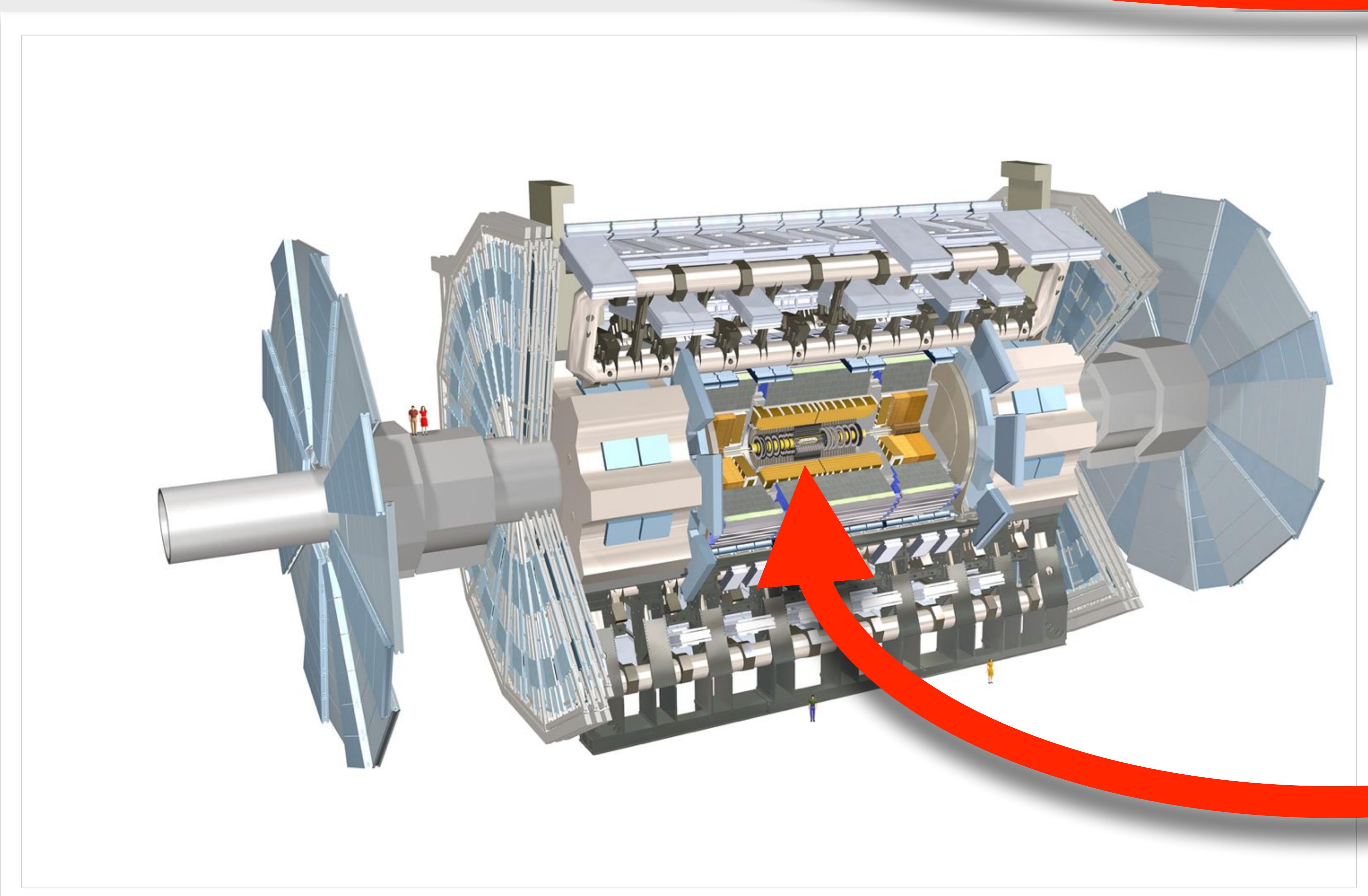
ATLAS silicon strip detector - 6 million individual measurements



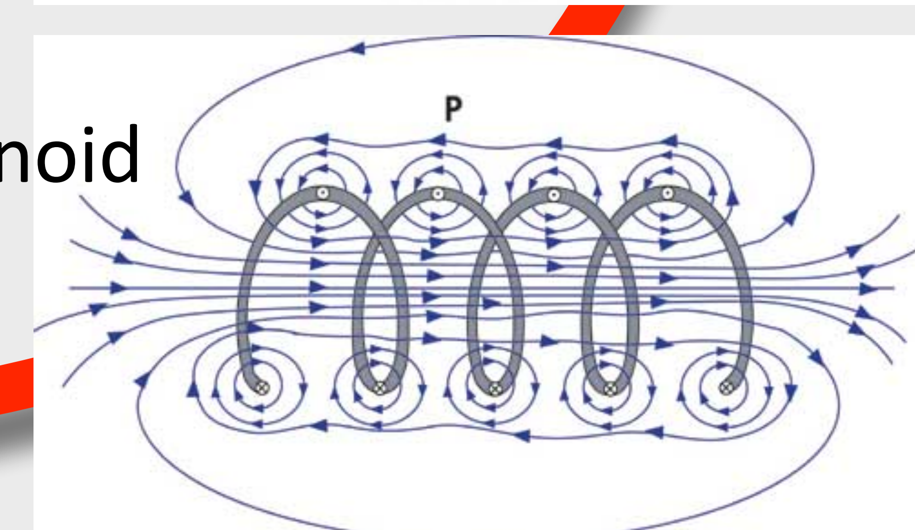
as little as 30 microns on a side: 30×10^{-6} m

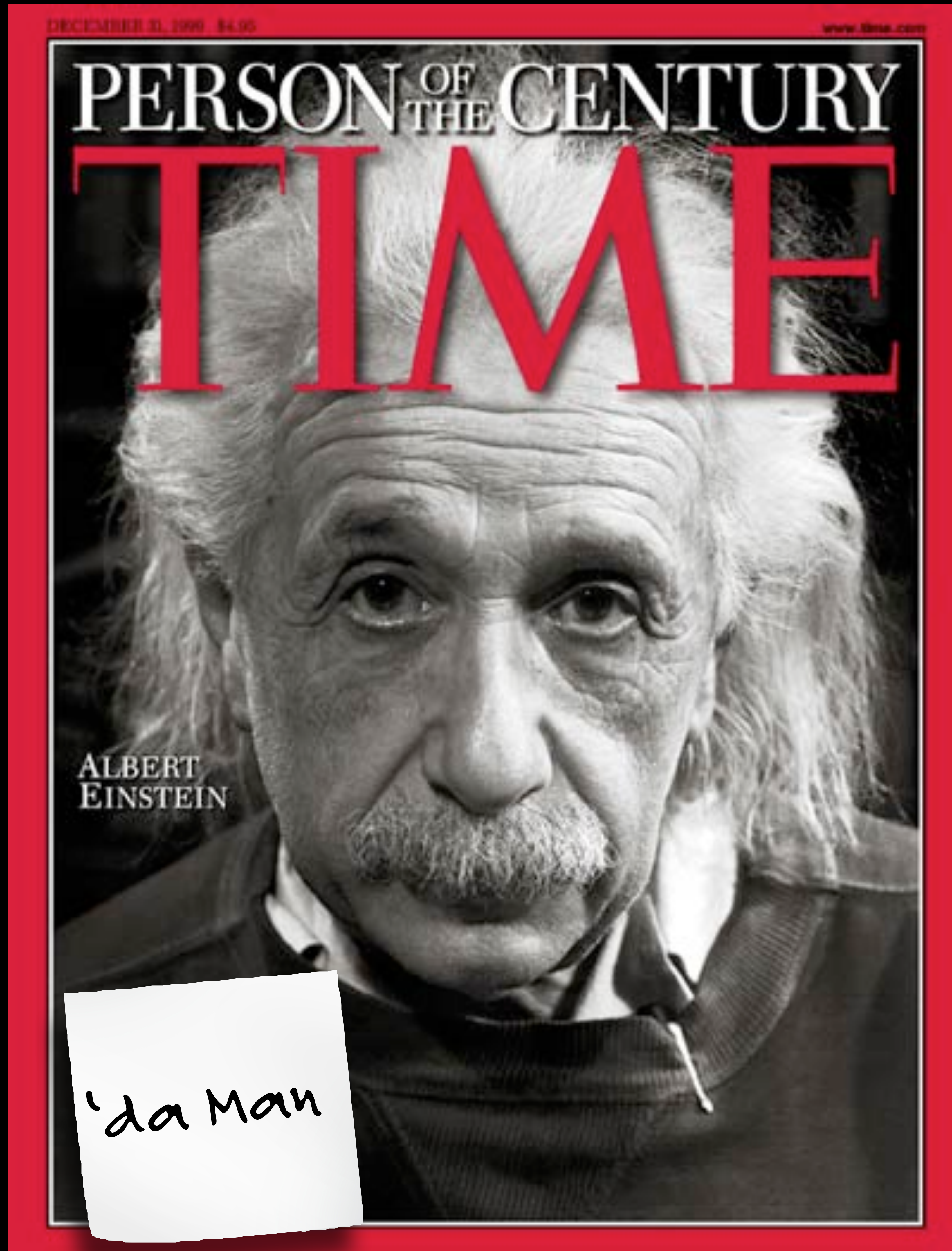
ATLAS central detector





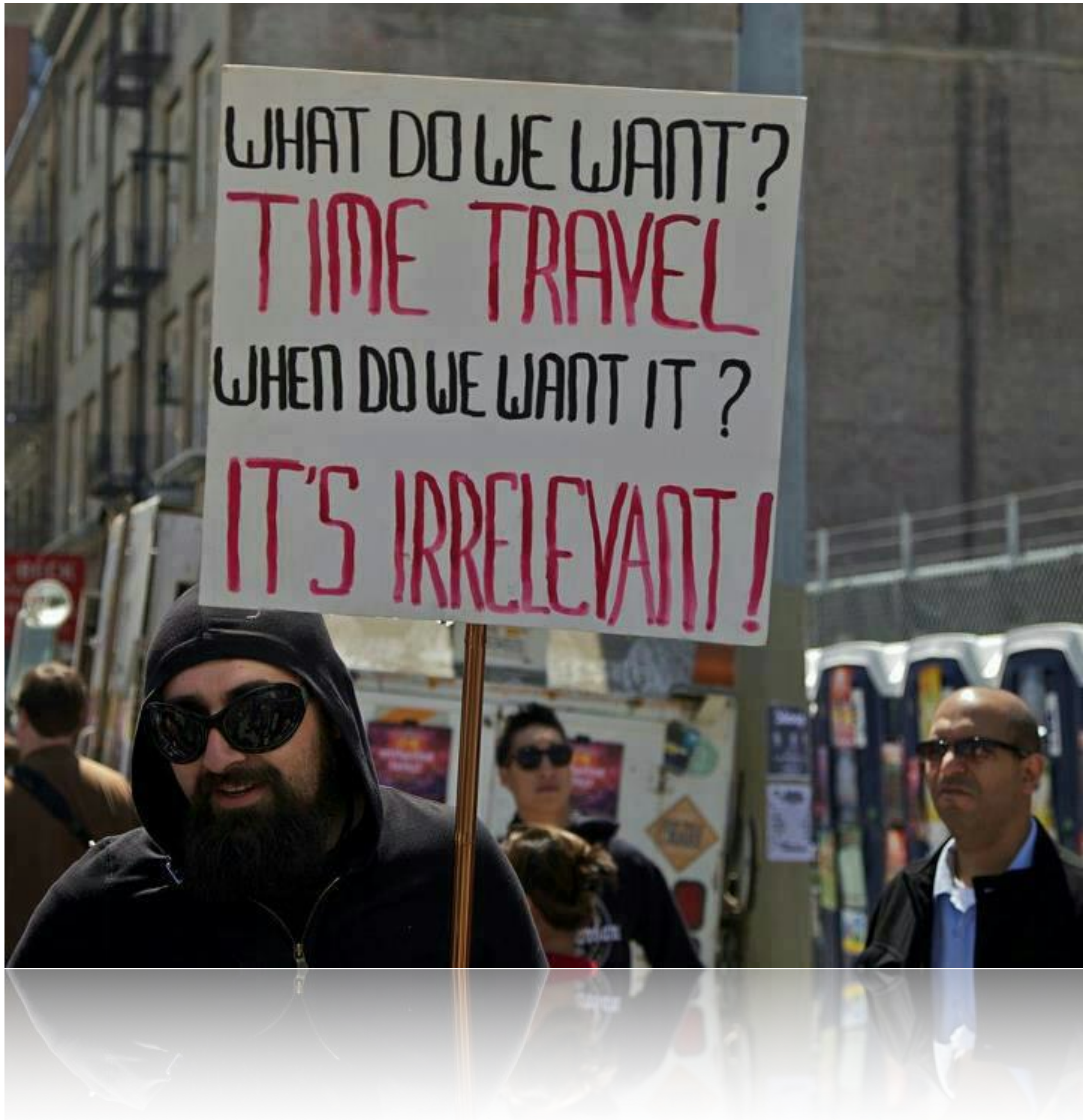
a solenoid




PERSON OF THE CENTURY
TIME
ALBERT EINSTEIN
'da Man

Special Relativity

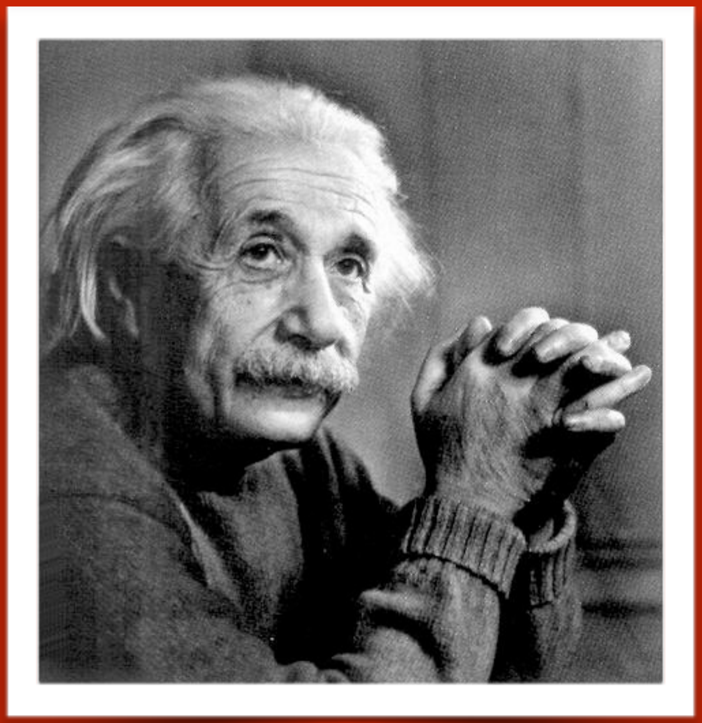
I suggest reading my manuscript chapter


WHAT DO WE WANT?
TIME TRAVEL
WHEN DO WE WANT IT ?
IT'S IRRELEVANT!

1905

Albert Einstein

1879 – 1955

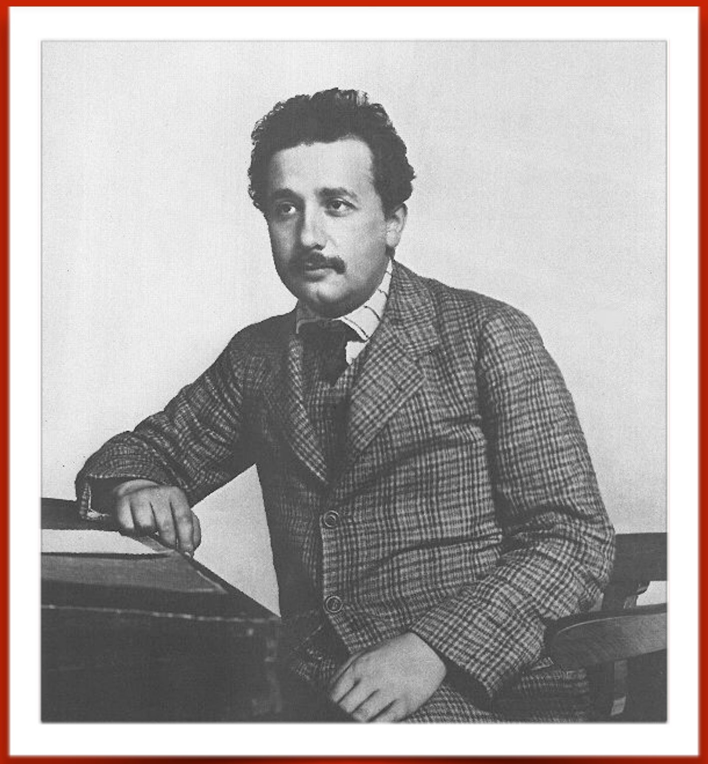


> Oh, that Einstein, always skipping lectures... I certainly never would have thought he could do it.

former professor
Hermann Minkowski

back to Einstein

following his nose



March, 1905: The photoelectric effect paper.

May, 1905: Brownian Motion...
http://www.aip.org/history/einstein/brownian.htm

couple of weeks

June, 1905: The Special Theory of Relativity

September, 1905: $E = mc^2$ paper

this week

This? ...a pretty good year.

1907, 1911, 1912, 1915, 1917: General Relativity

General Relativistic Cosmology

next week

Lots of Einstein on the web. This is good:
http://www.aip.org/history/einstein/index.html

The Einstein House in Bern
http://www.einstein-bern.ch/index.php?lang=en&show=start

he moved around

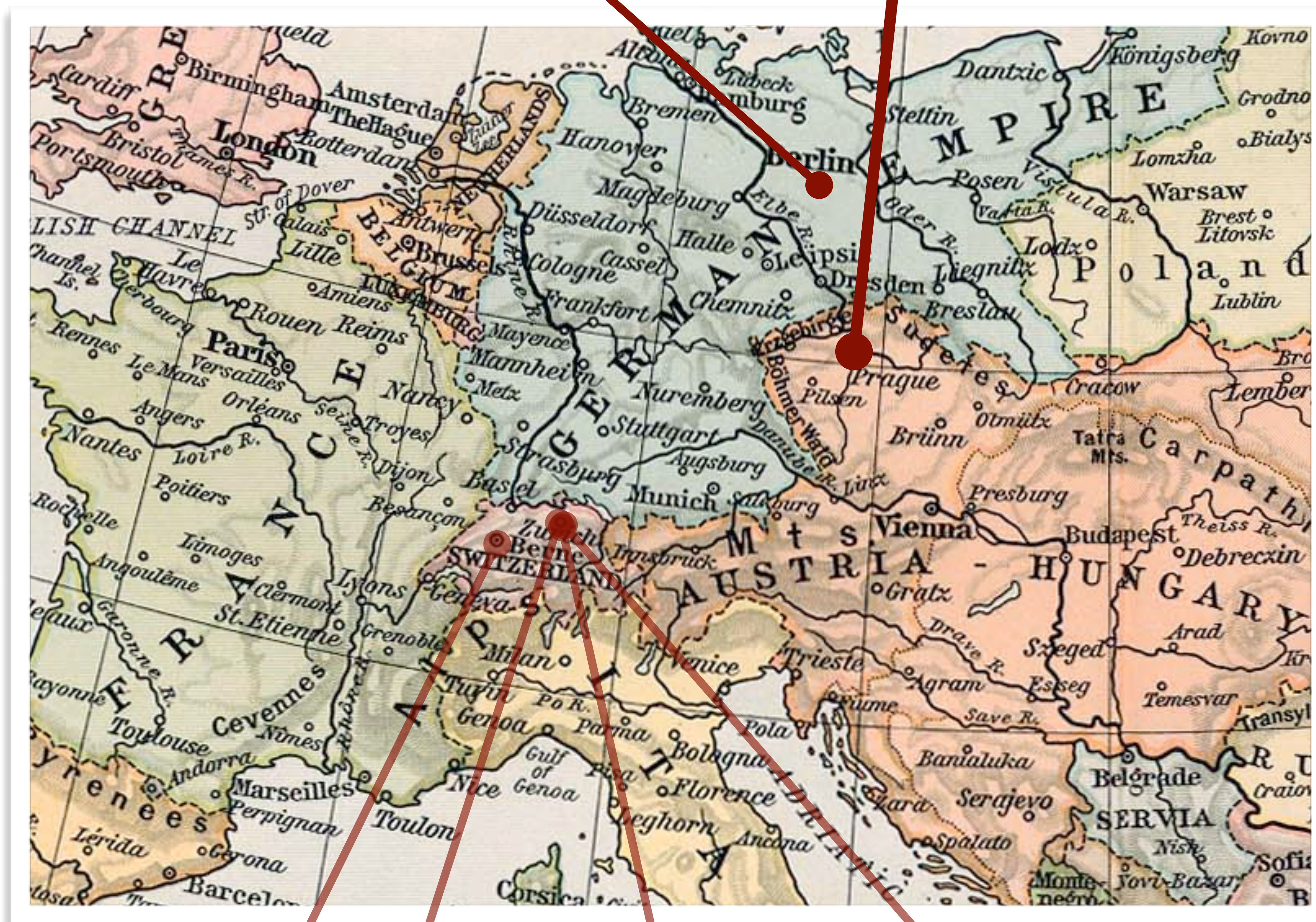
1905: patent clerk at the Swiss Patent office

1915 4 lectures with complete GR theory
1916 publishes GR theory
1917 1st paper on Cosmology
introduces Cosmological Constant
moves in with Elsa
1919 divorces Mileva, marries Elsa
Solar Eclipse data confirmed by Eddington

1920 anti-relativity lectures in Berlin
1922 Nobel Prize
1931 rejects Cosmological Constant
1933 Hitler elected Chancellor
Einstein renounces German citizenship
Moves to Princeton

1913 Professor
separates from Mileva

1911 Professor

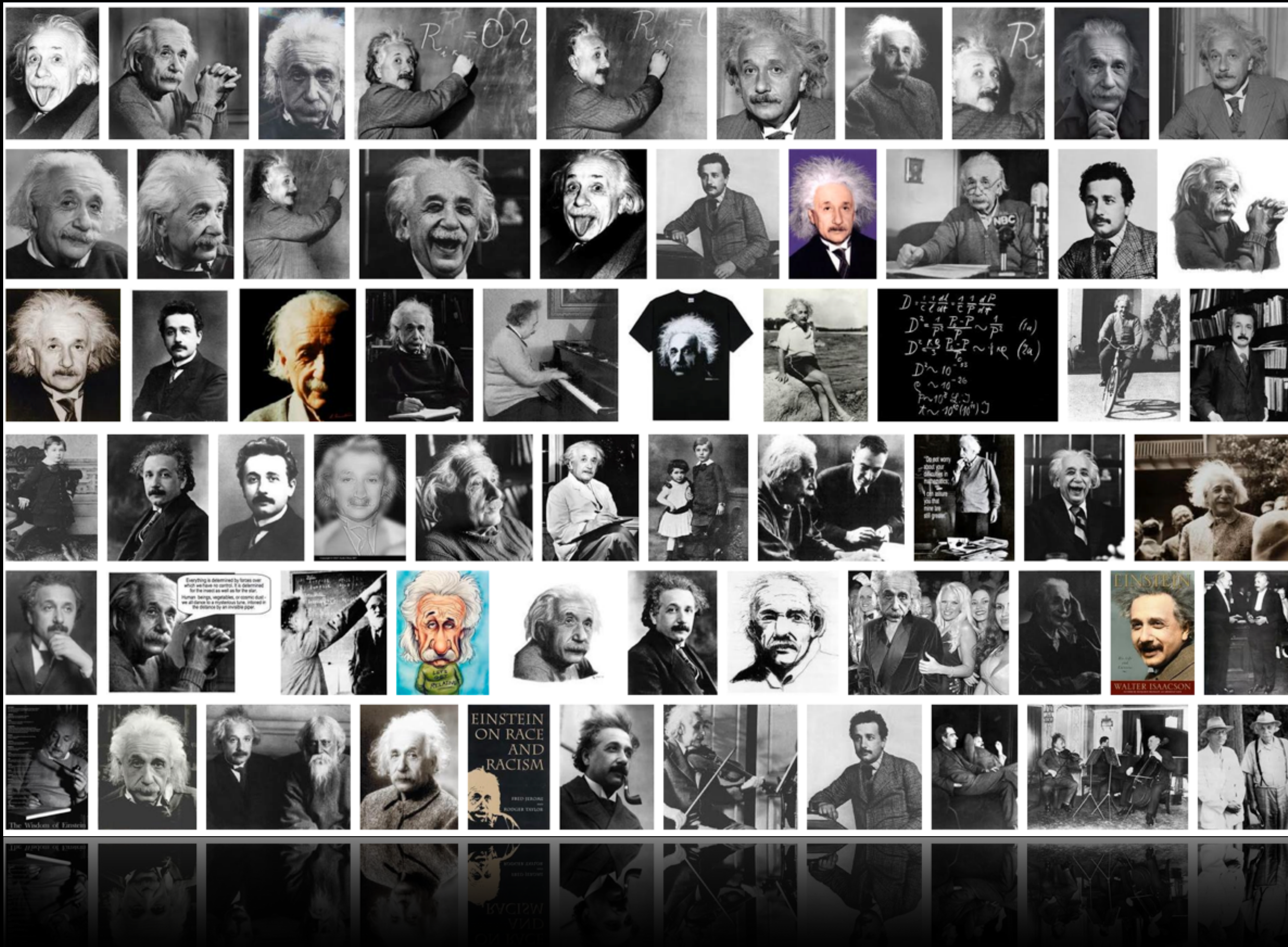


1909 Professor

1912 Professor
work with Grossman
1913 1st GR paper

1906 Doctorate

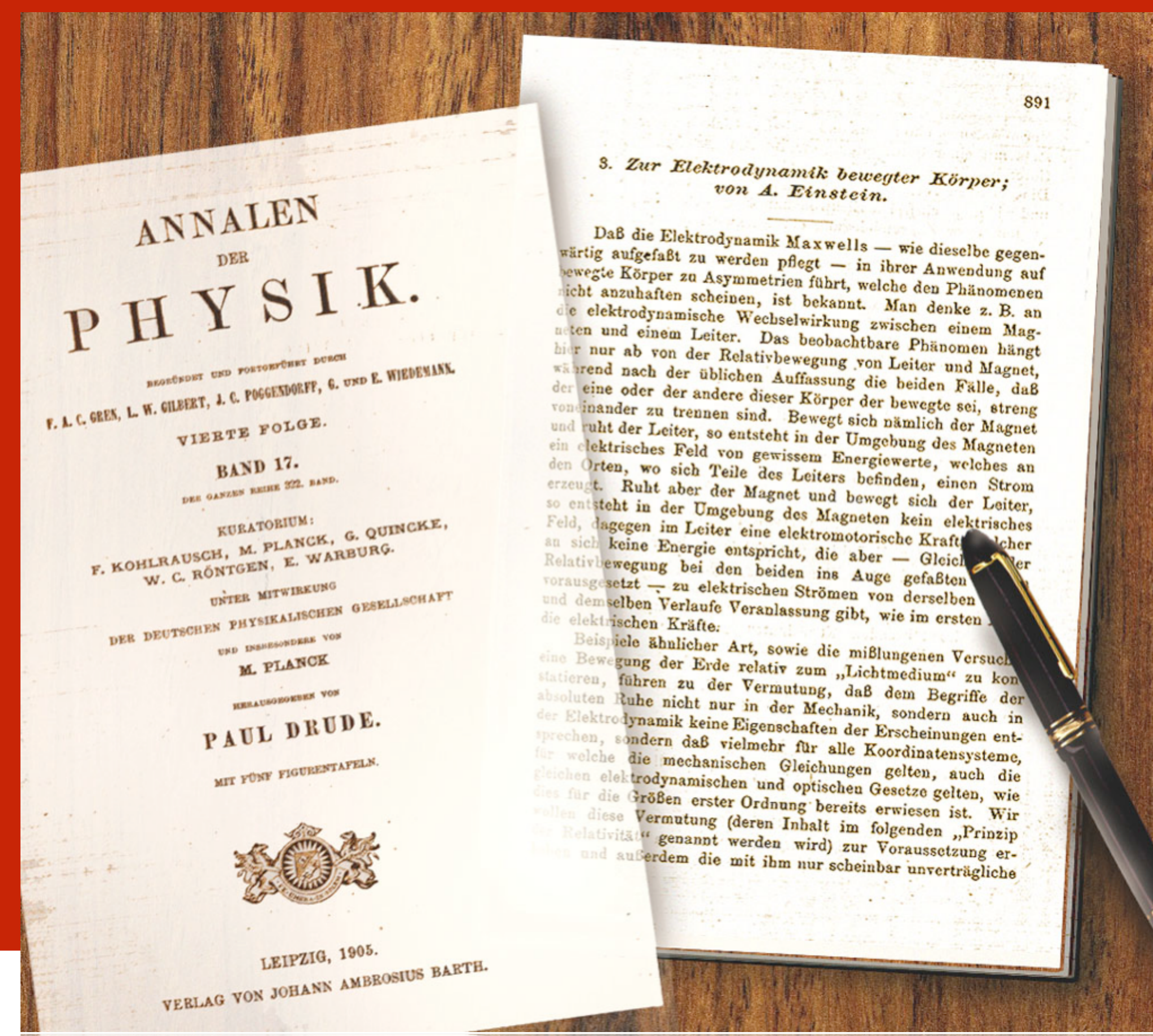
1907 University Bern? nope


NBC
Everything is determined by forces over which we have no control. It is determined for the insect as well as for the star.
Human beings, vegetables, or cosmic dust - we all dance to a mysterious tune, intoned in the distance by an invisible piper.
EINSTEIN
WALTER ISAACSON
EINSTEIN ON RACE AND RACISM
The Wisdom of Einstein

His 1905 Relativity paper:

On the Electrodynamics of Moving Bodies

"A storm broke loose in my mind."



Galileo had solved a serious problem

The bus/train/car-beside-you-illusion

you've all had the sensation:

you're in a bus/train/car next to a bus/train/car

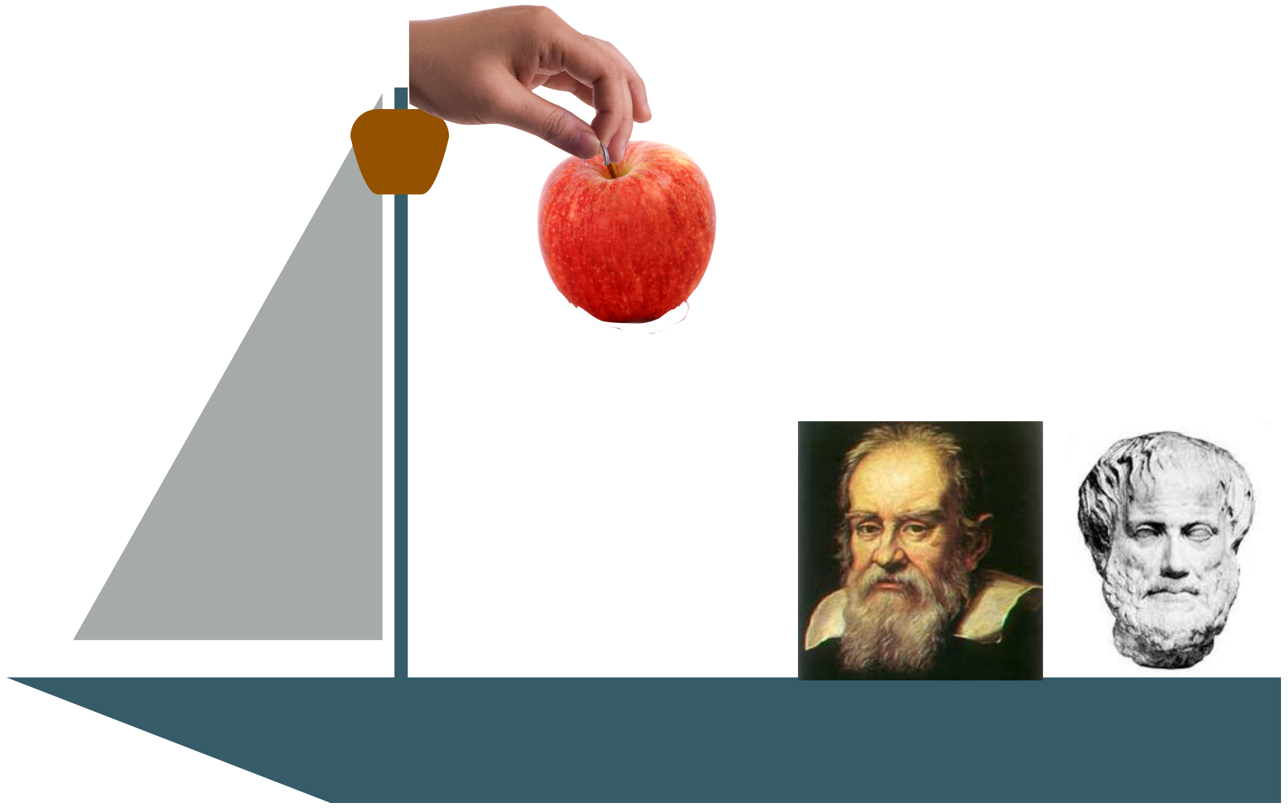
one of them moves…you instantly wonder if it's your bus/train/car or the other bus/train/car…right?

Aristotle would not have been amused

they disagreed about what would be the case

between two different frames of reference

“Galilean Relativity”



G and A:
standing on deck, boat still
Same on shore

Galileo

1632

He says that the physics doesn't know the difference between moving at constant speed and not moving at all

"Shut yourself up with some friend in the main cabin below decks on some large ship, and have with there some flies, butterflies, and other small flying animals. Have a large bowl of water with some fish in it; hang up a bottle that empties drop by drop into a wide vessel beneath it. With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin. The fish swim indifferently in all directions; the drops fall into the vessel beneath; and, in throwing something to your friend, you need throw it no more strongly in one direction than another, the distances being equal; jumping with your feet together, you pass equal spaces in every direction. When you have observed these things carefully (though there is no doubt that when the ship is standing still everything must happen in this way), have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. **You will discover not the least change in all the effects named,** nor could you tell from any of them whether the ship was moving or standing still."

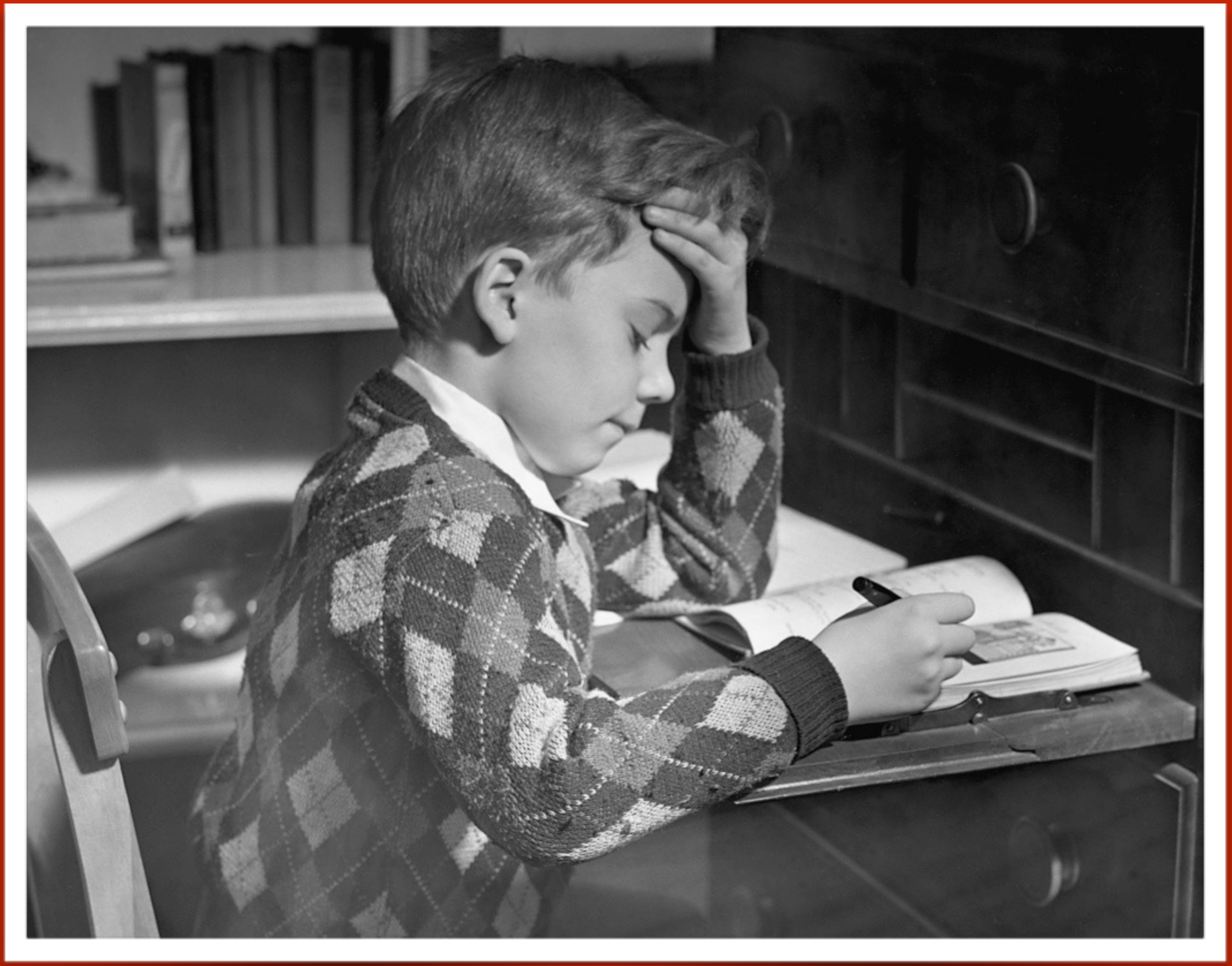
let's think

hard about

SPACE and TIME

~~moving~~ coordinate systems

relatively moving



a frame of reference: Cool Guy and Old Guy.

They each have a coordinate system attached

They each have a clock attached

Each is at rest in his own frame of reference –

his unique **Rest Frame**

If the relative speed of Cool Guy is constant with respect to Old Guy...

They are each in an **Inertial Frame of Reference**

What does Cool Guy see?
(when he's not looking in a mirror)

Old guy moving backwards.

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

likewise, a non-inertial frame is

a frame that's not inertial

where constant motion is not observed – acceleration is at work

....and where there is acceleration there is a ___force___ careful, now!

remember Newton's (Galileo's) First Law

An object
...at rest will remain at rest or
...if in uniform, straight line motion, will continue straight line motion

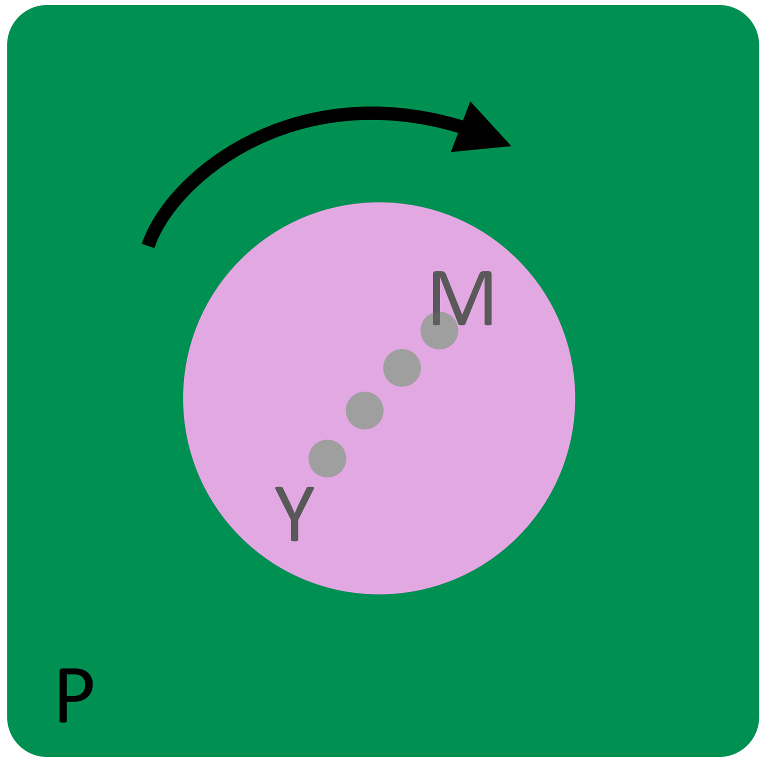
unless a force acts on it.

So if an object is seen to be moving in a not-straight path, then there is a force acting on it.

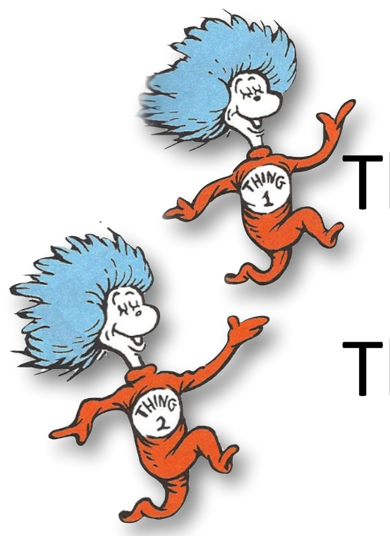
You

Me

...on a merry go-round, MGR
...in the Park, P
You throw a bowling ball to **M**e



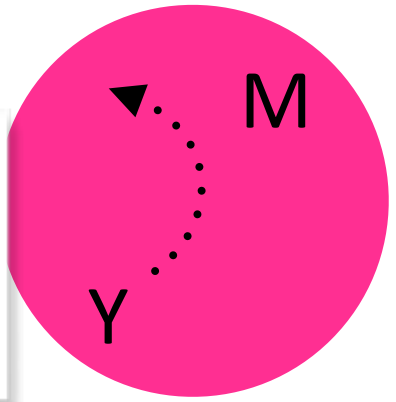
Notice 2 things:



Thing 1: the ball goes straight as far as P is concerned

Thing 2: the ball ends up to the right of M in the MGR

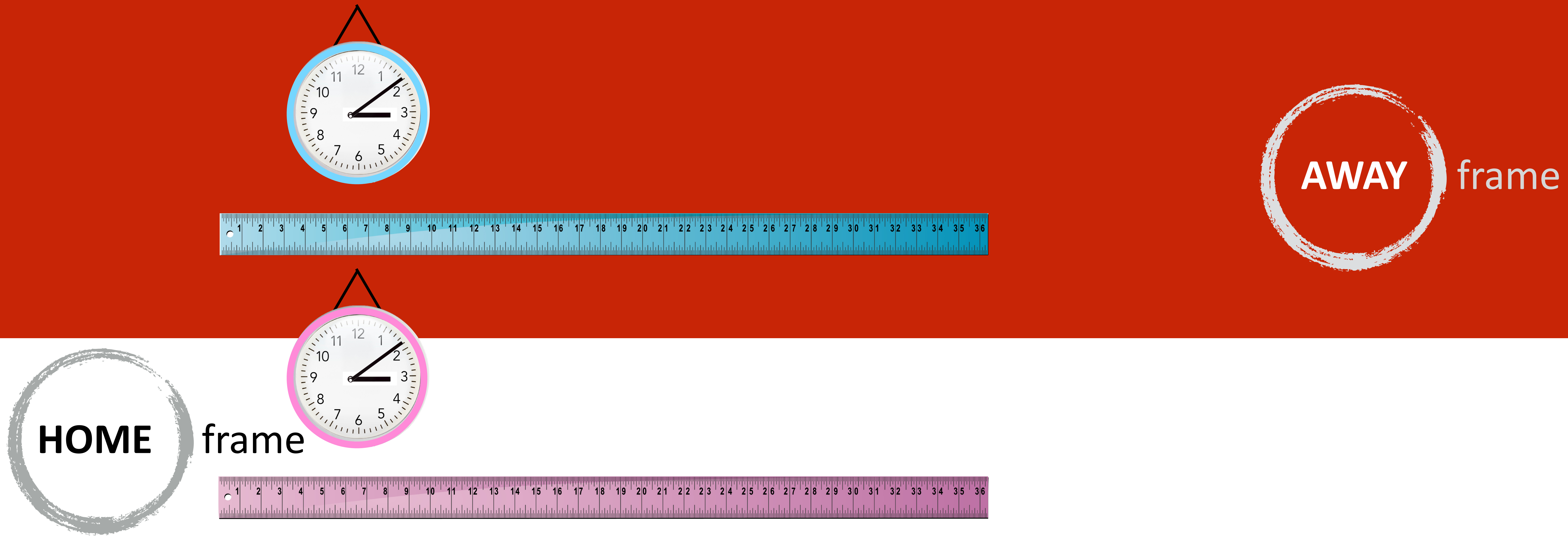
a Non-Inertial Frame of Reference



an indication that a force exists inside of MGR for measurement of motion, all you have are

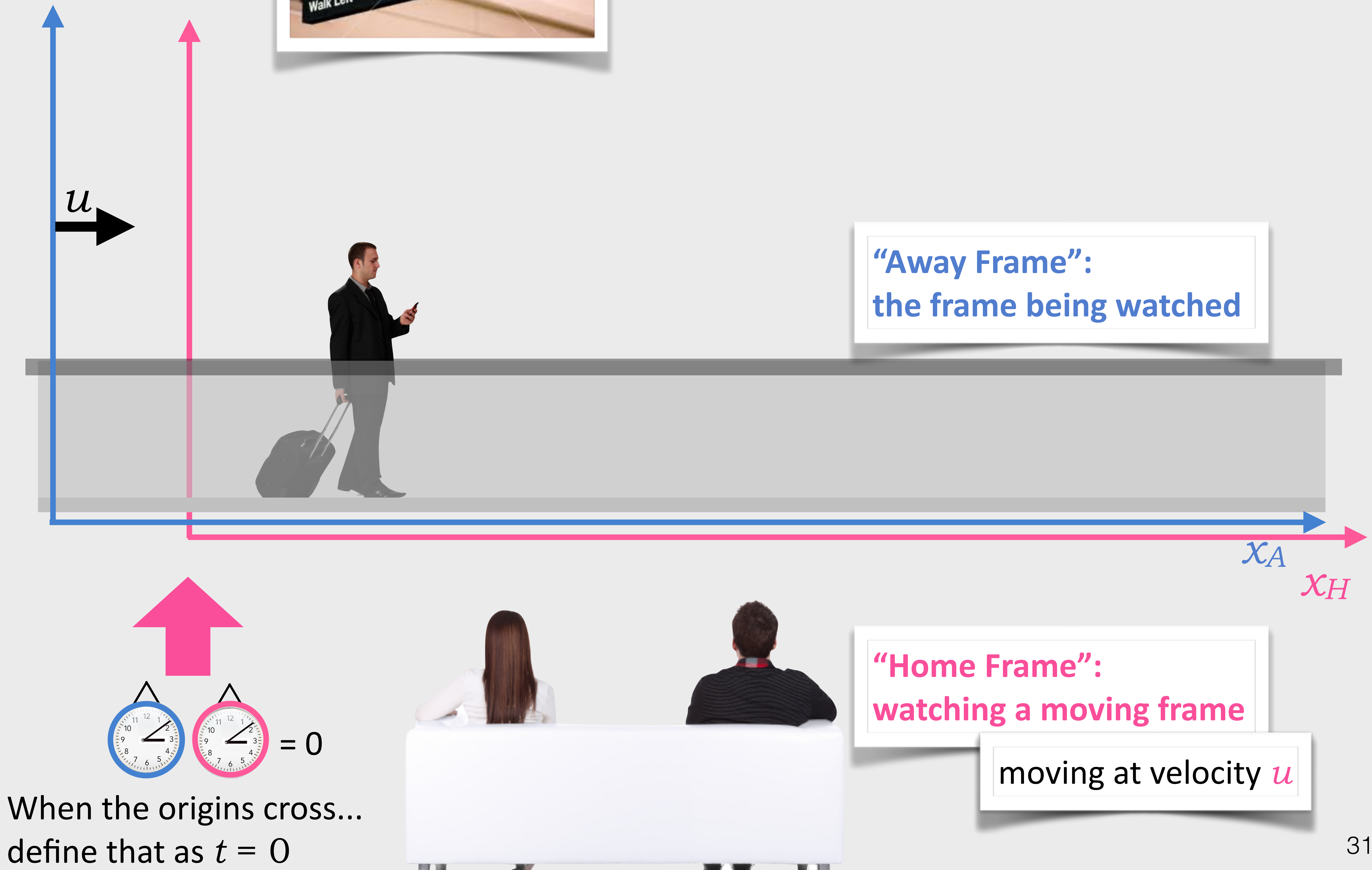
clocks and rulers.

that might move relative to one another



the airport

Moving Walkway
Walk Left
Stand Right



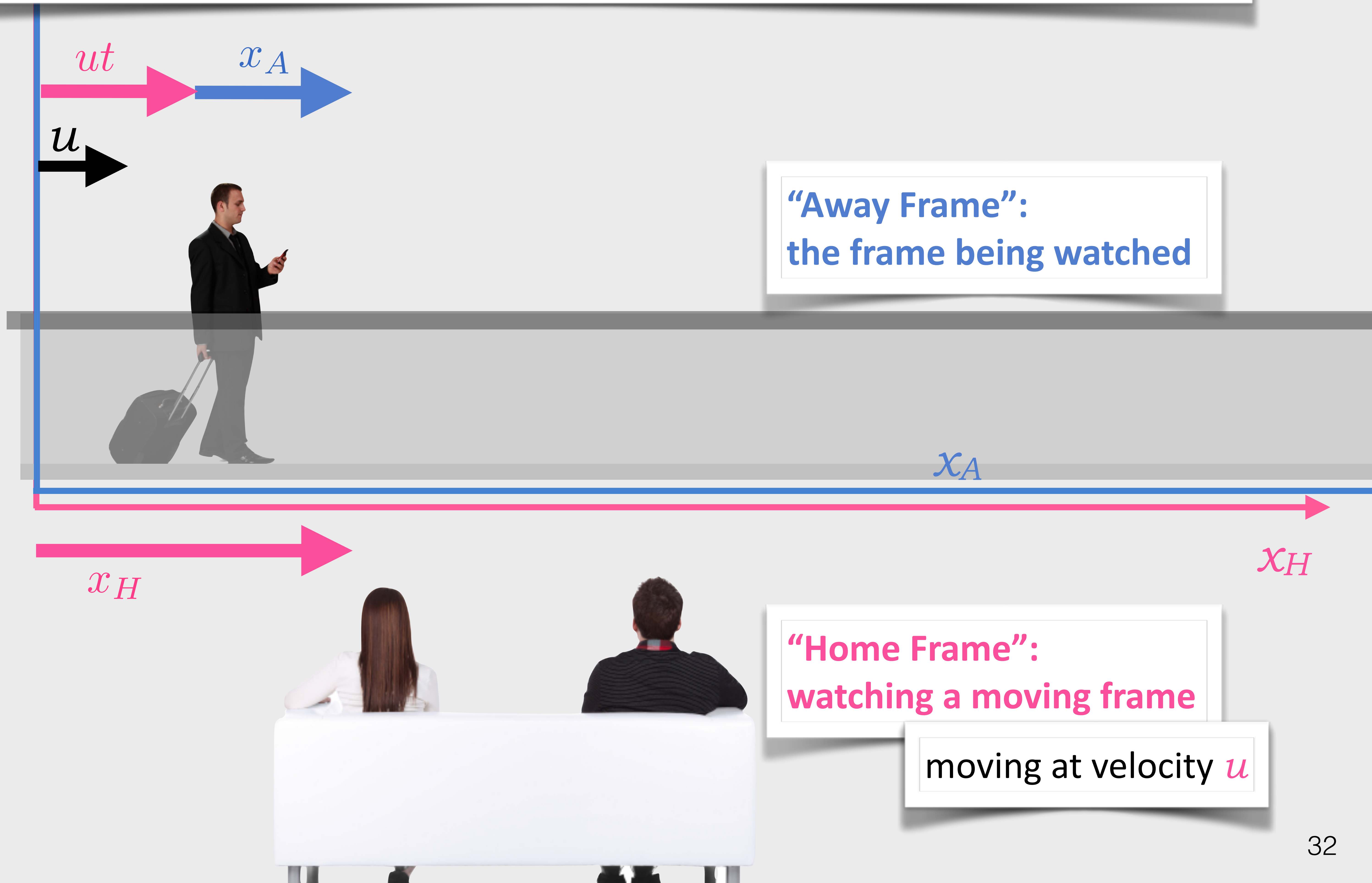
u
“Away Frame”:
the frame being watched
x_A
x_H
“Home Frame”:
watching a moving frame
moving at velocity u
= 0
When the origins cross...
define that as $t = 0$

the airport

sidewalk velocity relative to concourse: $u = 2$ m/s

after 2 s, how far has the sidewalk moved relative to the concourse?

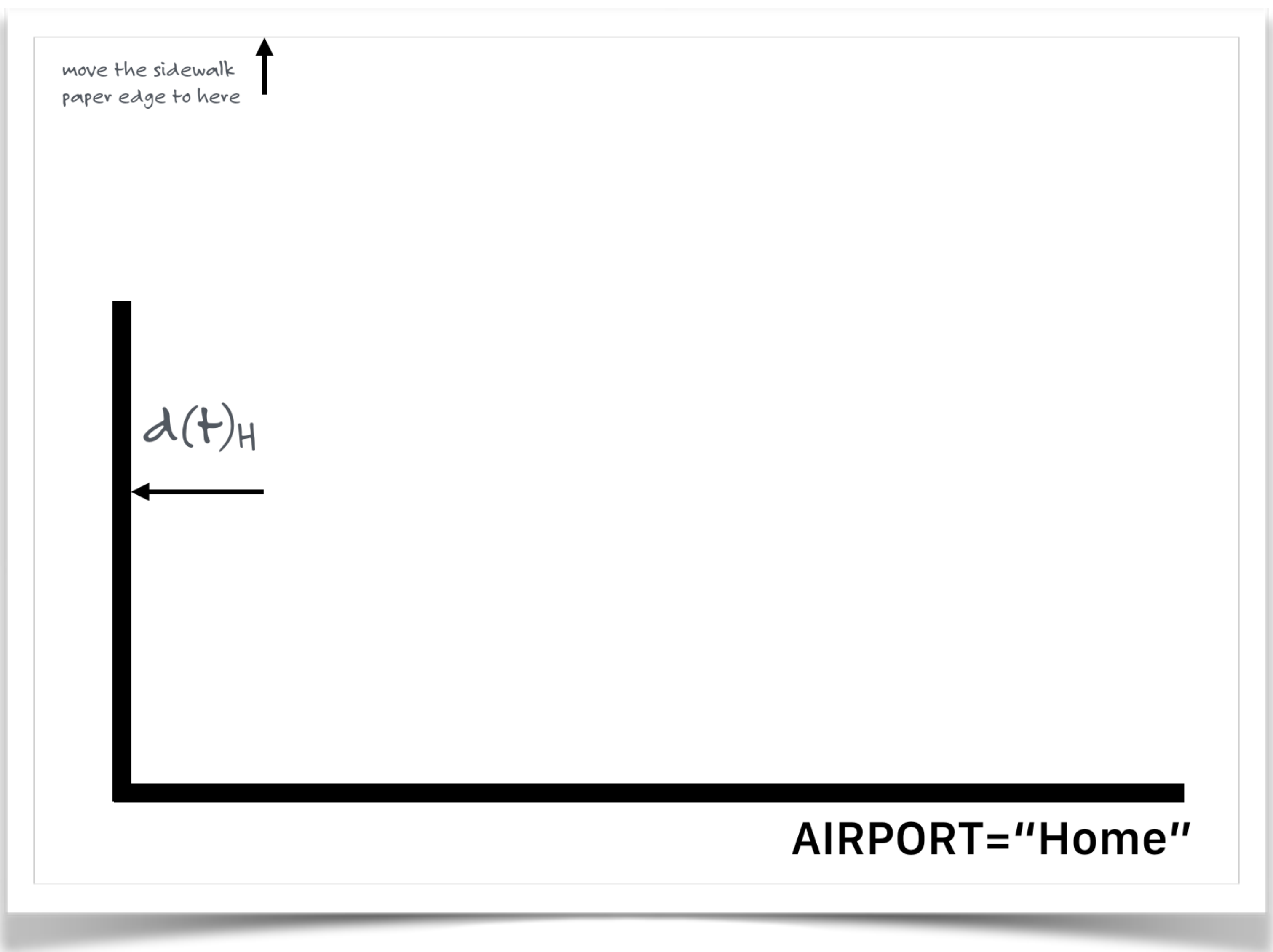
traveler is at $x_A = 2$ m, what's traveler's position relative to the concourse after 2 s?



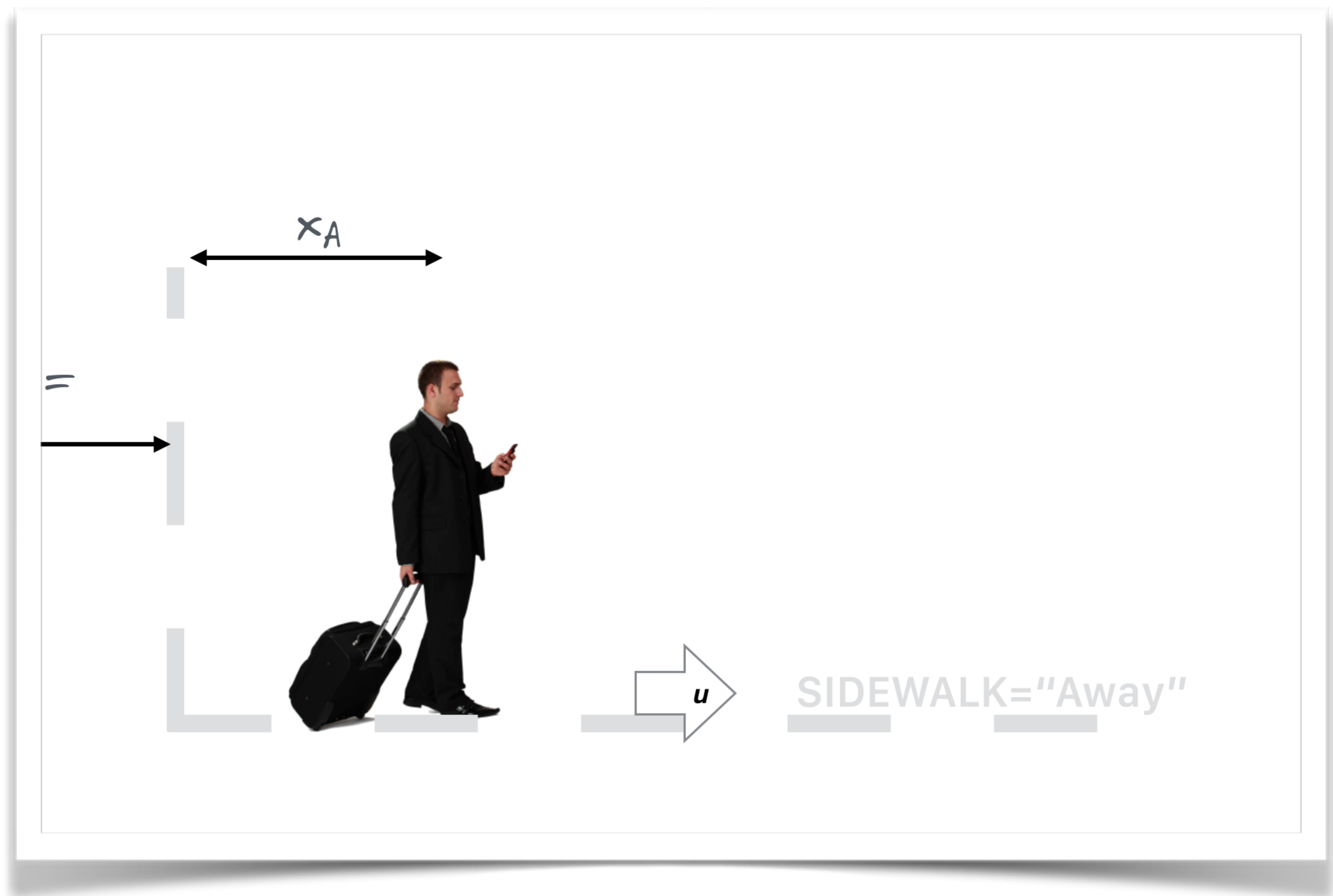
"Away Frame":
the frame being watched

"Home Frame":
watching a moving frame

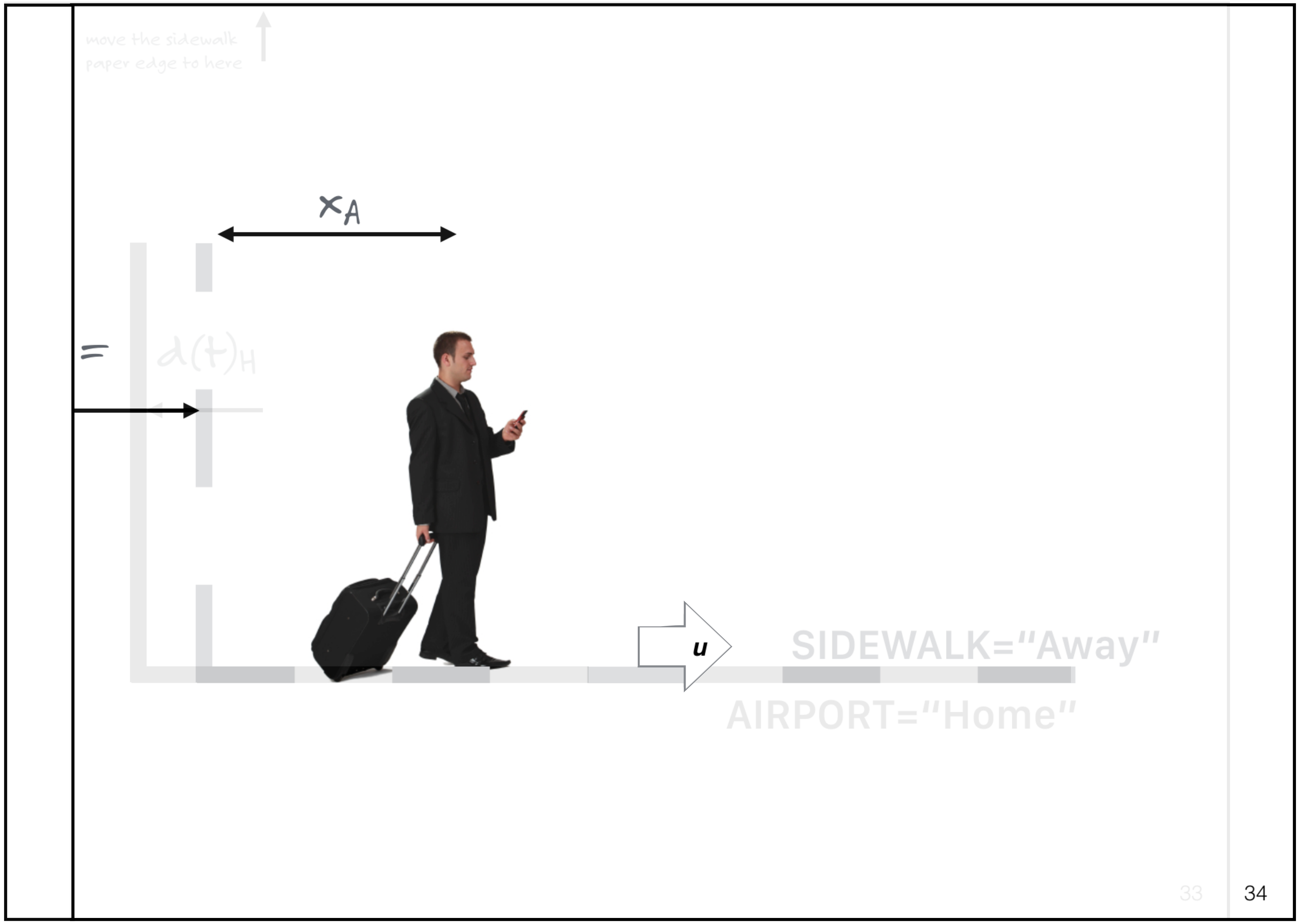
moving at velocity u



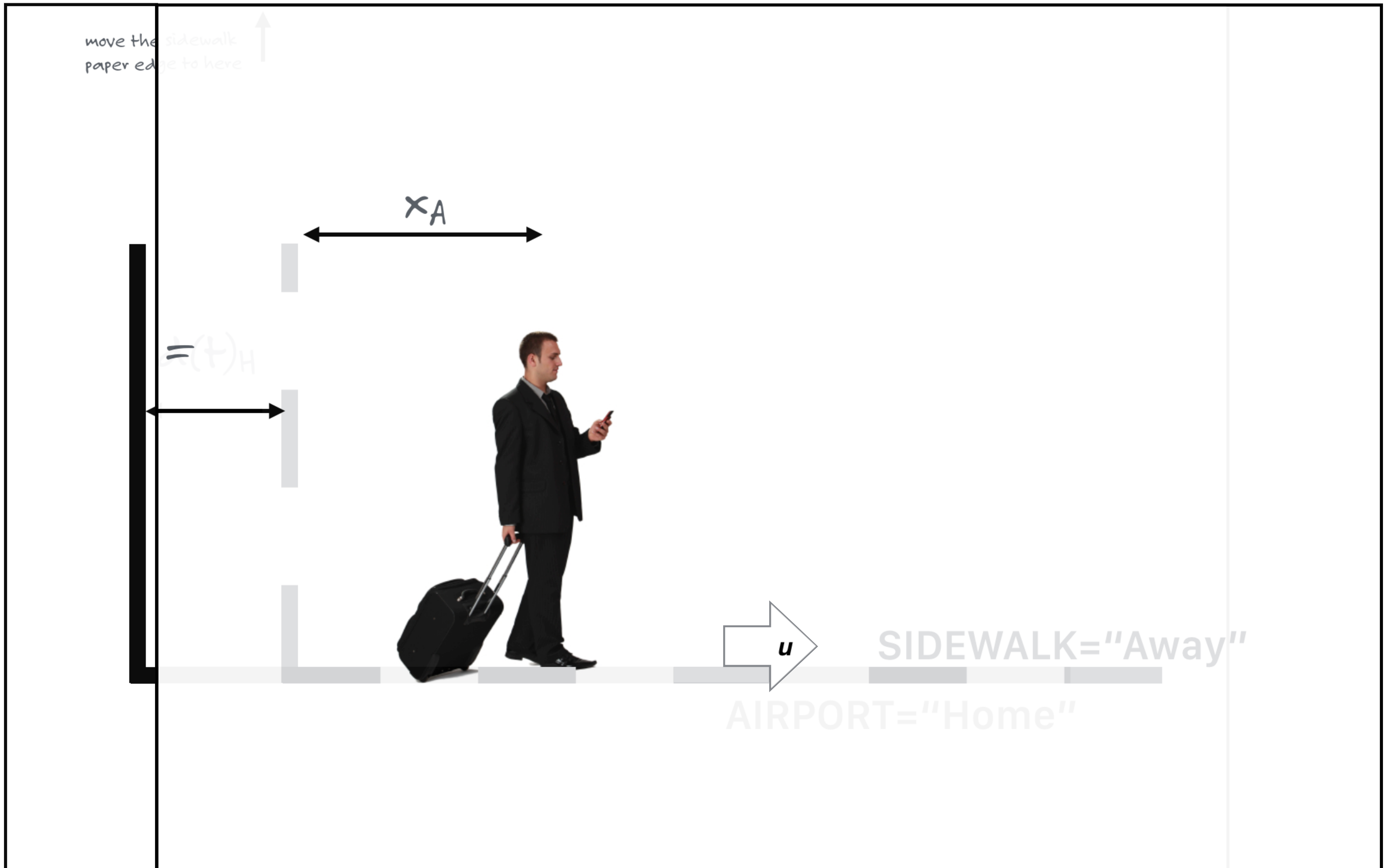
move the sidewalk
paper edge to here
d(t)H
AIRPORT="Home"



xA
=
u
SIDEWALK="Away"



move the sidewalk
paper edge to here
x_A
=
$d(t)_H$
u
SIDEWALK="Away"
AIRPORT="Home"
33


move the sidewalk
paper edge to here
x_A
u
SIDEWALK="Away"
AIRPORT="Home"

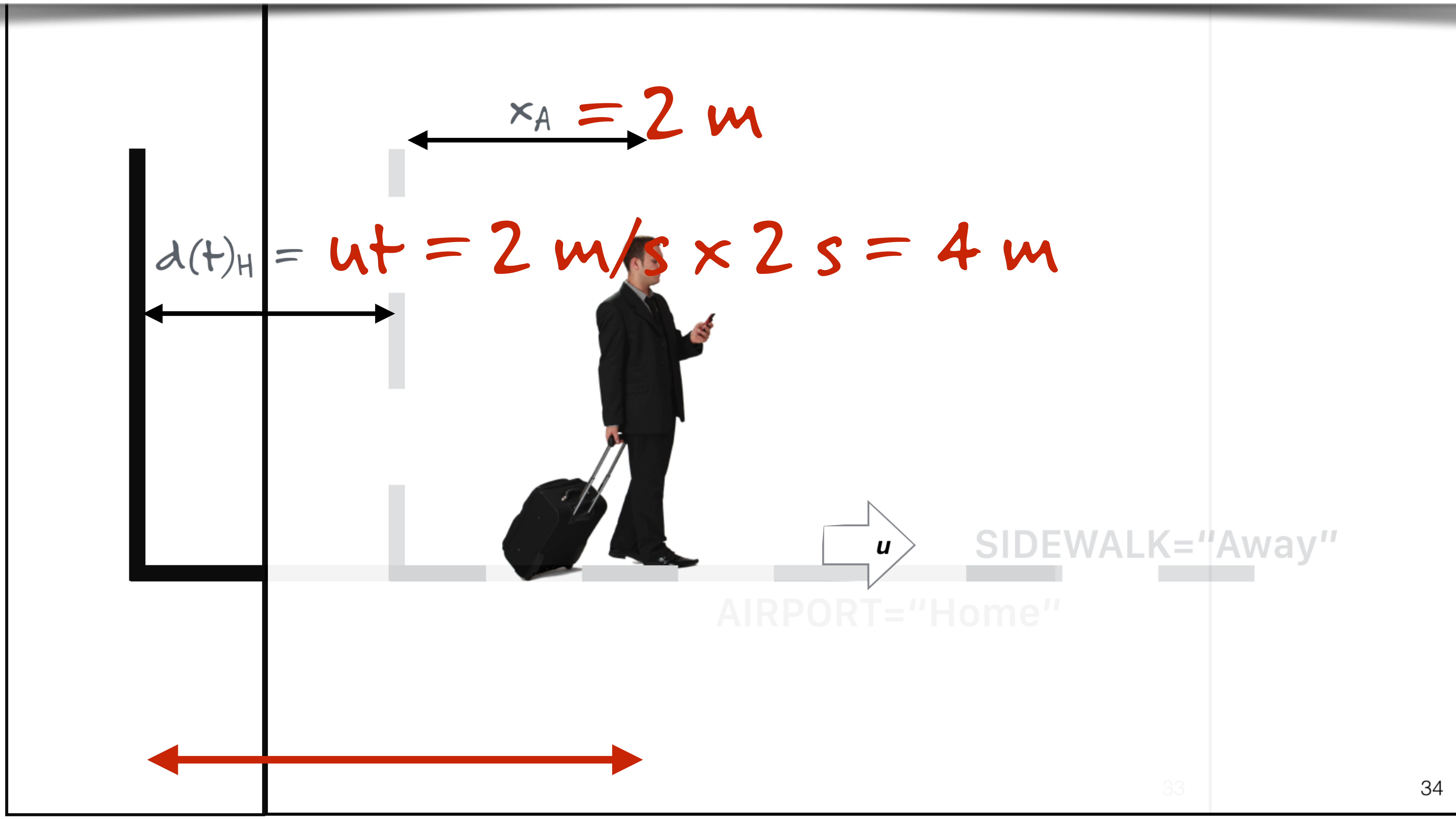
sidewalk velocity relative to concourse: $u = 2\ \mathrm{m/s}$

after 2 s, how far has the sidewalk moved relative to the concourse?

4 m

traveler is at x_A = 2 m, what's traveler's position relative to the concourse after 2 s?

6 m



$$x_H = x_A + d(t)_H = 2 + 4 = 6\ \mathrm{m}$$

‘‘coordinate transformation’’

take the coordinates in one Frame and

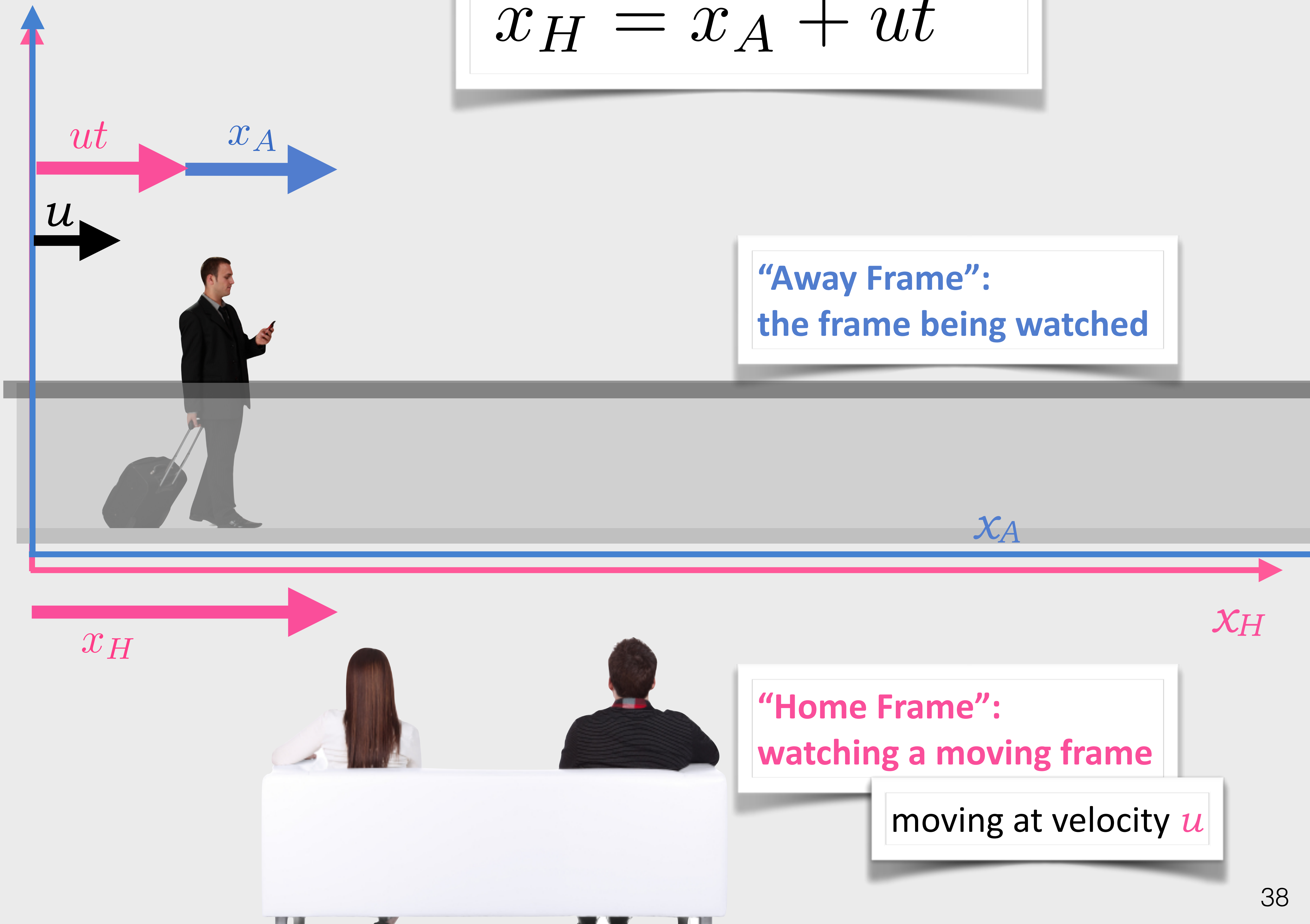
write them in a different Frame

here, Home and Away

the airport

"Galilean Transformation"

$$x_H = x_A + ut$$



"Away Frame": the frame being watched

"Home Frame": watching a moving frame

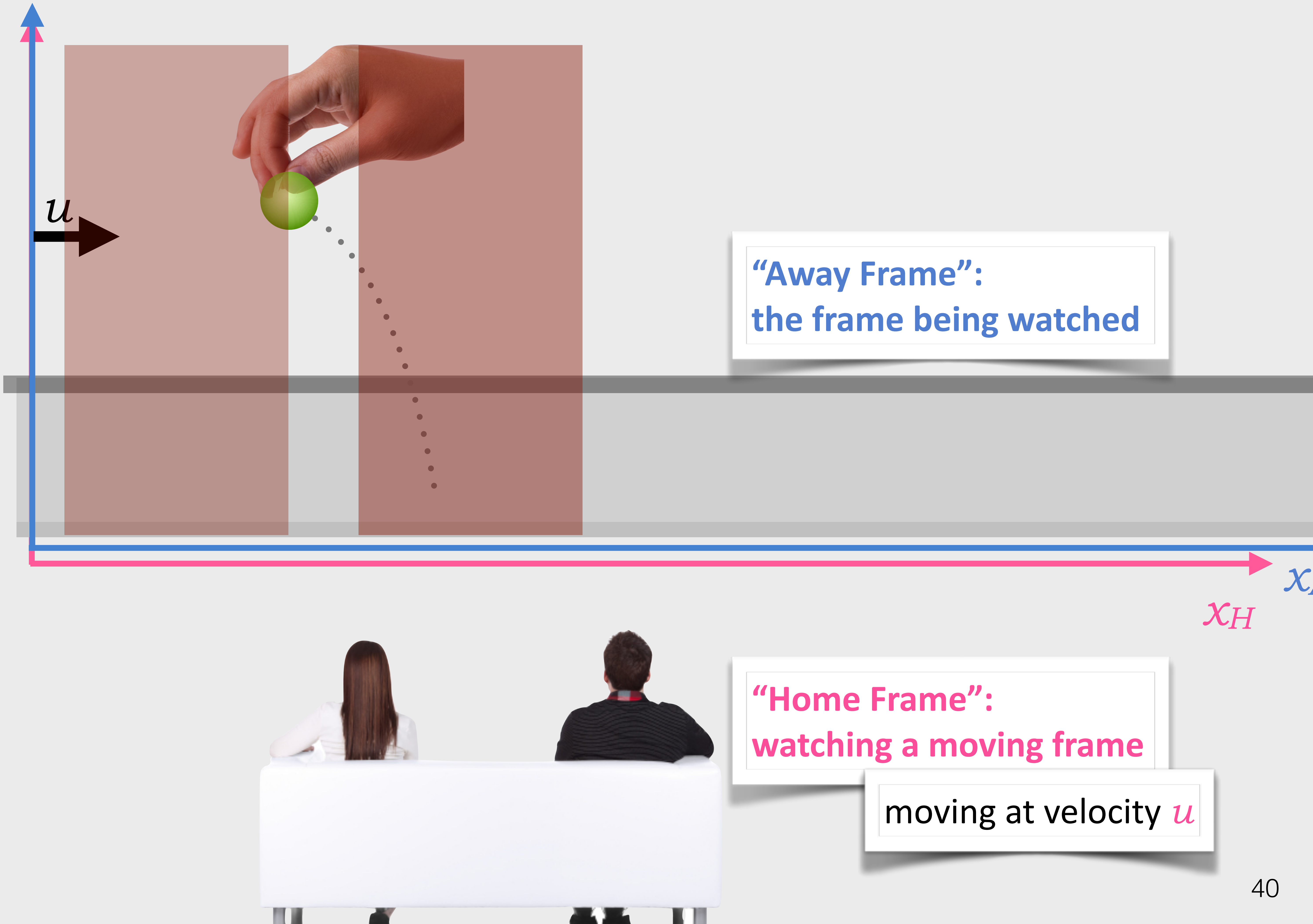
moving at velocity u

Remember, what Galileo said was:

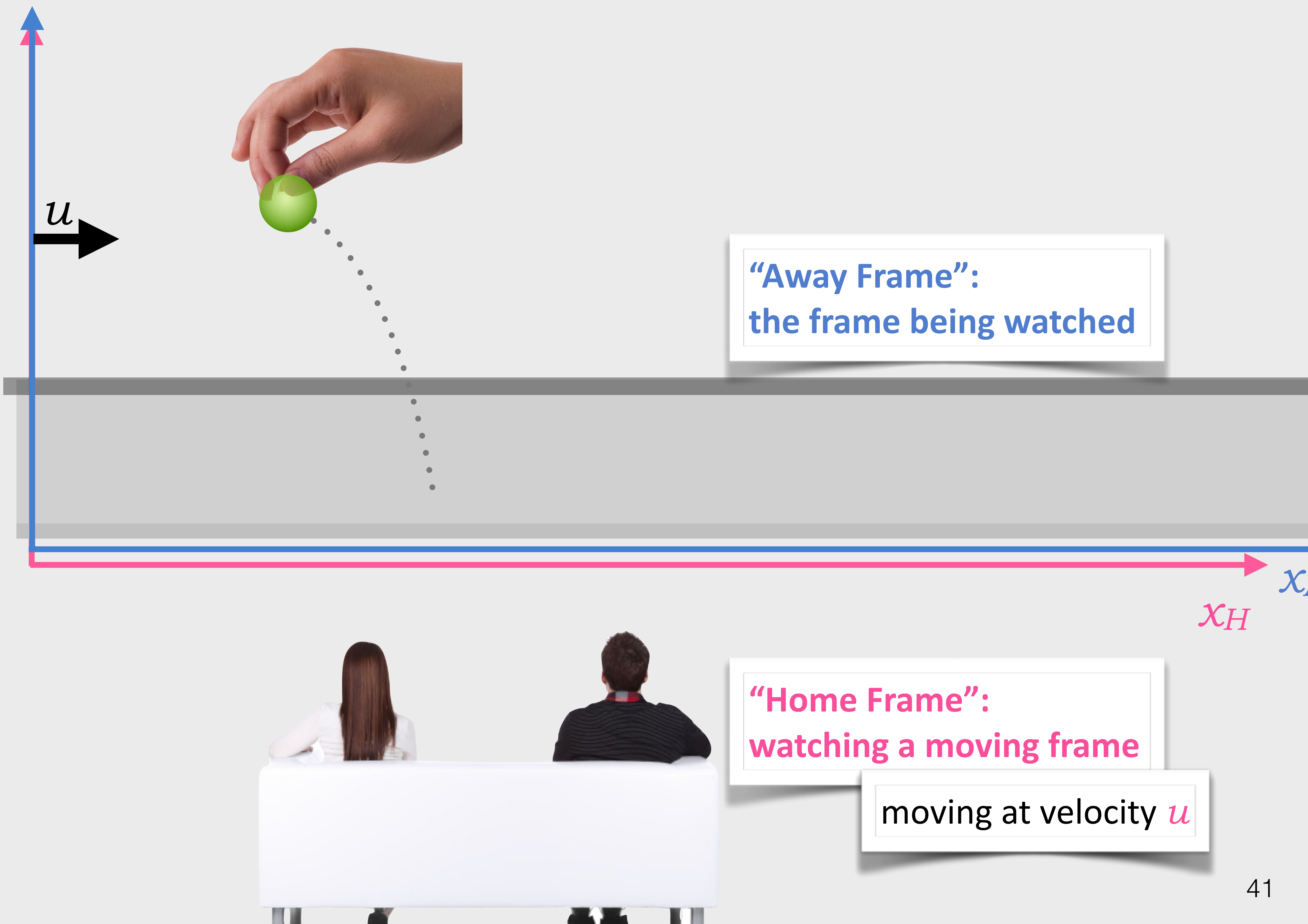
the physics doesn't care

about constant-velocity motion

view from the moving sidewalk:



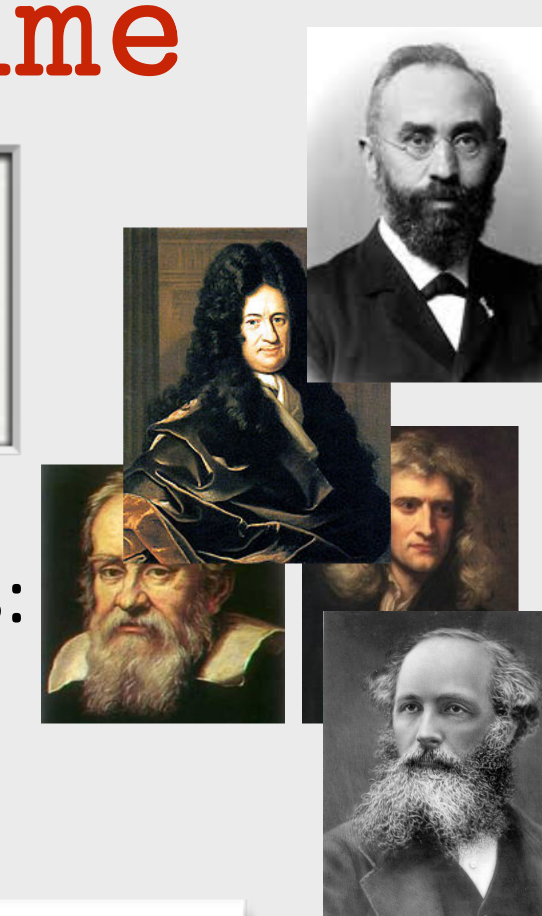
view from the concourse:

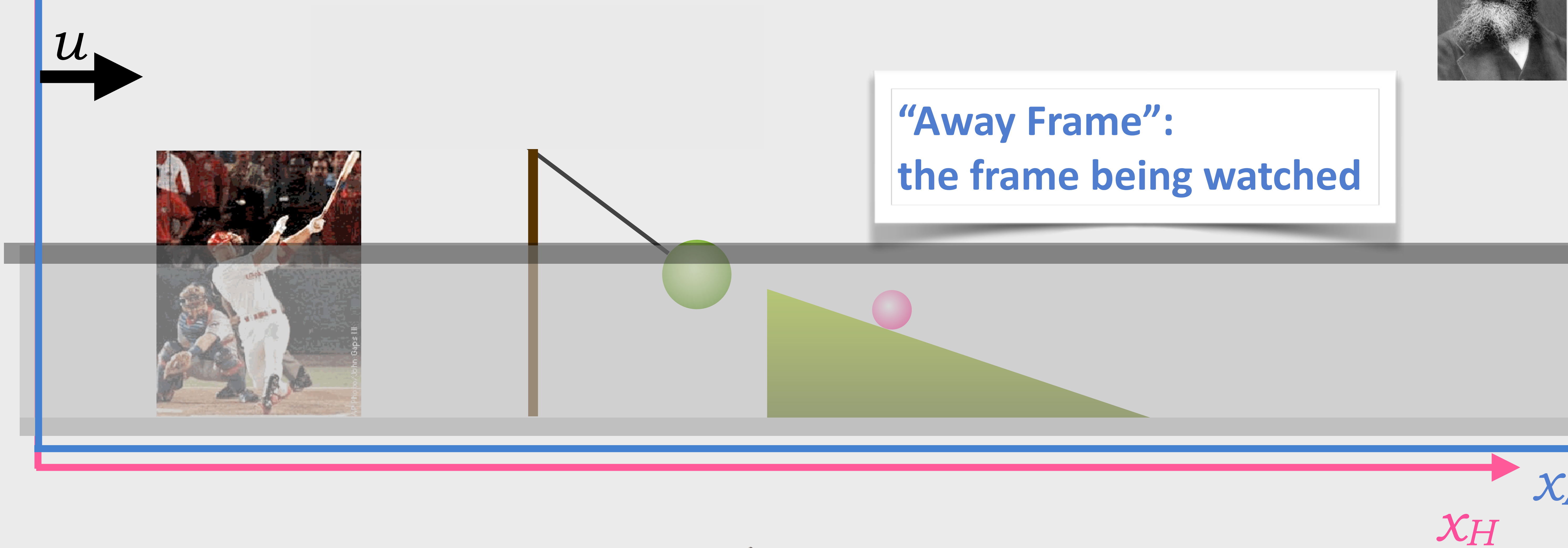


the physics should be the same

Do any mechanical experiment, and the results are the same, regardless of from which Frame the measurements are done

Says:





"Away Frame": the frame being watched

"Home Frame": watching a moving frame

moving at velocity u

what does it mean to say that the "physics is the same"

the "laws"...the equations are no different if you

$x_H \rightarrow x_A$ and $t_H \rightarrow t_A$

In many ways "Relativity" theory is mis-named.
It's not about what changes...but what stays the same.

Here, it's the form of the equations that stay the same...labels don't matter

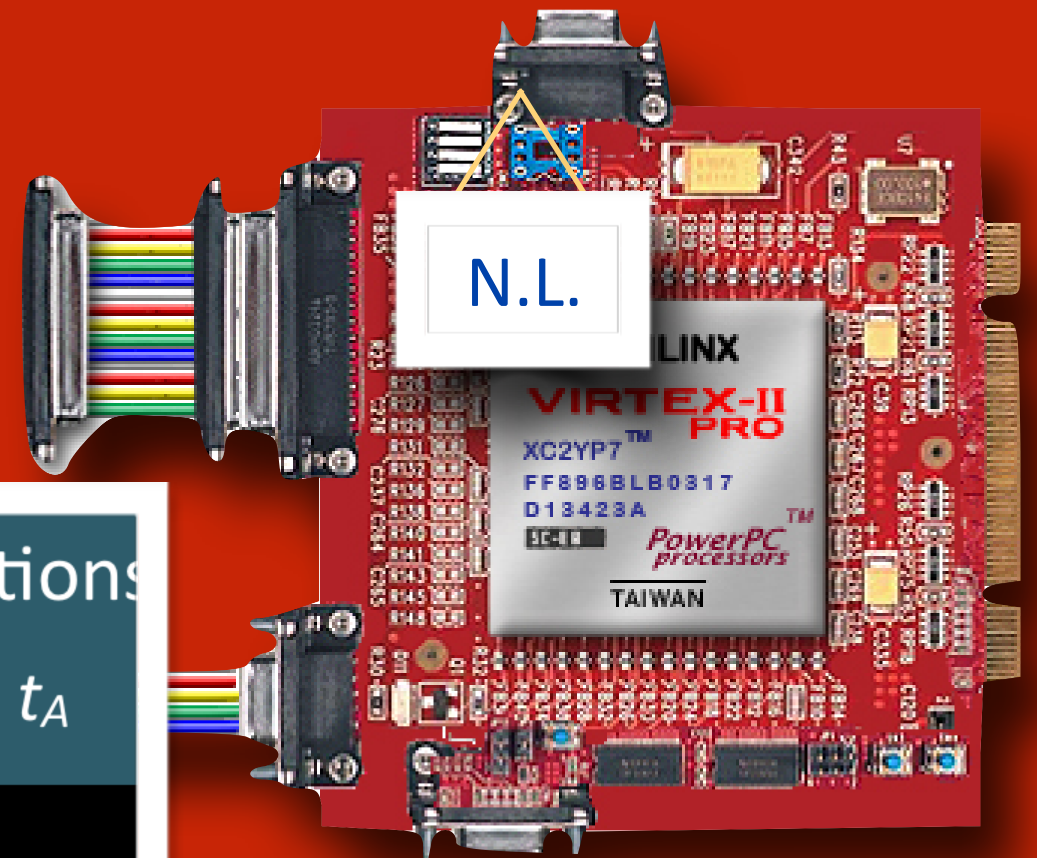
"Galilean Transformation"

$$x_H = x_A + ut$$

NEWTON'S LAWS of DYNAMICS don't change form.

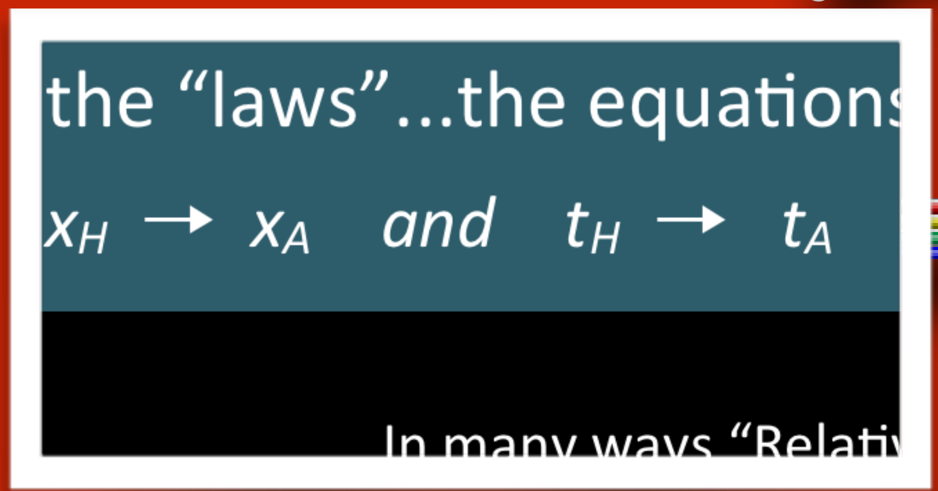
make a Galilean transformation in Newton's Second Law:

$$F = ma_H$$



$$F = ma_H$$

$$x_H = x_A + ut$$



$$F_H = m\frac{\Delta}{\Delta t}\left(\frac{\Delta x_H}{\Delta t}\right) \rightarrow F_A?$$

$$F_A = m\frac{\Delta}{\Delta t}\left(\frac{\Delta x_A}{\Delta t}\right)$$

So mechanical physics seems not to care

what about the other Big System:

Electromagnetism?

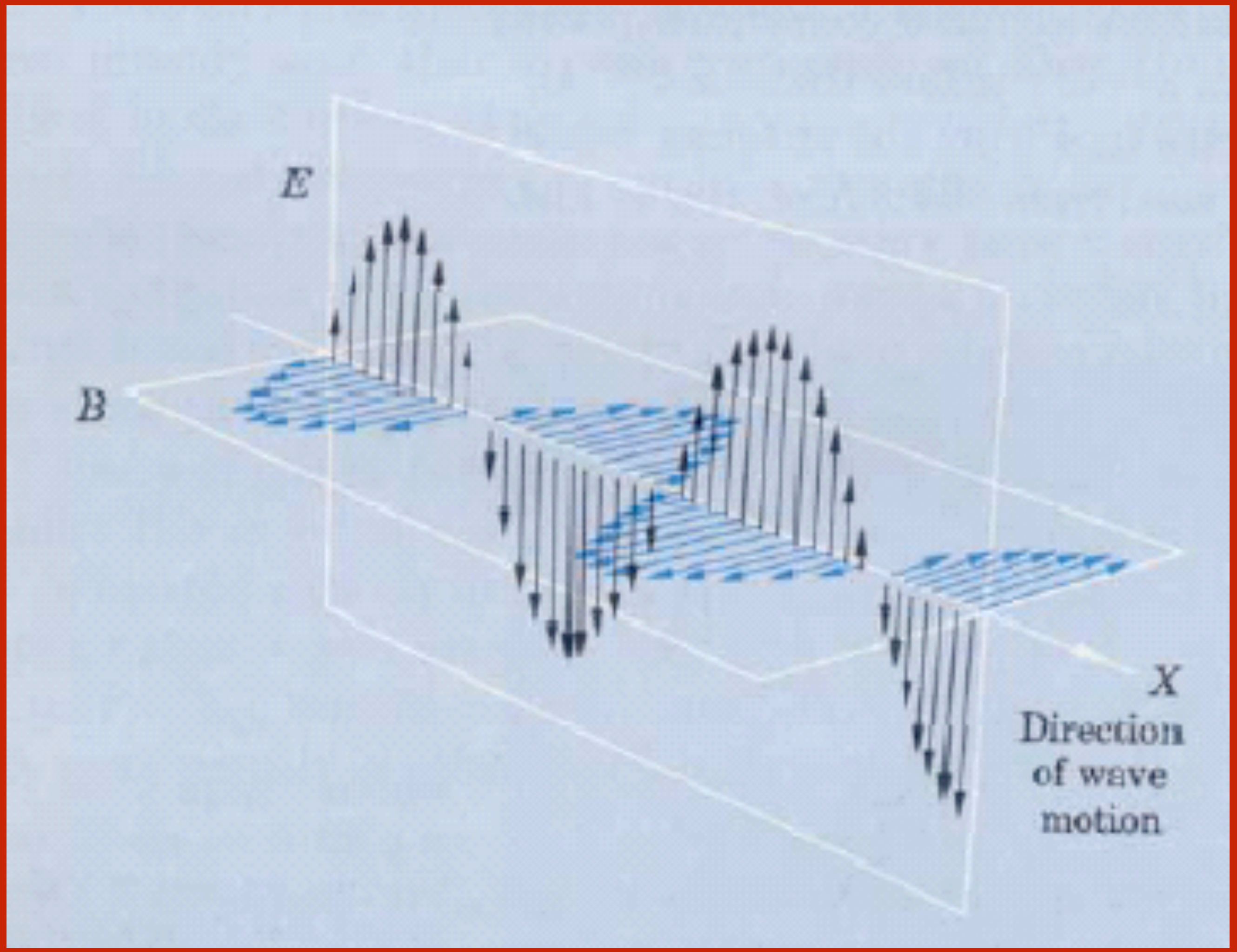
Einstein always asked

simple questions.

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

It’s stopped! No changing E, B!

No wave any more!



since it's a traveling pair of waves

changing E creating changing B

changing B creating changing E

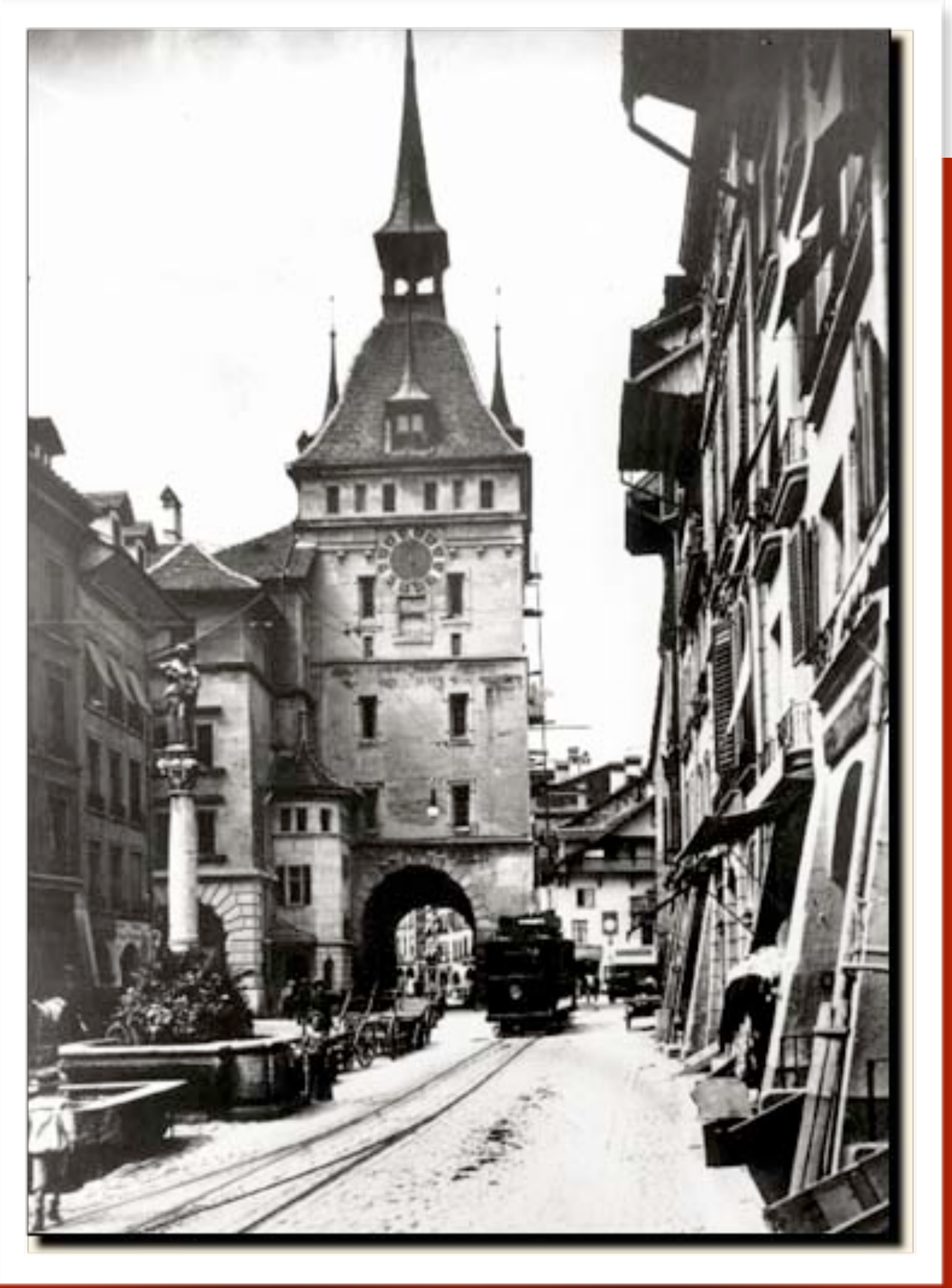
if there's no "changing"...is there light?

in fact

the faster in space you would travel

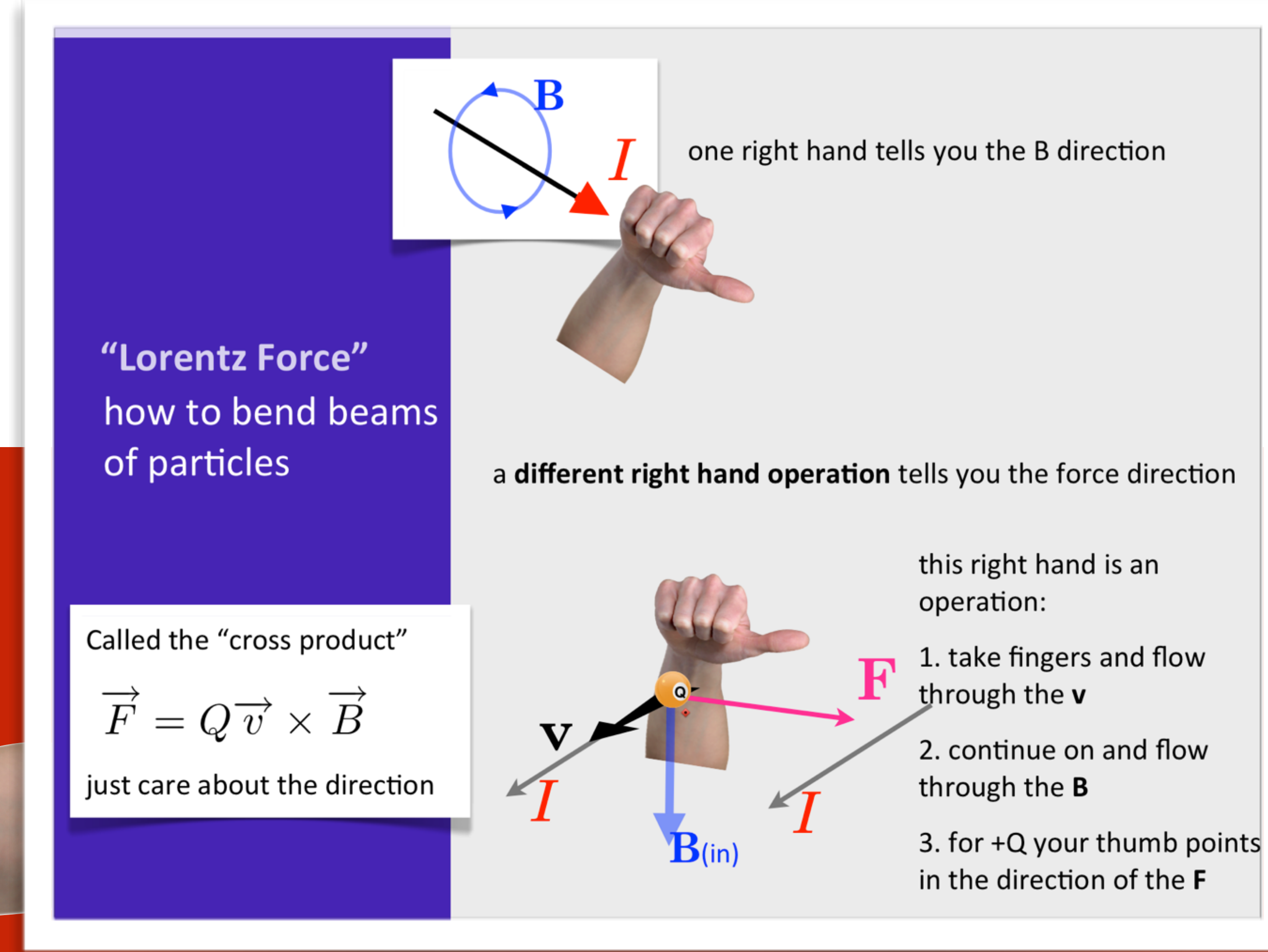
time would appear to stop

a light beam from the clock could not keep up



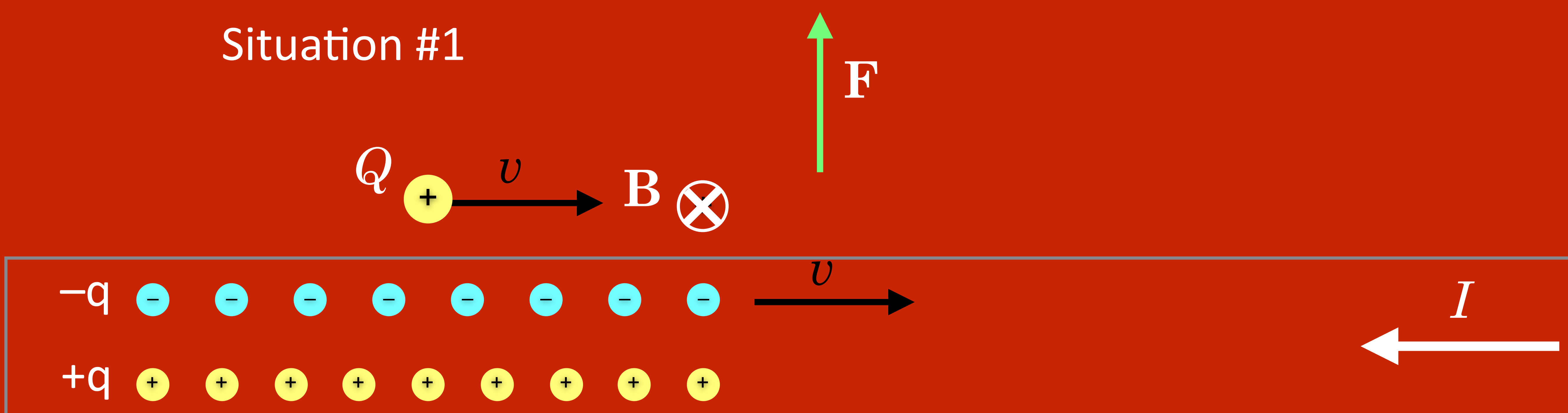
The famous clock tower in Bern, Switzerland
that Einstein mused about

a simple question

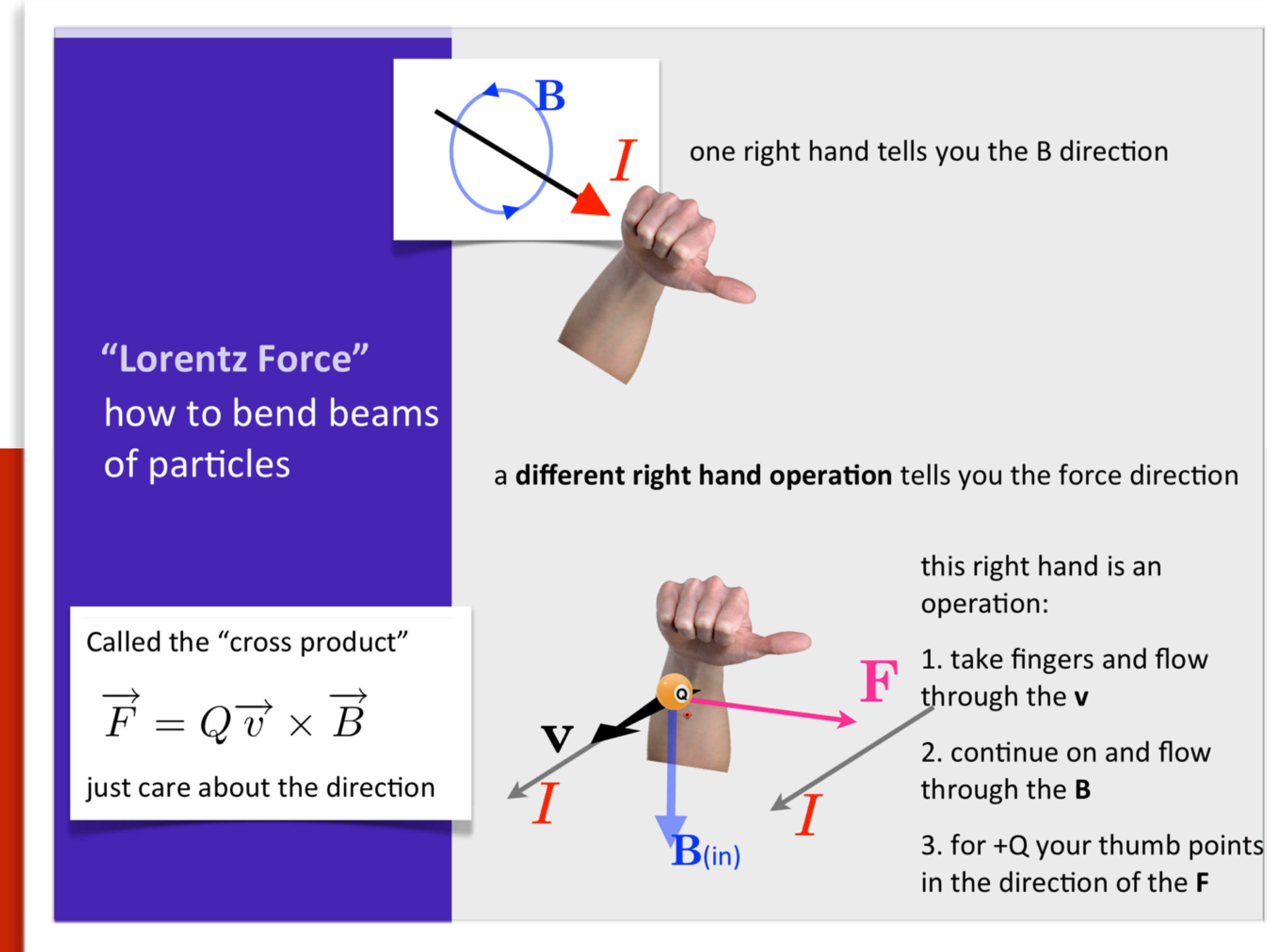


how about a charge next to a current?

Situation #1

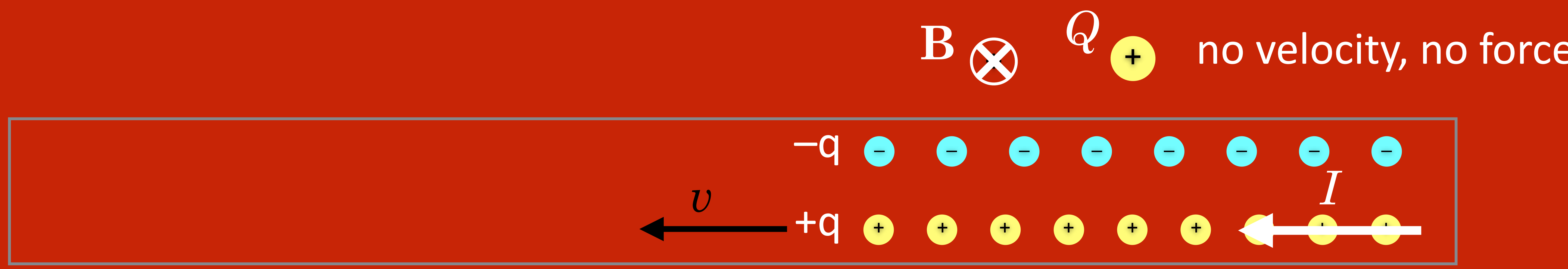


a simple question



how about a charge next to a current?

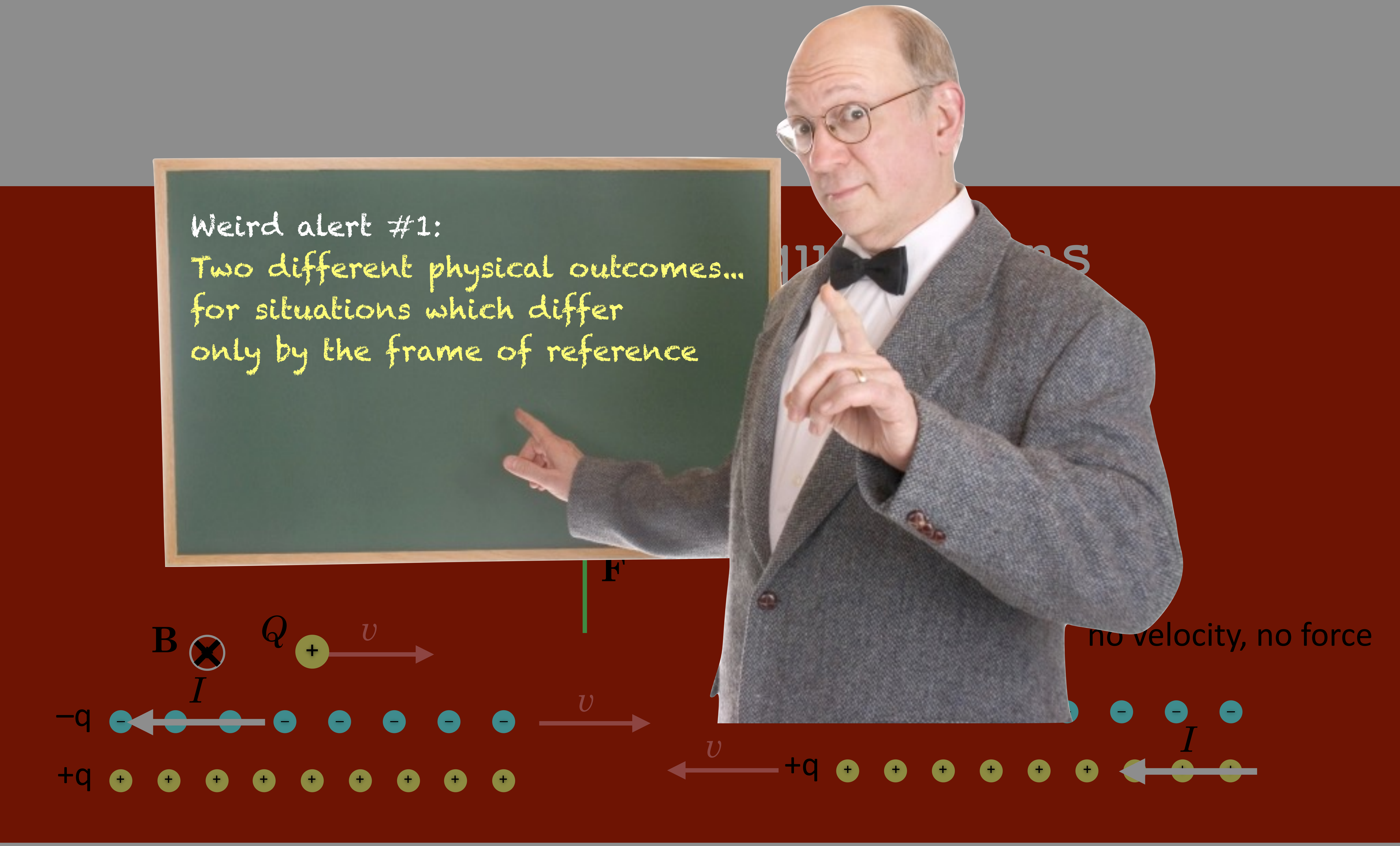
Situation #2



These situations differ only in the reference frame...

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

hold the phone.



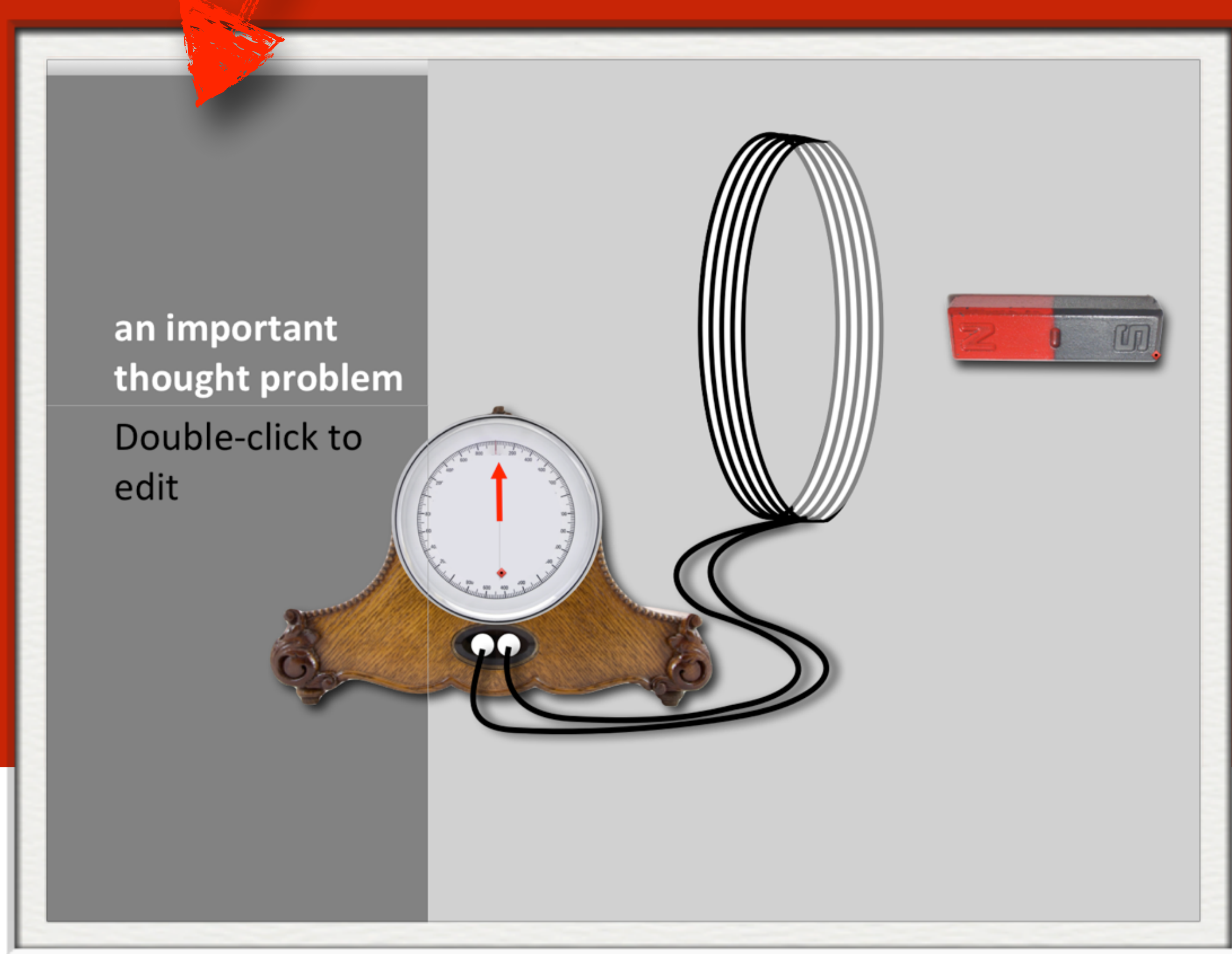
These situations differ only in the reference frame...

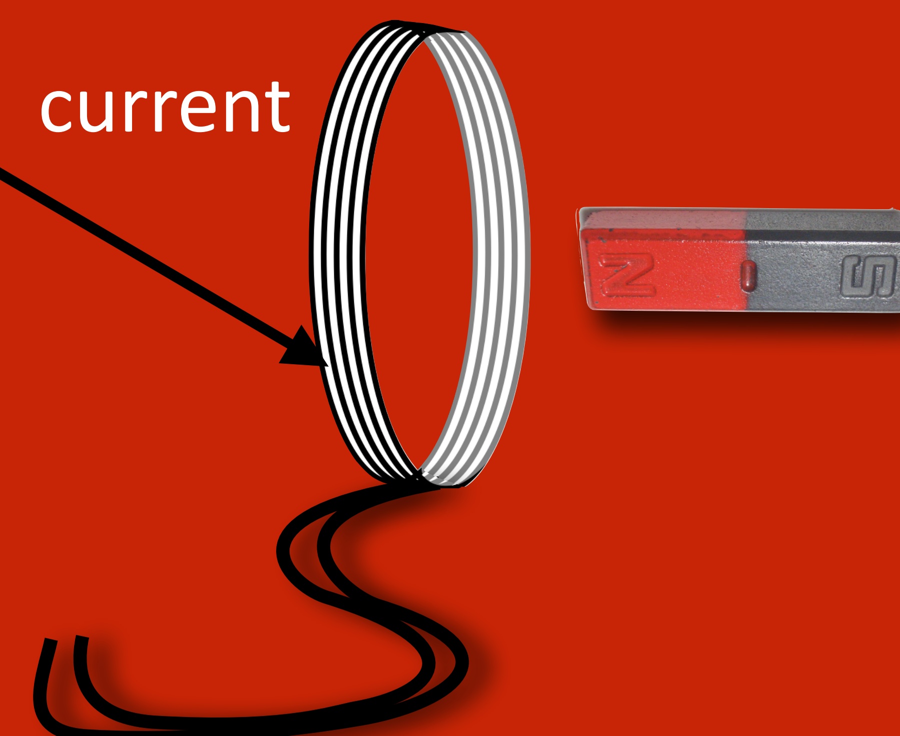
But, the physical effect – force or no force – is different!

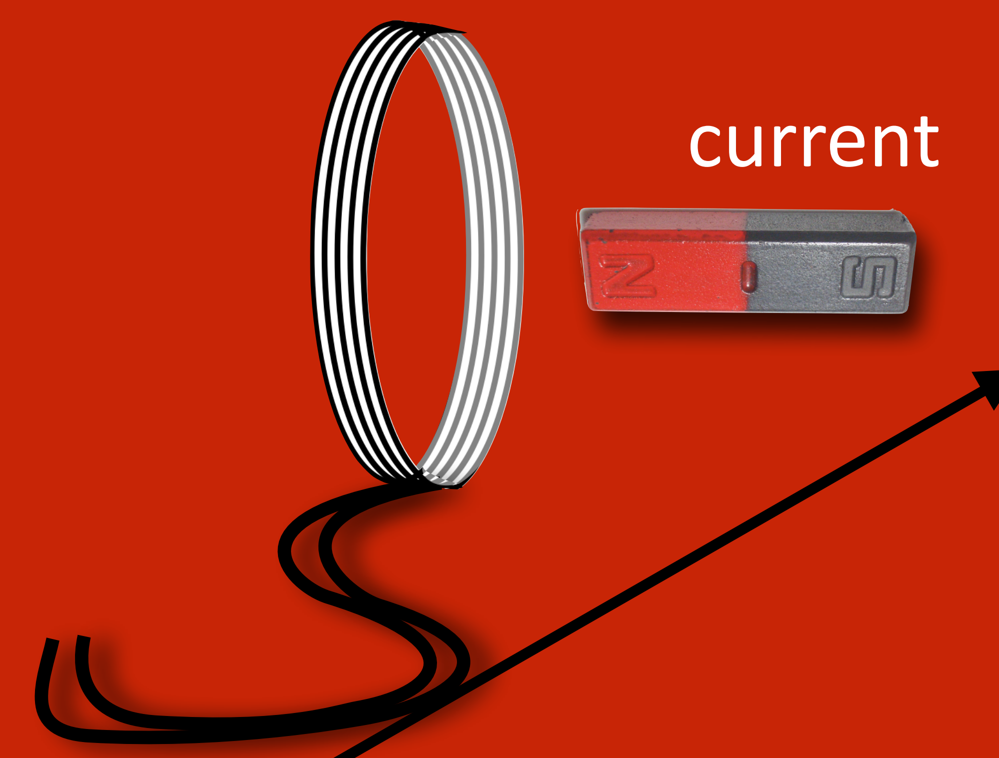
The changing magnetic field creates an electric field in wire
That produces a force on electrons
which moves them in the wire – **which is a current**

here's another one

my favorite coil-magnet





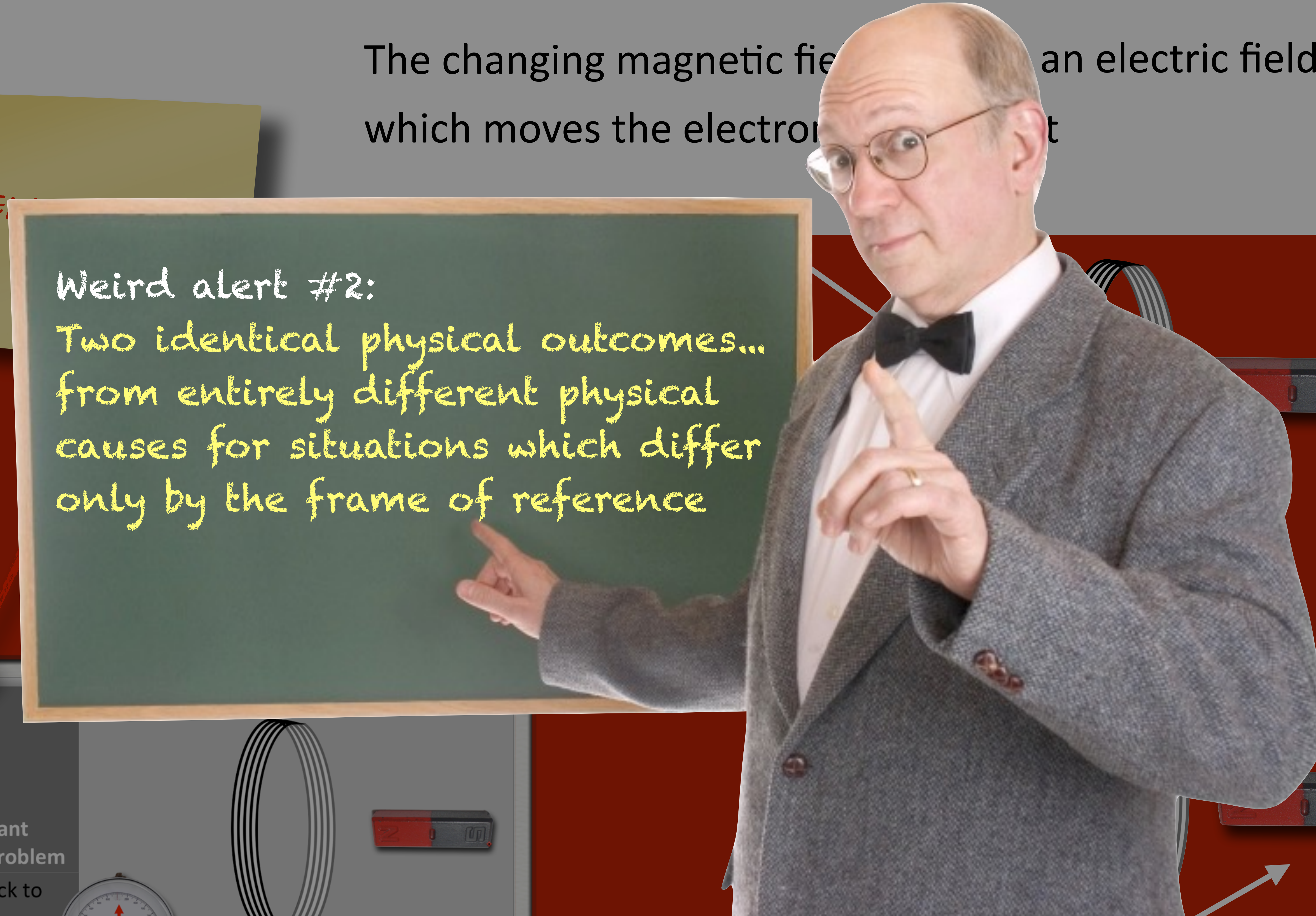


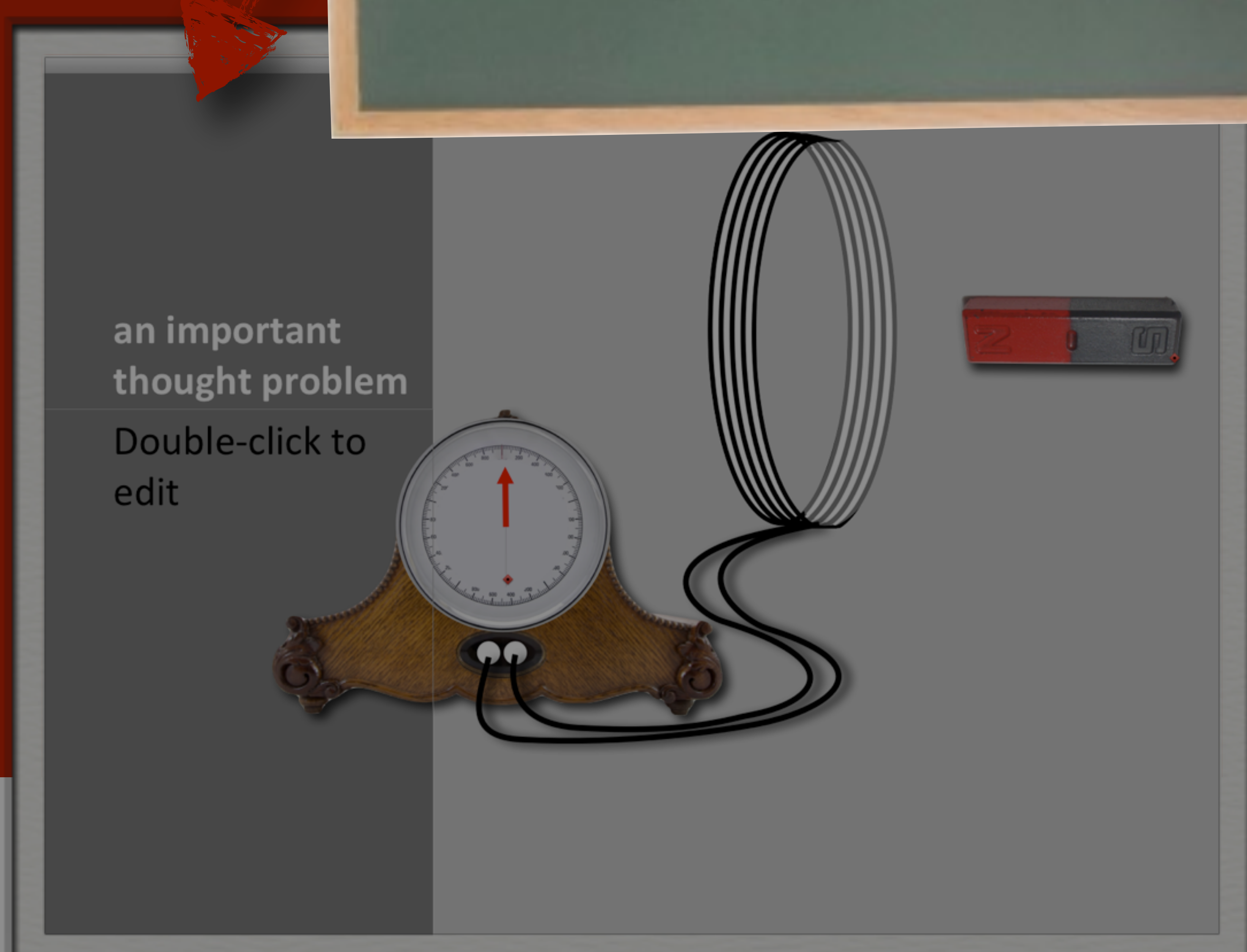
Magnetic field is constant – no electric fields
The electrons in the wire have a velocity passing by a magnetic field...

<u>That</u> produces a force on them – **which is a current**

The changing magnetic fie an electric field in wire

which moves the electro t





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Magnetic field is constant – no electric fields

The electrons in the wire have a velocity

That produces a force on them – a current