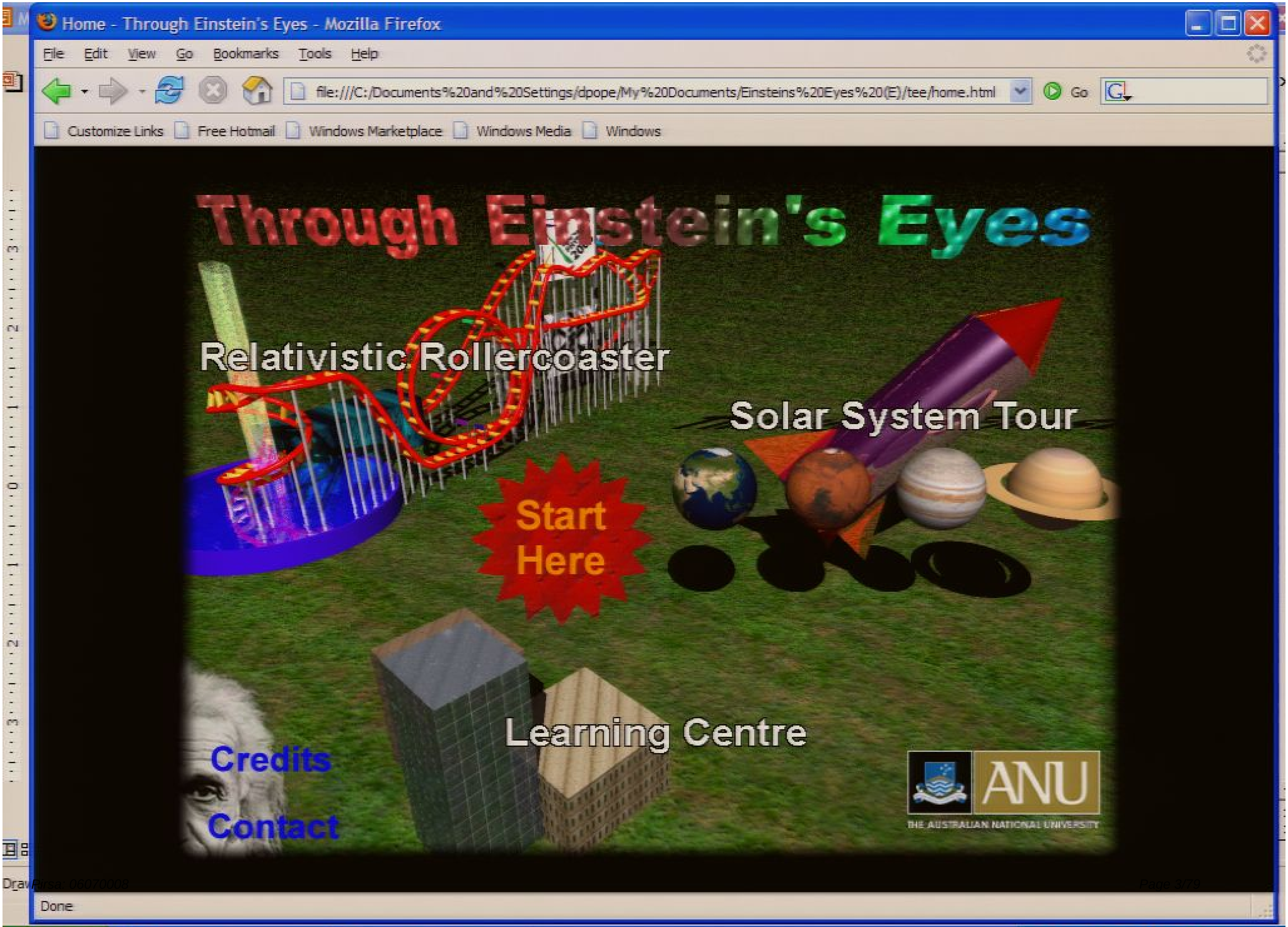
Title: Enrichment Presentation on Special Relativity

Date: Jul 06, 2006 09:00 AM

URL: http://pirsa.org/06070008

Abstract:

Core concepts of special relativity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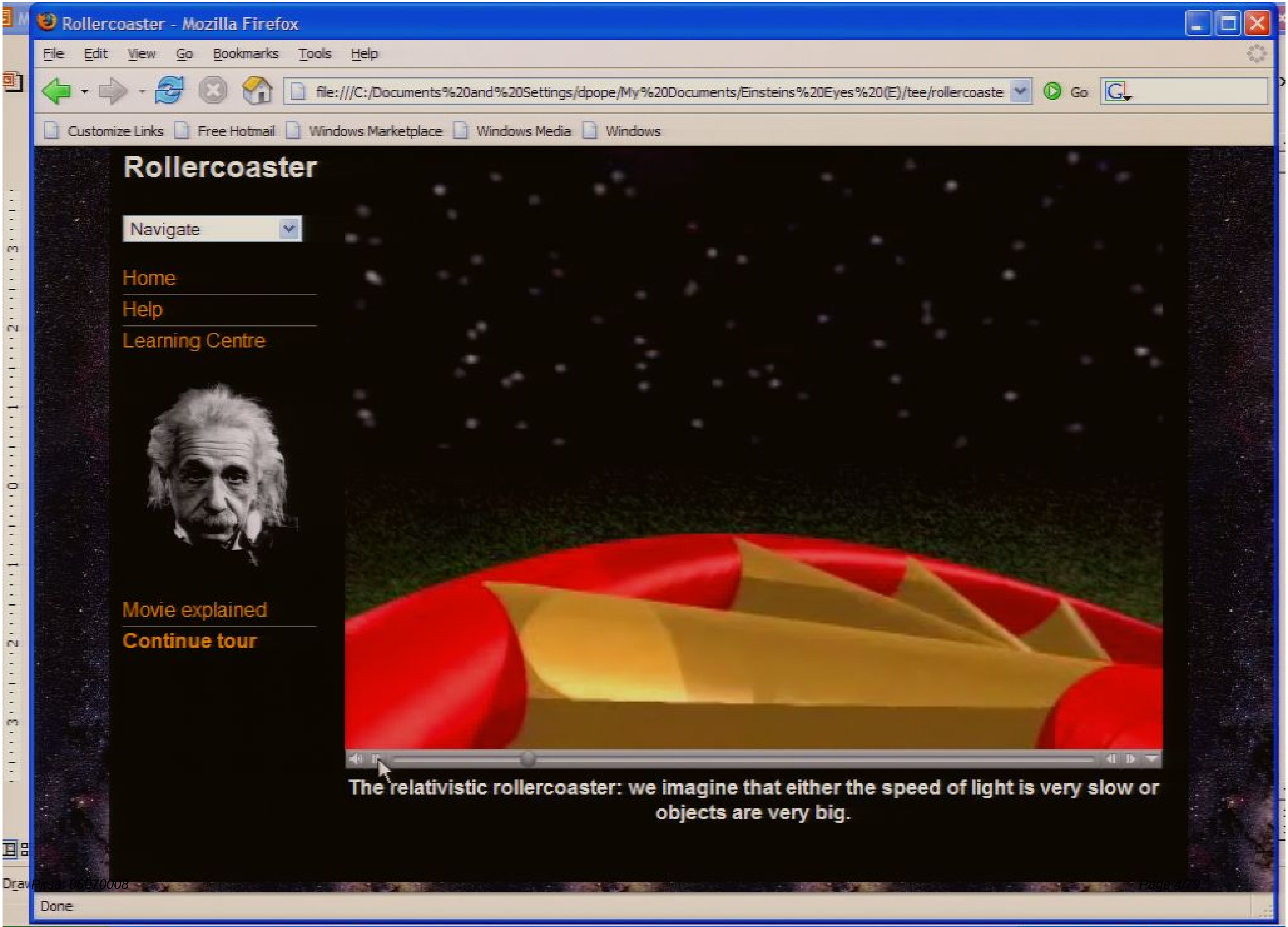
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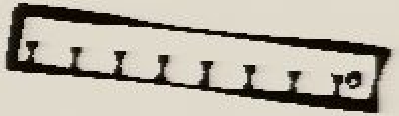
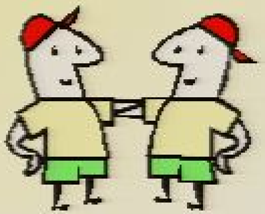
The relativistic rollercoaster: we imagine that either the speed of light is very slow or objects are very big.
Done

Summary

- Two postulates of special relativity
- Plotting happenings (events) in space and time: spacetime diagrams.
- Metric for spacetime
- Switching reference frames
- Time dilation and length contraction revisited



- The twin paradox



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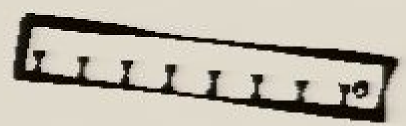
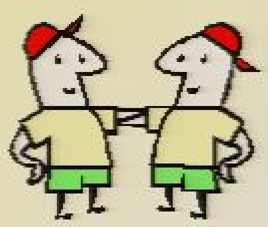
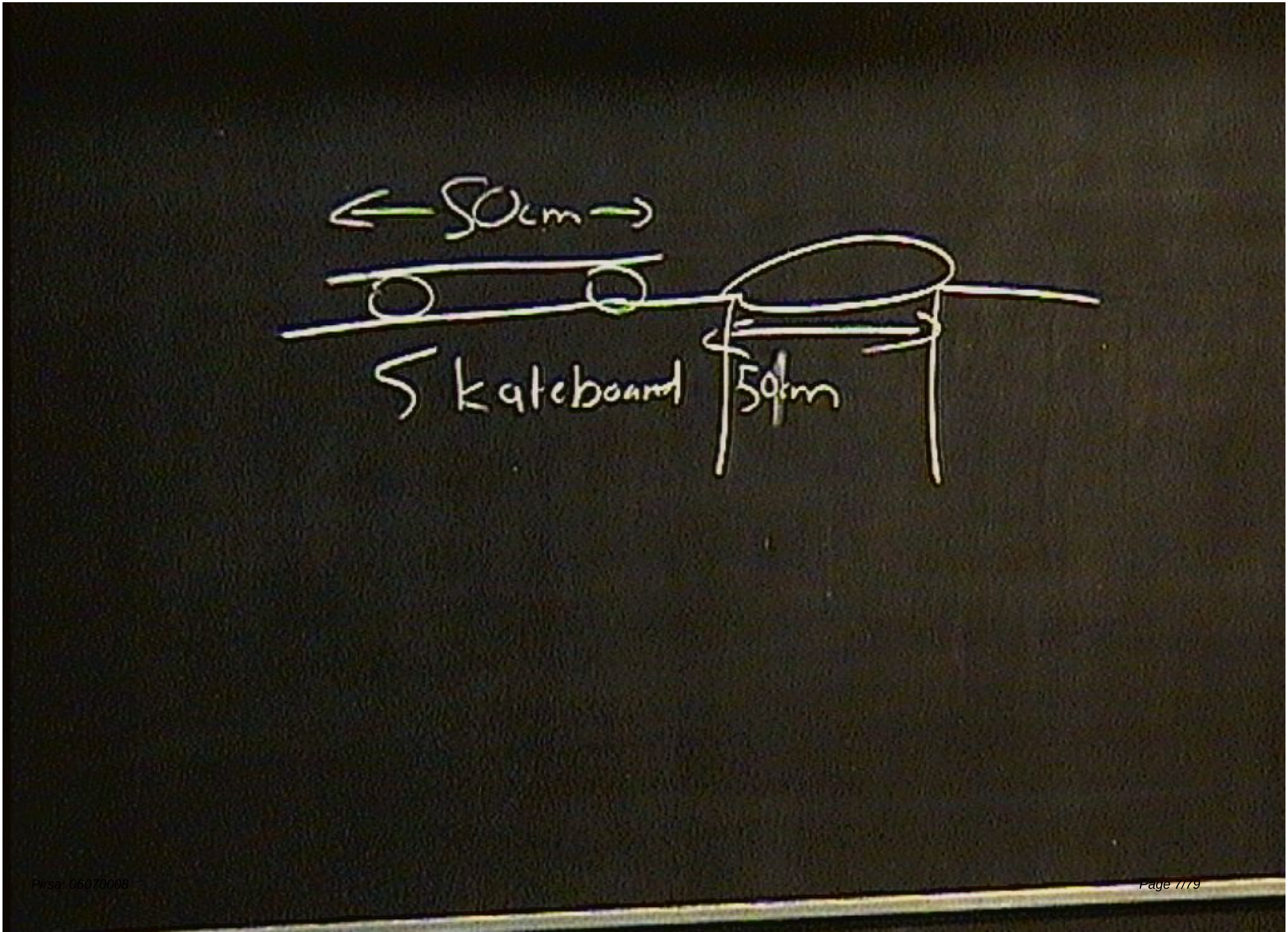
- Time dilation and length contraction revisited  
- The twin paradox 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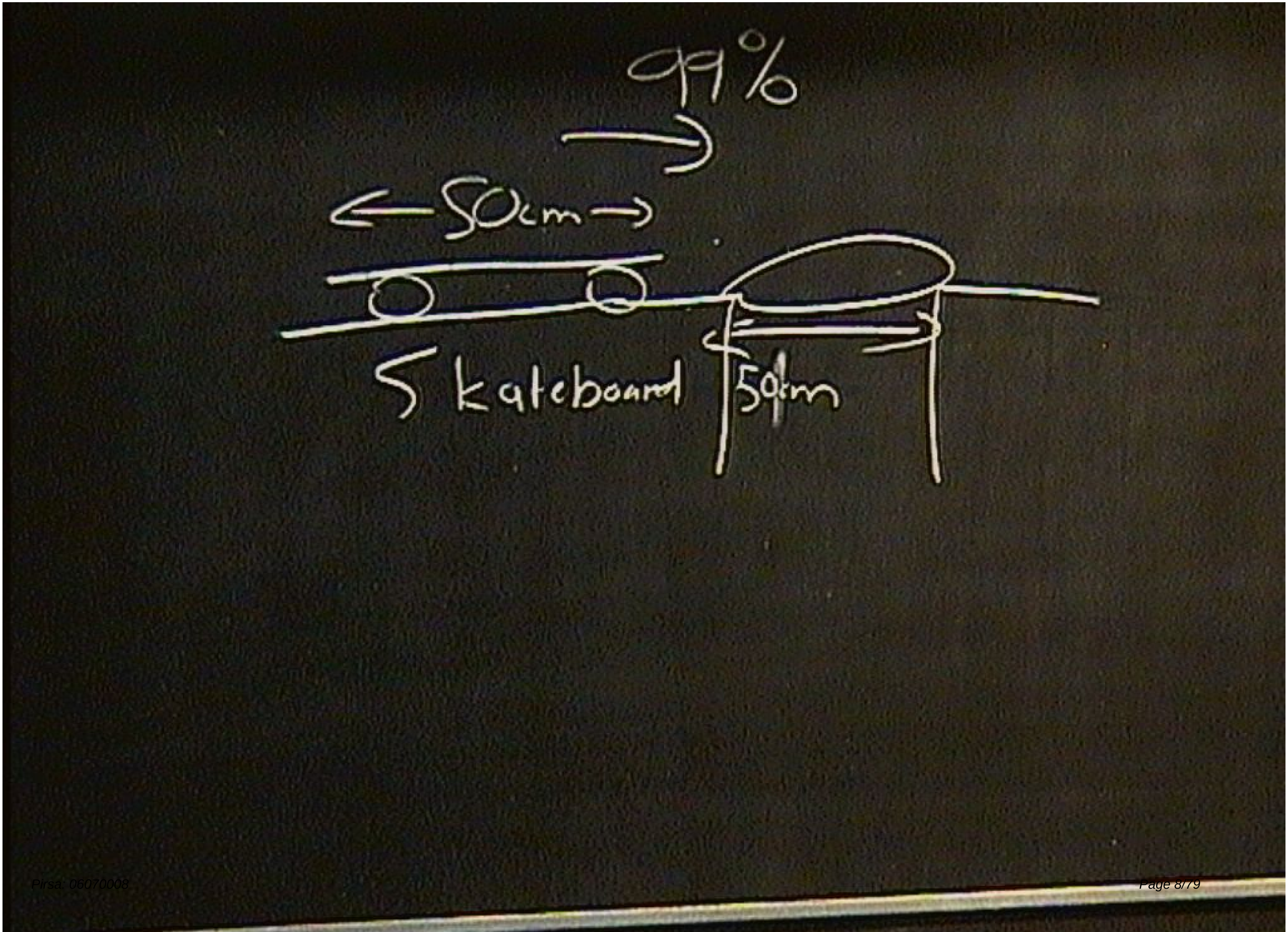
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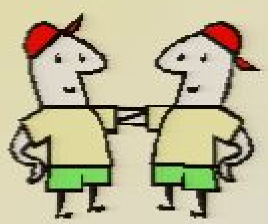
- The twin paradox 

Some background to special relativity

- Einstein at 16 years of age: daydream about riding alongside a beam of light
- Overturned more than 200 years of thinking about space and time.
- Cultural impact
- theory about space, time and motion
- What happens to these three things as relative velocities change.
- Only deals with constant velocities, no acceleration.

Twin postulates of special relativity

- 1. **Relativity Postulate:** The laws of physics are the same in all inertial reference frames.
- 2. **Speed of light postulate:** Light travels at the constant speed of c (3×10^8 ms^{-1}) through empty space relative to all inertial observers.
- *What is an inertial reference frame?*
  No acceleration.
  Newton's first law holds.
- Consider the relativity postulate:
  Physics should be universal, democratic

  In 1905, it was both revolutionary and pre-dated.

- Galileo in the 17th century: The laws of *mechanics* are the same in all inertial reference frames.

- Revolutionary aspect of the relativity postulate was that Einstein broadened ‘mechanics’ to ‘physics’.

- Part of Einstein’s genius was to boldly believe that that the laws of electromagnetism (Maxwell’s equations) applied to all inertial observers, even though he knew that this had radical implications. (Eg. he knew that this implied that the speed of light was independent of an observer’s velocity relative to the light’s source).

- One view of the relativity postulate:
- One morning, you wake up and find yourself in an unfamiliar room.
- A strange man and a women walk up to you and say ‘You have been kidnapped. But, we will let you go if you can tell us if the room is i) fixed to the ground and stationary with respect to it or ii) inside a a plane flying at very low altitude at a constant velocity with respect to Earth.
- The relativity postulates says that there is no way to reliably distinguish between the two possibilities, no matter what equipment you have (provided you cannot get information from outside of the room. Eg. calling an outside friend).

Speed of light postulate

- Crudely speaking, 'Everyone measures light to travel at c'.
- Counter-intuitive

- What speed will you see the snowball moving towards you at?
  a) 45 kmh^{-1}
  b) 15 kmh^{-1}
  c) 2 kmh^{-1}
  d) 30 kmh^{-1}

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- What speed will you see the light moving towards you at?

  a) c

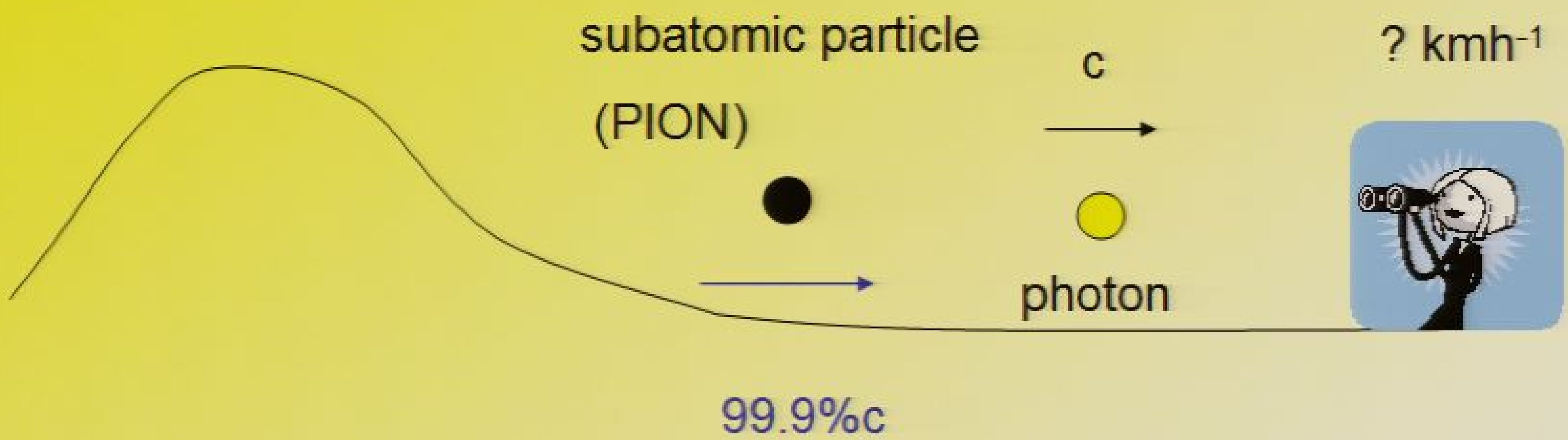
  b) c + 30 kmh^{-1}

  c) c - 30 kmh^{-1}

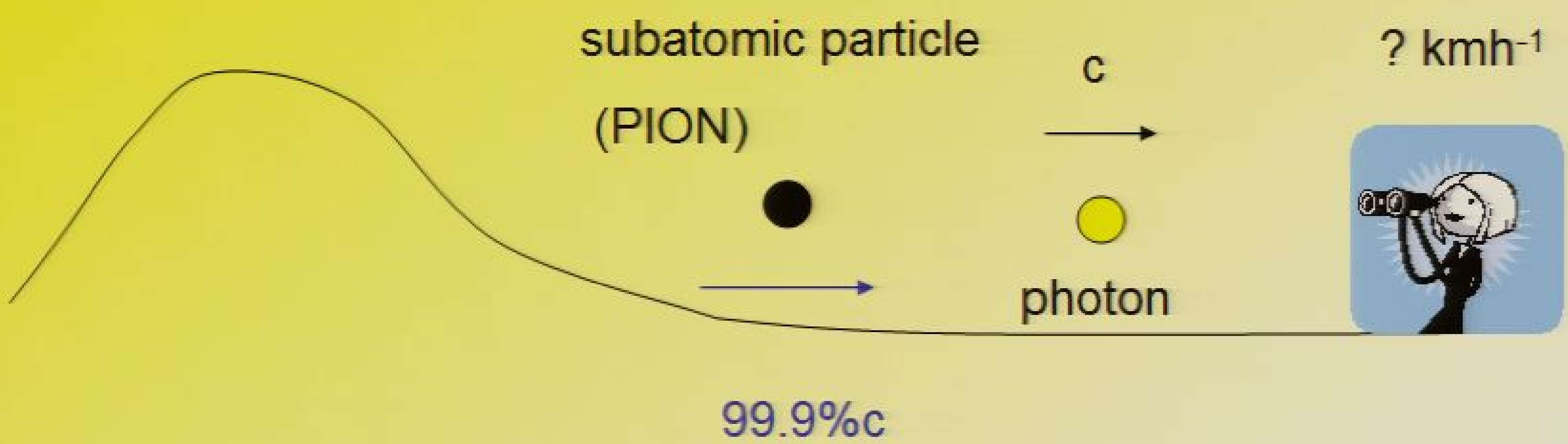
  d) c/(30 kmh^{-1})

What speed will you see the light moving towards you at?

a) c
b) c + 100,000 kms^{-1}
c) c – 100,000 kms^{-1}
d) c/(100,000 kms^{-1})



- What speed will you see the light moving towards you at?
- a) c
- b) 199.9% c
- c) 99.9% c
- d) 50% c



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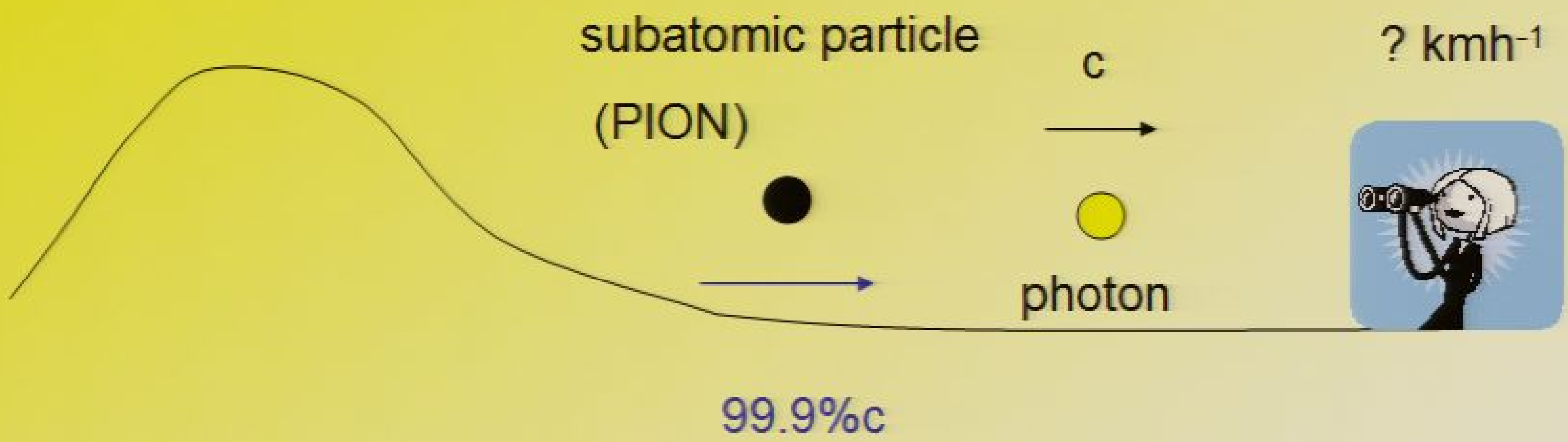

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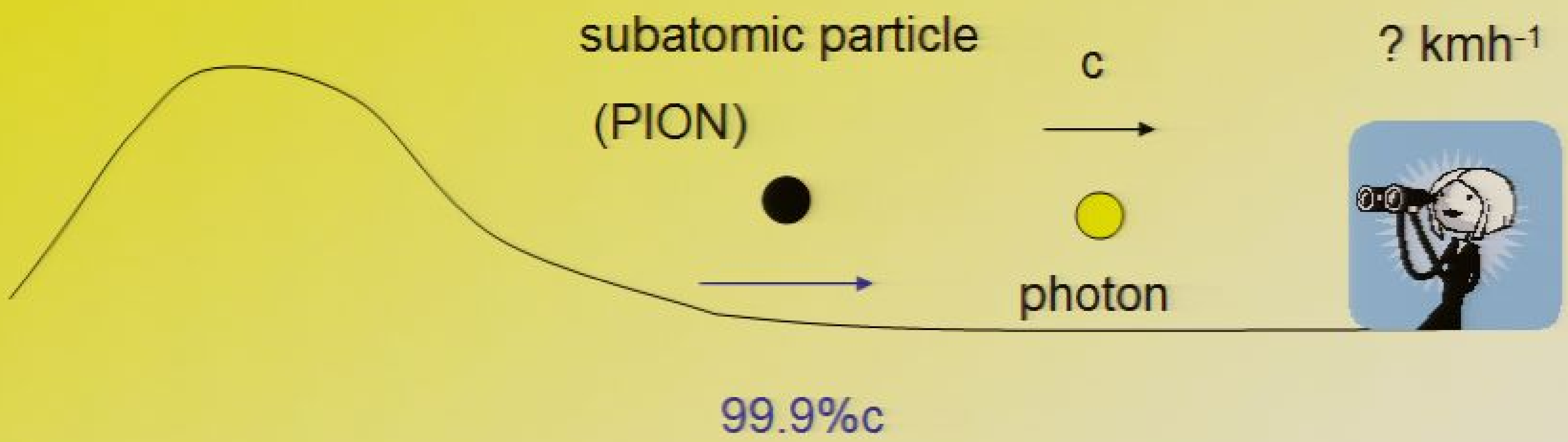

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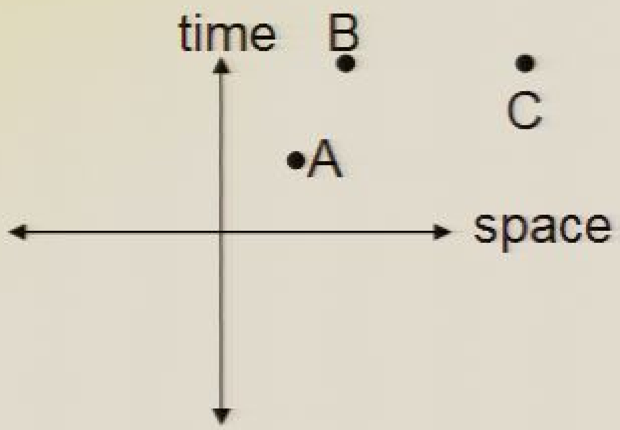
Spacetime diagrams

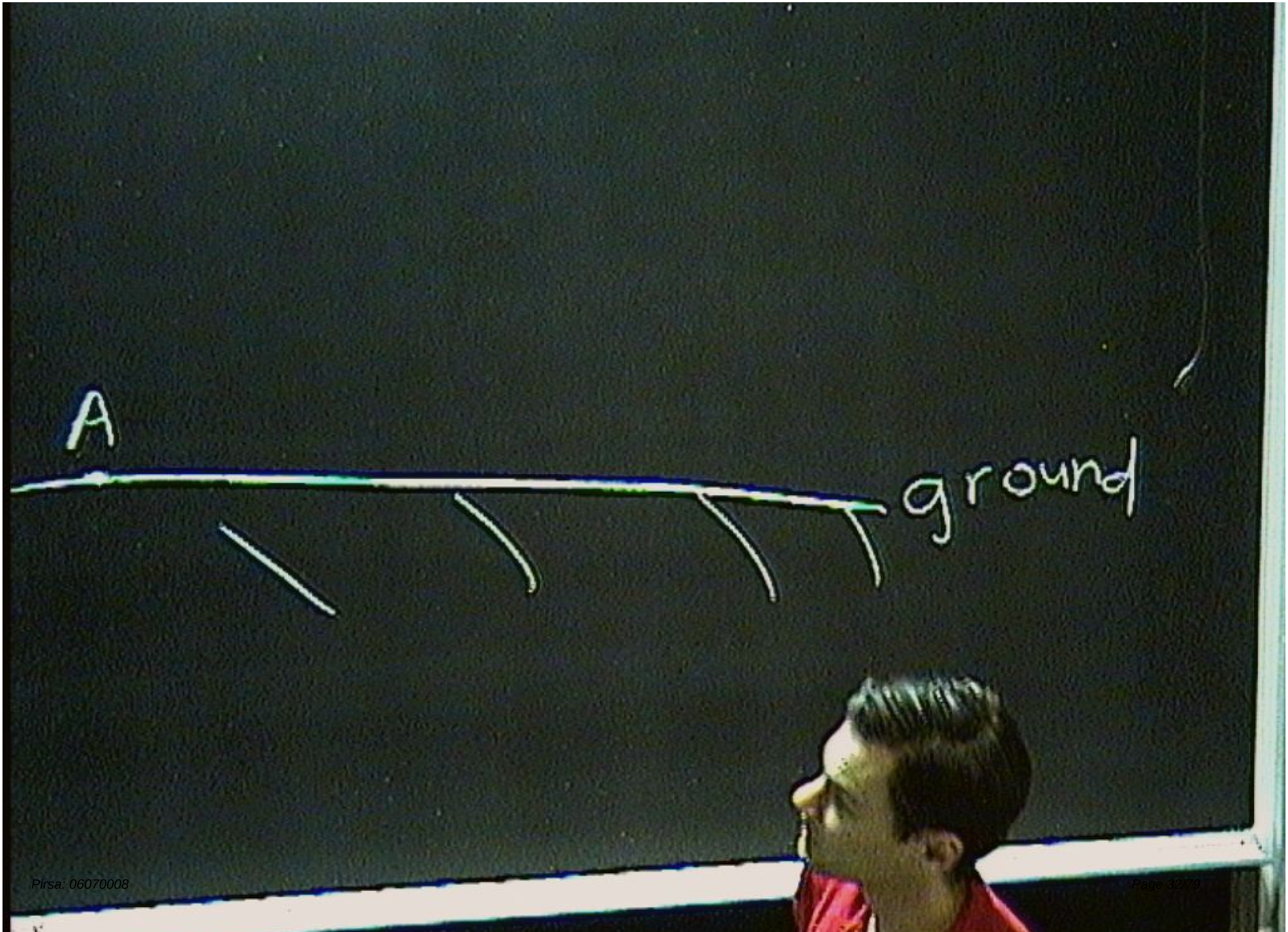
- Consider the following unrelated happenings or *events*.
  An apple falling from a tree, (A)
  A bird taking flight from a tree, (B)
  A car coming to a stop at a set of traffic lights, (C)

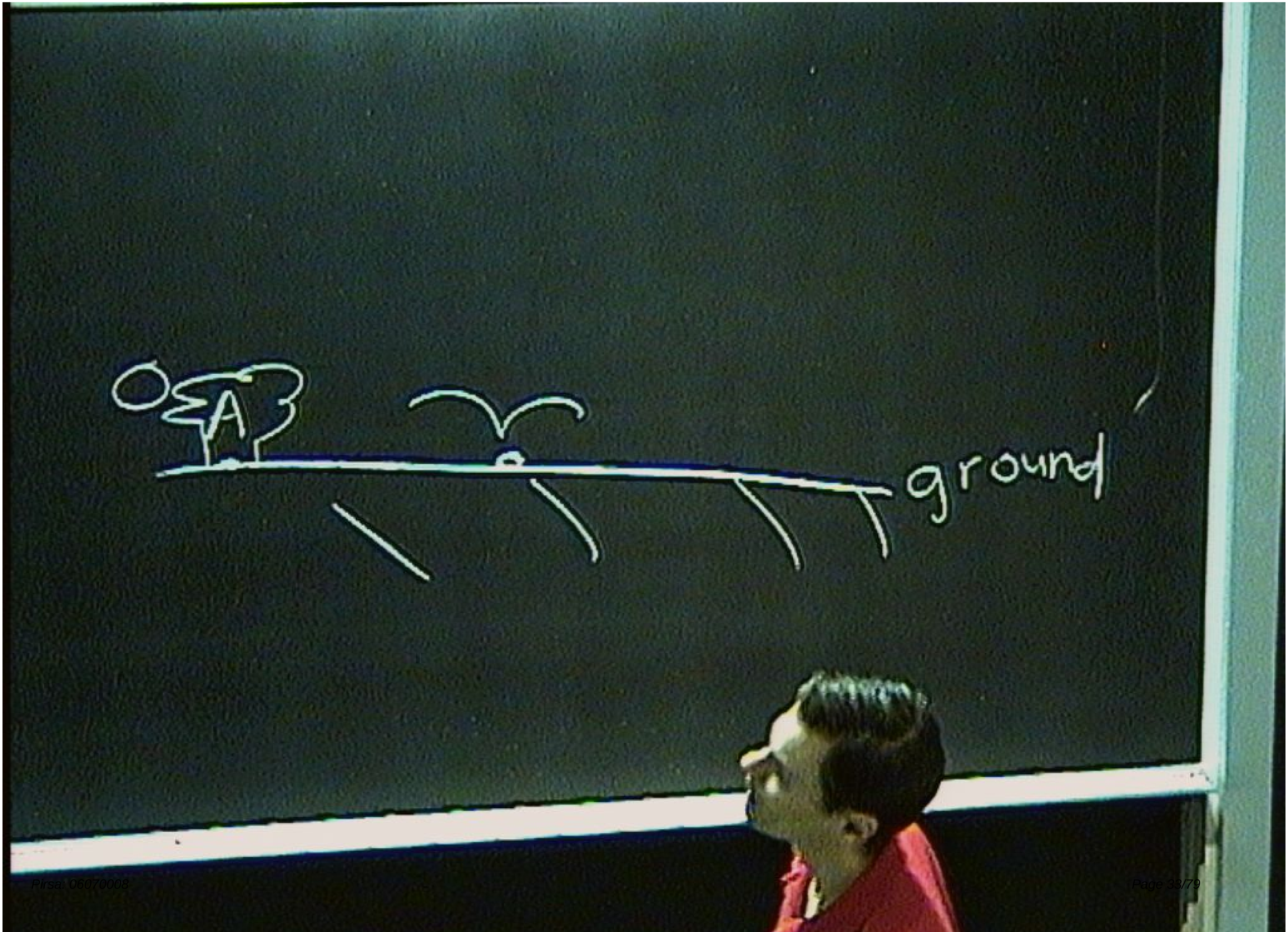
  They all occur at a particular location and time

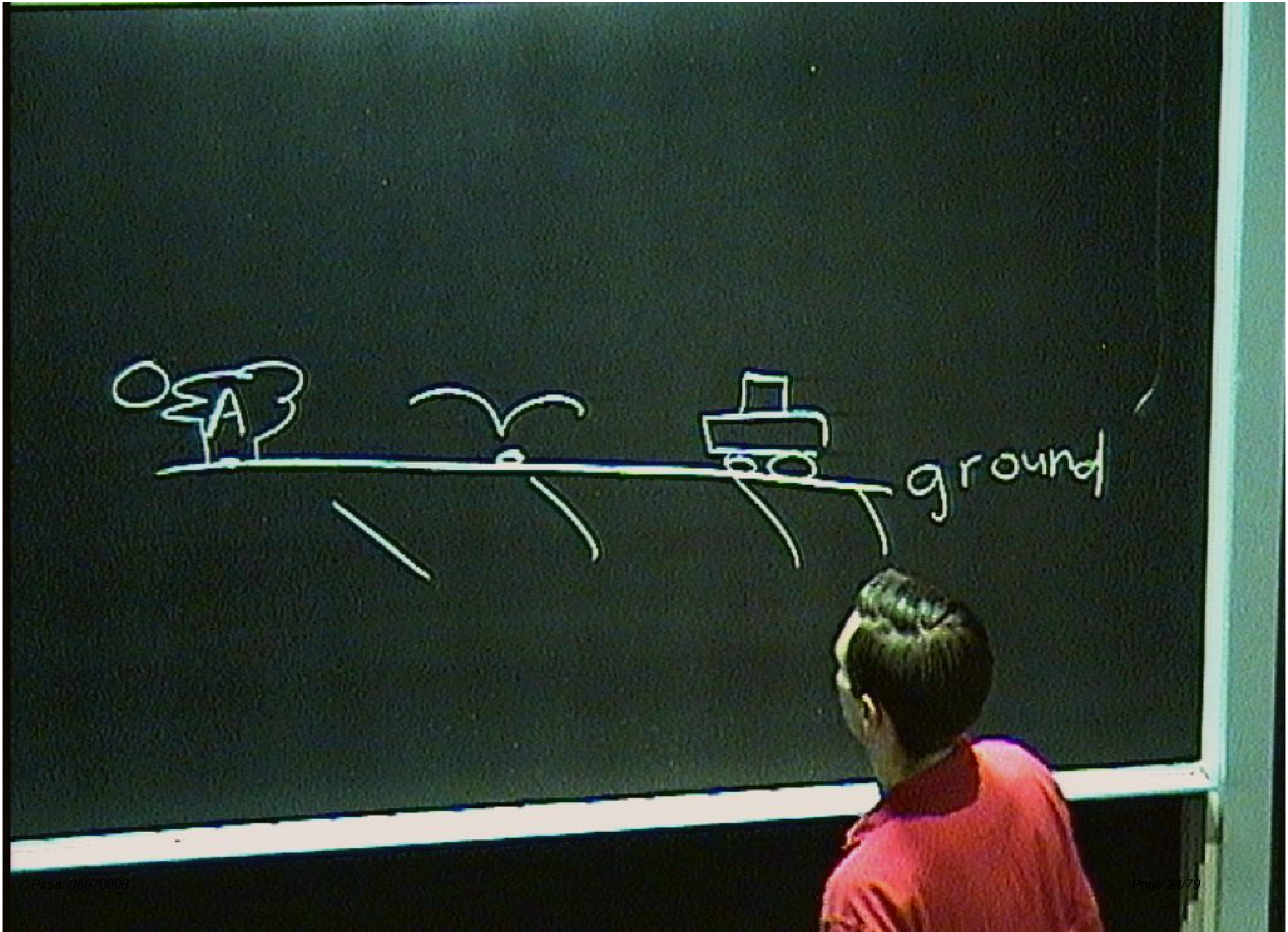
- Natural to plot or represent them graphically on a graph with space and time axes.

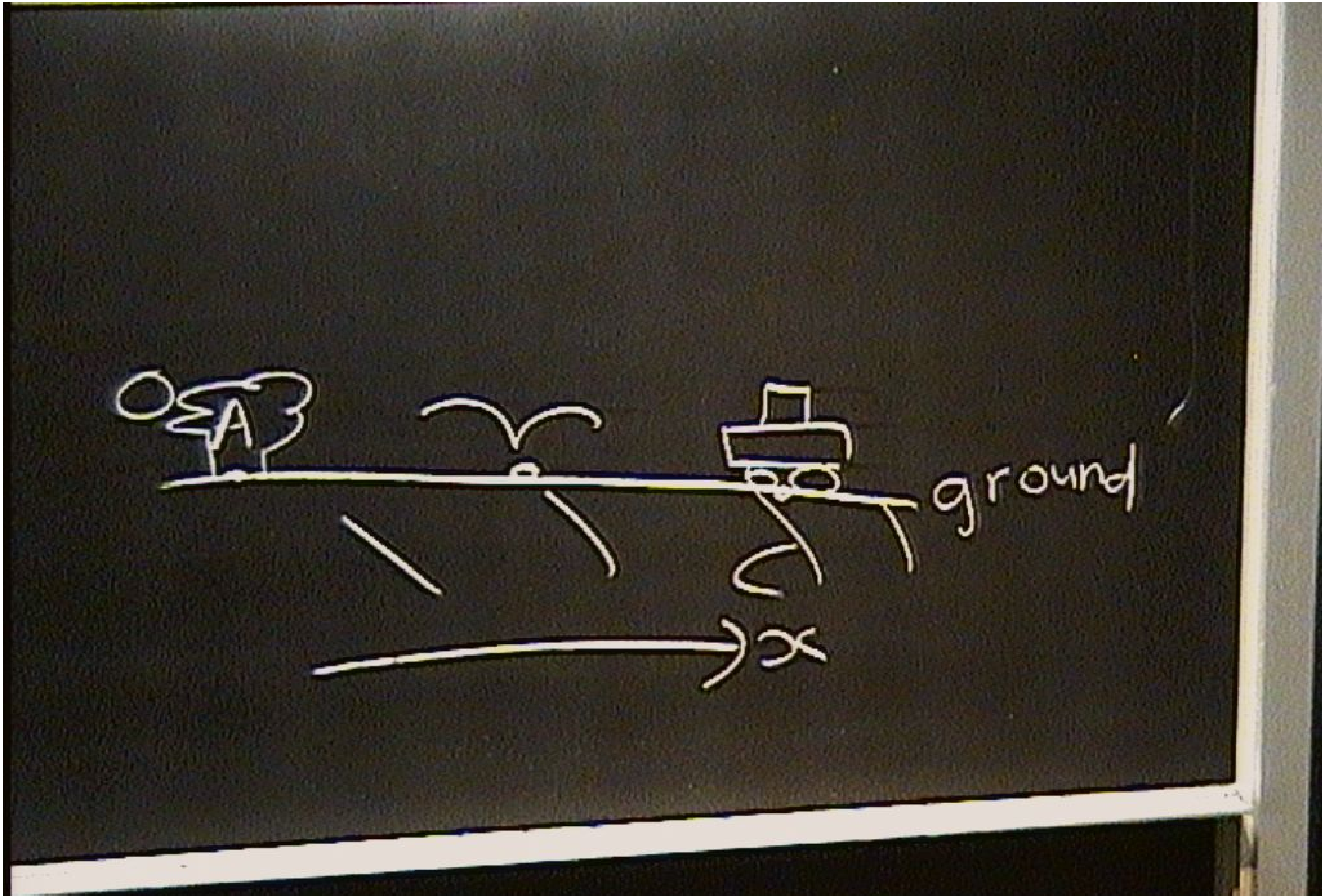
- By convention, we put time on the vertical axis.




A
ground


ground


ground


A
ground
x

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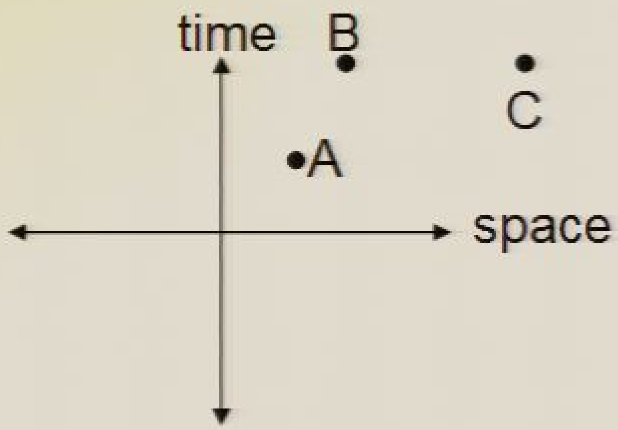

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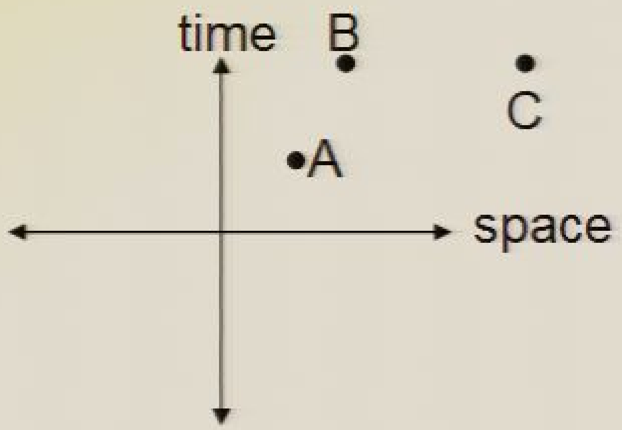
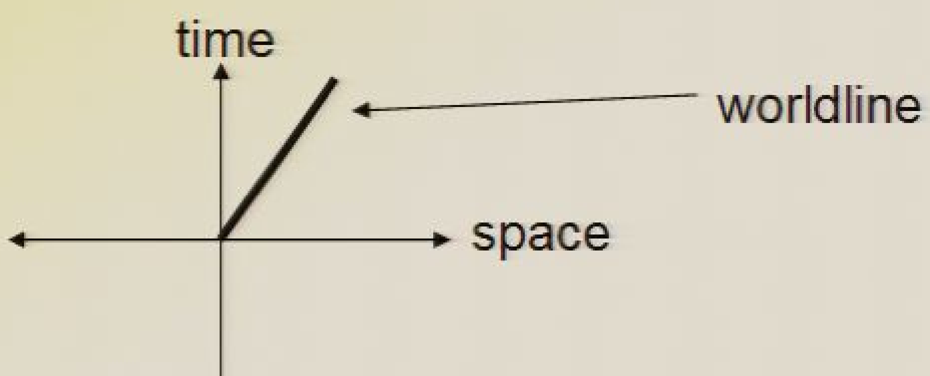


- Such a graph is called a *spacetime* diagram. Incredibly useful tool for understanding special relativity.

"Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality." — Hermann Minkowski

What do a series of events look like on a spacetime diagram? Eg. a car driving at 60kmh^{-1} in one direction on a highway.



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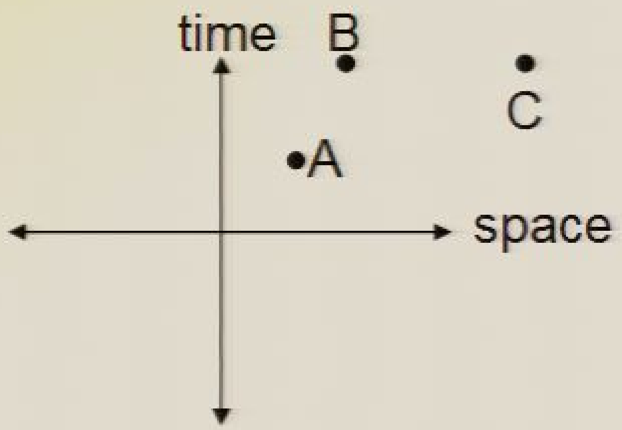

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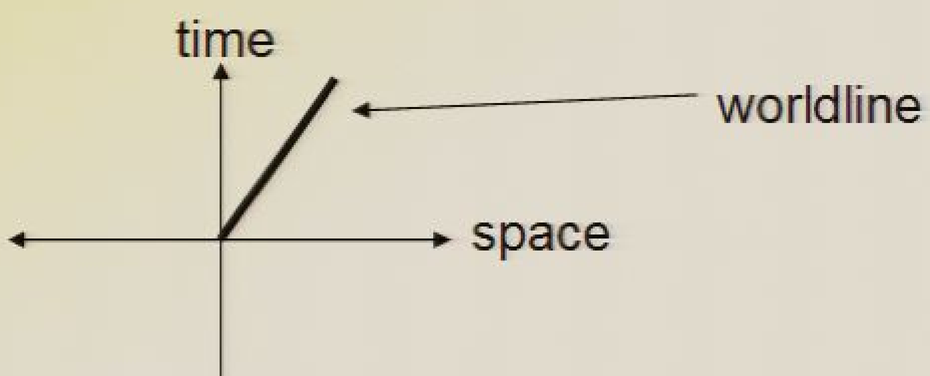


Activity

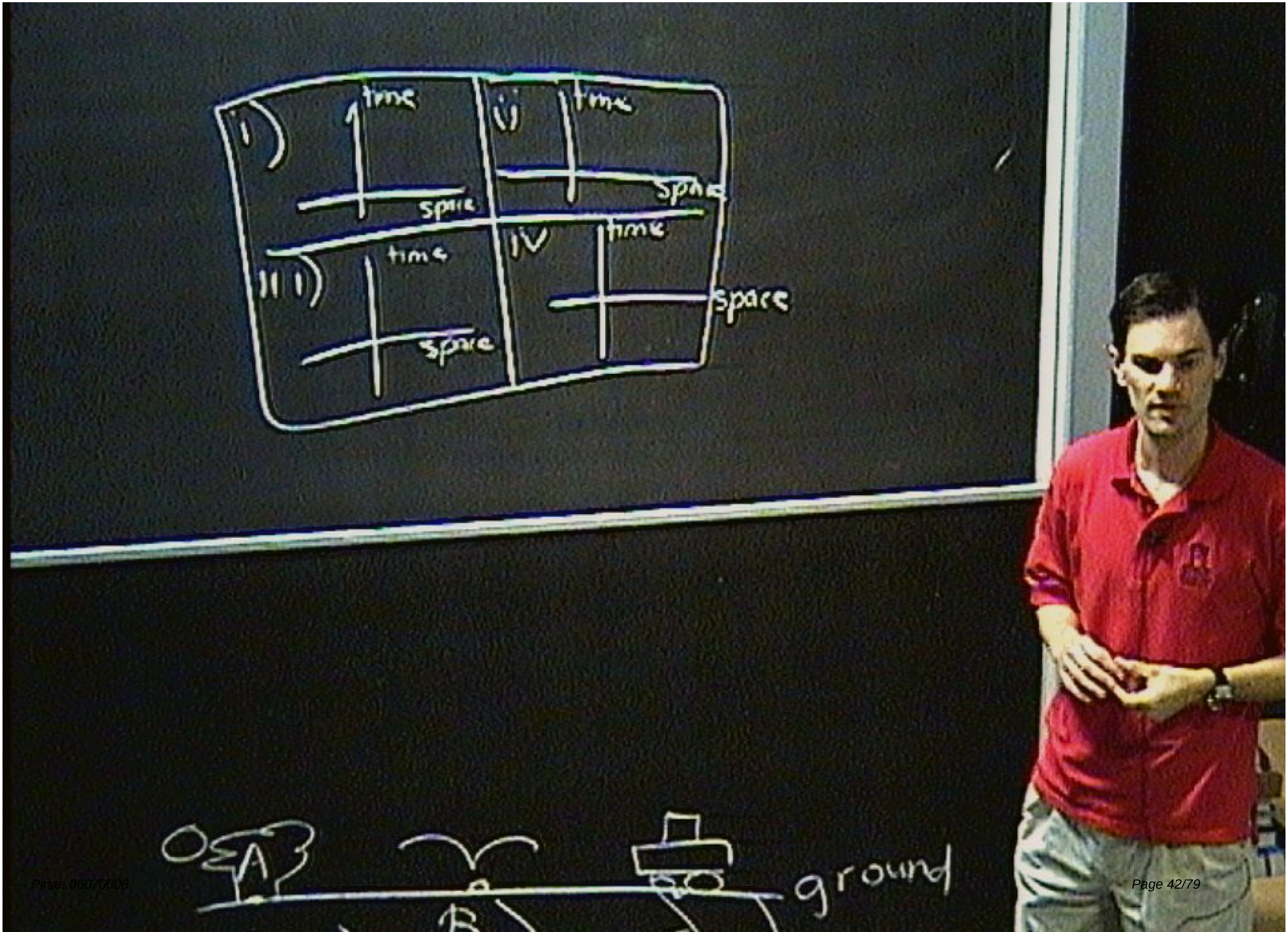
Draw spacetime diagrams that show the worldlines for:

i) A car that drives for one hour at 100 kmh^{-1} in one direction, turns around, and then drives for an hour in the opposite direction

ii) A Grade 12 physics student standing still waiting for a bus

iii) An Olympic athlete running at a constant velocity in a 100 metres race.

iv) A car driving around in circles (n.b. this requires a 3D spacetime diagram).


i)
time
space
ii)
time
space
iii)
time
space
iv)
time
space
A
B
ground

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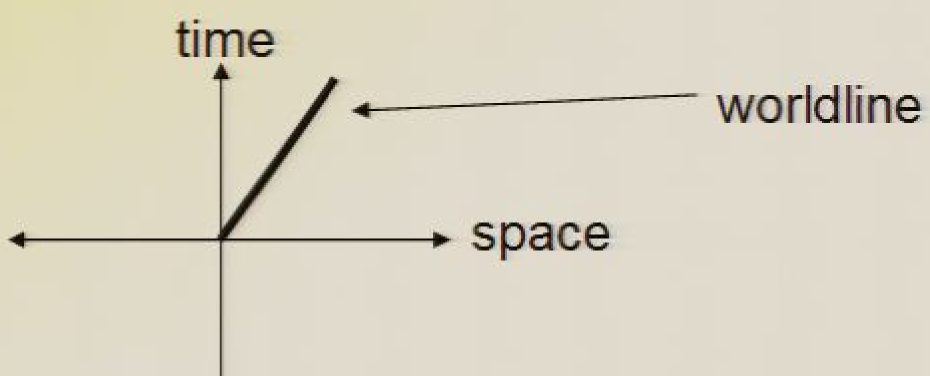

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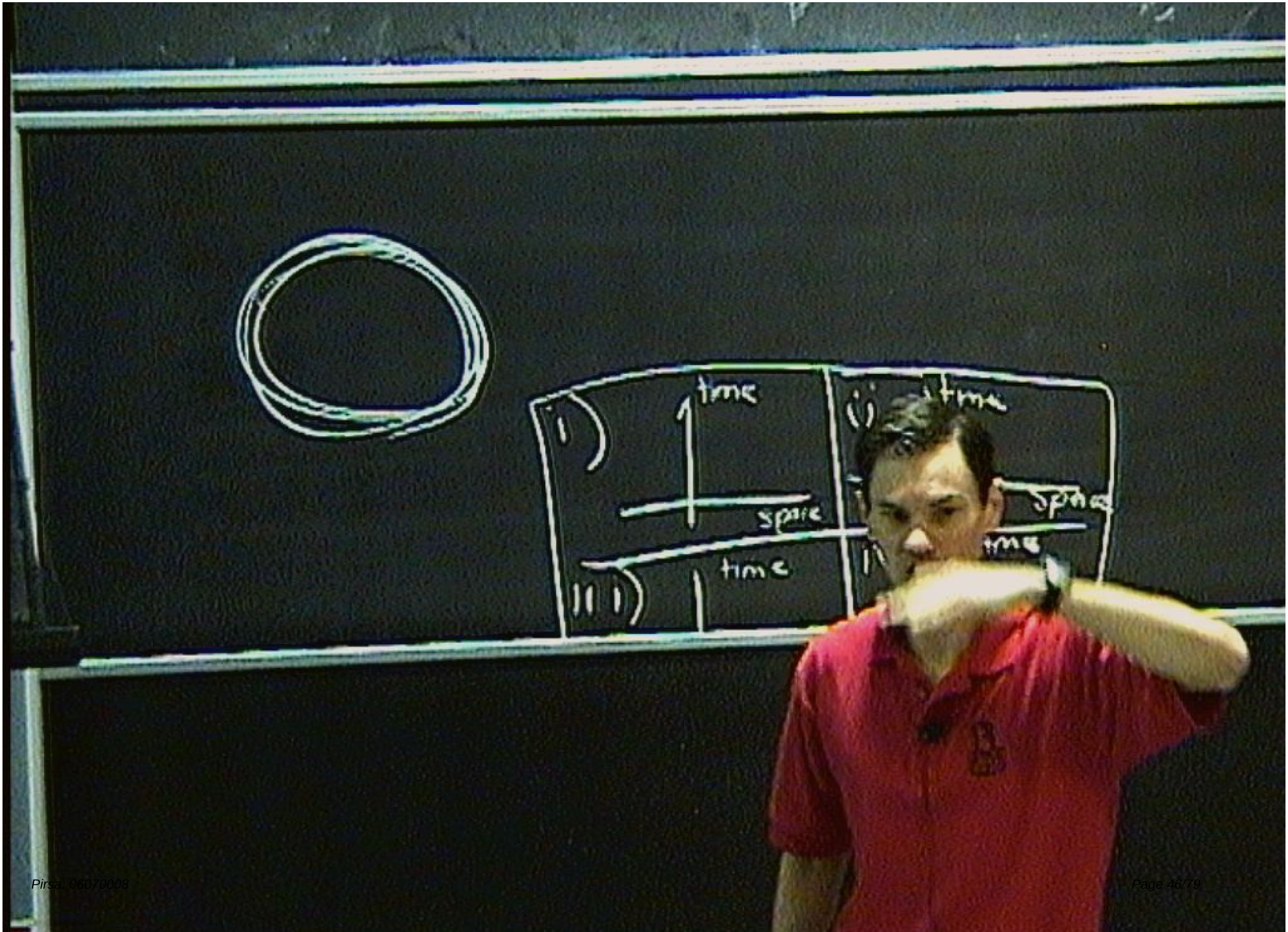
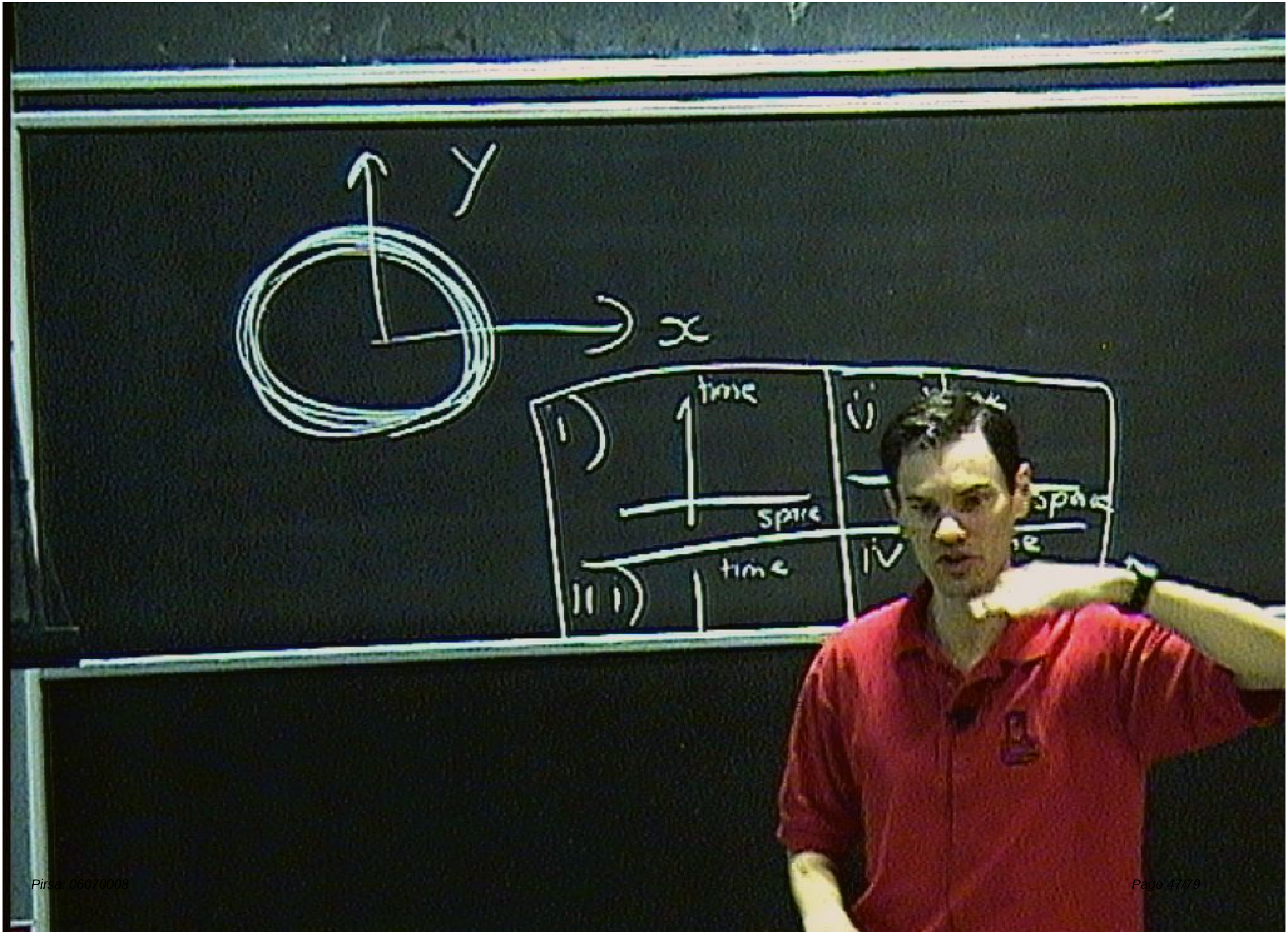
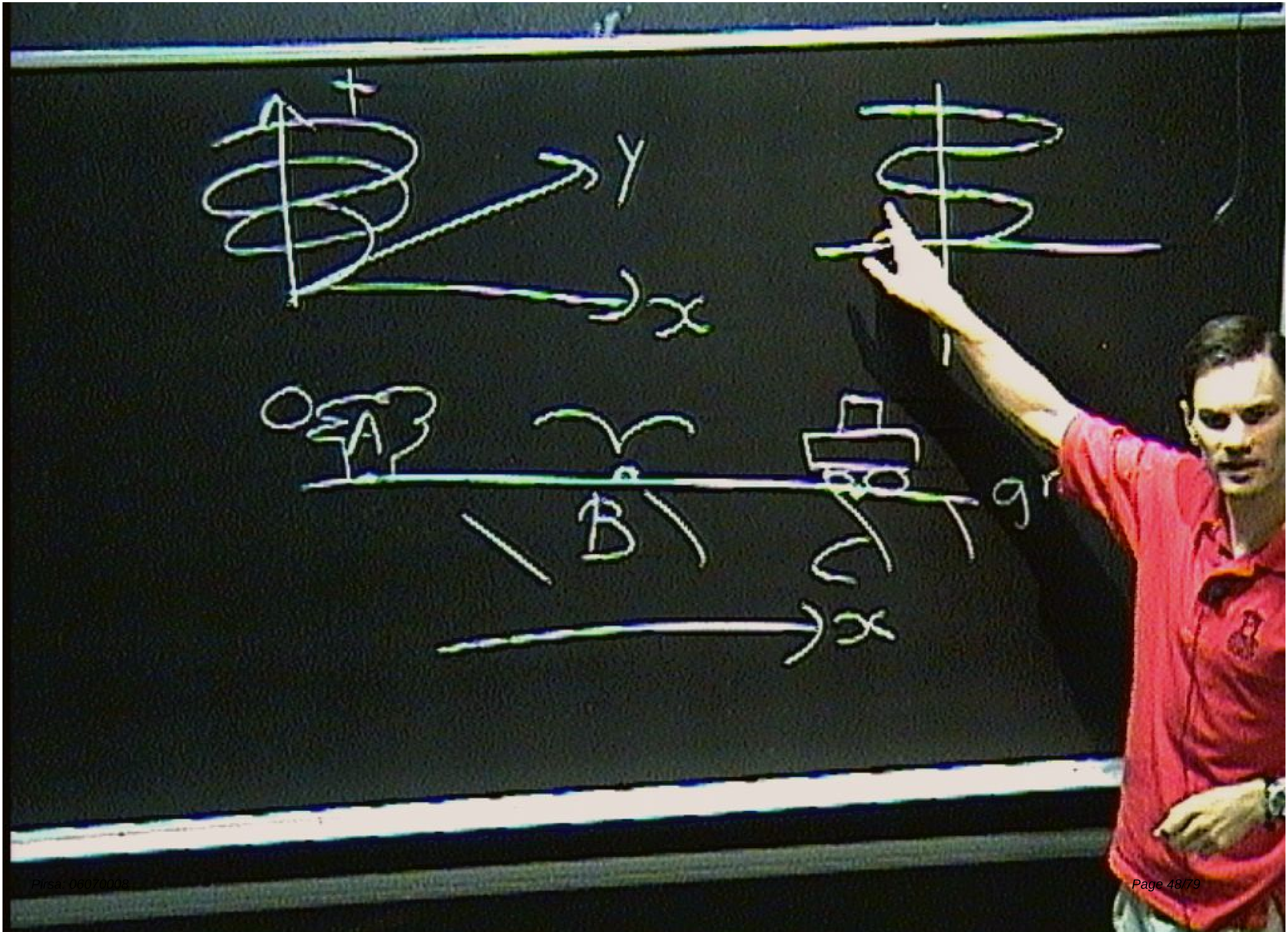
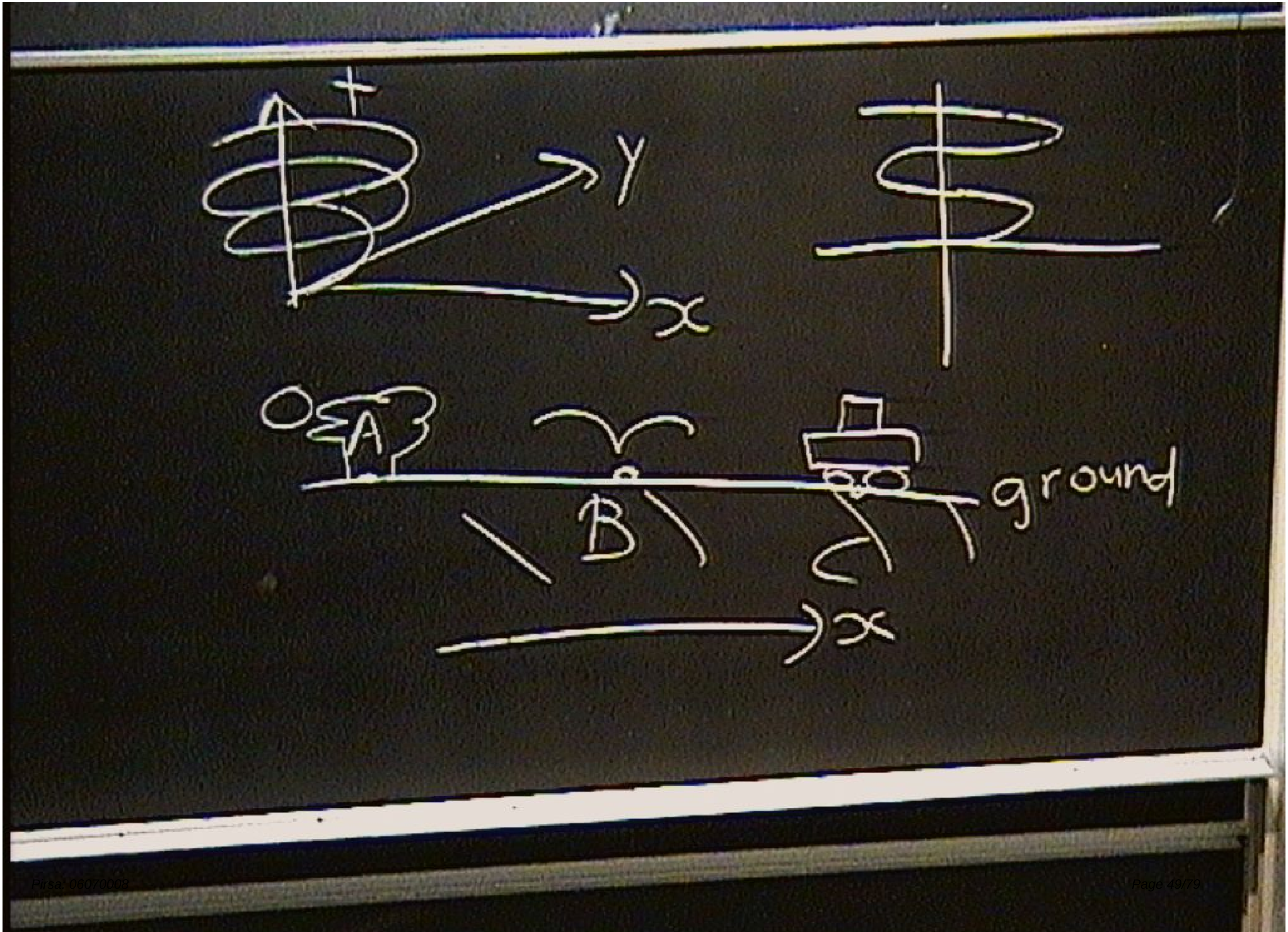

i)
time
space
ii)
time
iii)
time


y
x
i)
time
space
ii)
iii)
time
iv


y
x
A
B
C
x


y
x
A
B
ground
x

The metric of space and time

- Imagine that we would like to calculate the distance between points A and B on the map below.

- Use the Pythagorean theorem $d^2 = \Delta x^2 + \Delta y^2$ (nelgecting the earth's curvature)

This is called a *metric equation*

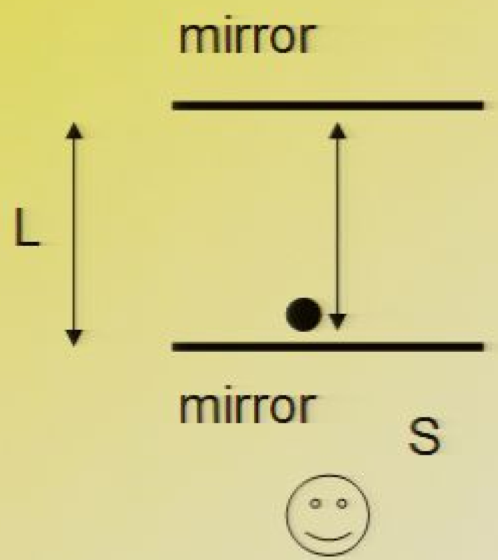
metric = technical term for distance

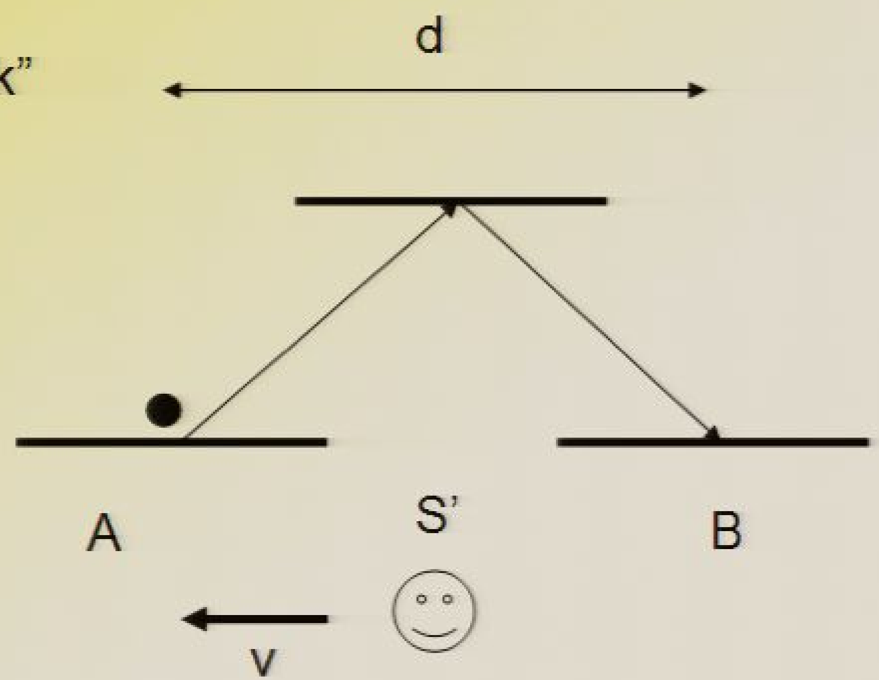
What is the metric equation for spacetime

- As the two axes are x and t is it just $d^2 = \Delta x^2 + (c\Delta t)^2$?

- Or perhaps, according to Einstein, there is something different about space and time.

- To held decide, consider a “light clock”





- A and B are the events corresponding to a photon hitting the bottom mirror on two successive occasions.

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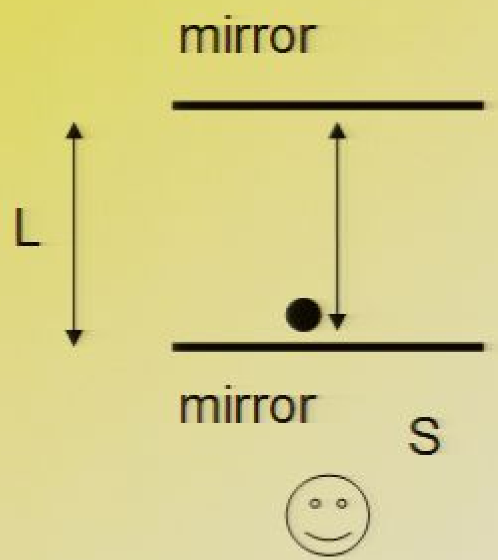

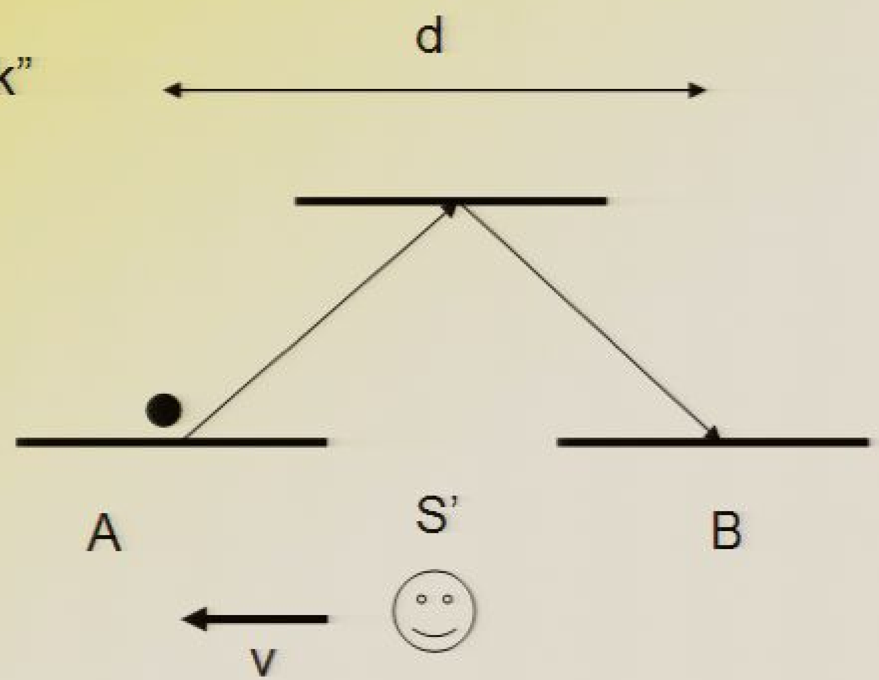

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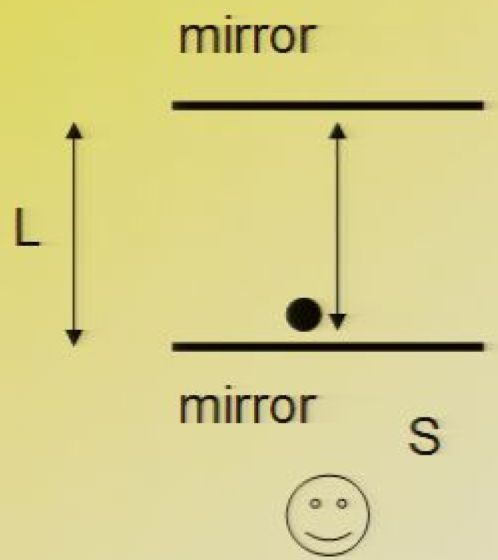

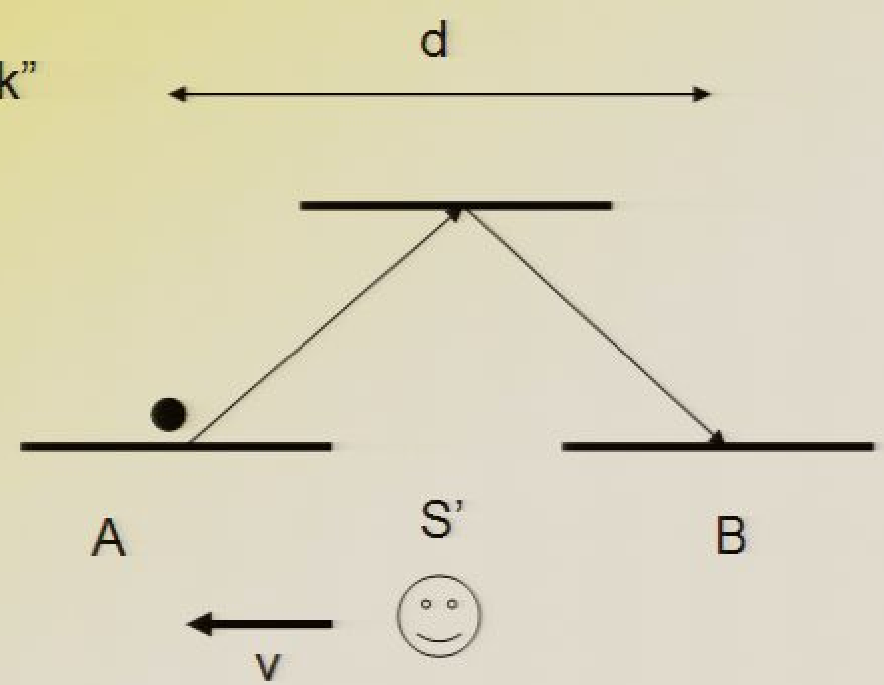

- A and B are the events corresponding to a photon hitting the bottom mirror on two successive occasions.

- Let us denote the spacetime ‘distance’ or interval between A and B by s

- In frame S, this interval is made up from just time and so s=2L

  (Using ‘light time’ where we measure time by the distance light travels in the time under consideration.)

- In frame S’, the time t’ between A and B is given by

$$t' = \frac{\text{distance}}{\text{speed}} = \frac{2\sqrt{L^2 + \left(\frac{d}{2}\right)^2}}{c}$$

- Plugging L=s/2 into the above equation and squaring both sides yields

$$t'^2 = \frac{s^2 + d^2}{c^2}$$

$$\boxed{\therefore s^2 = (ct')^2 - d^2}$$

- This is the metric equation for special relativity

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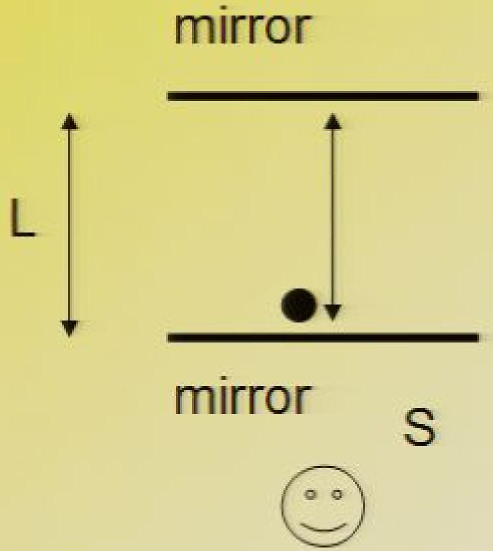

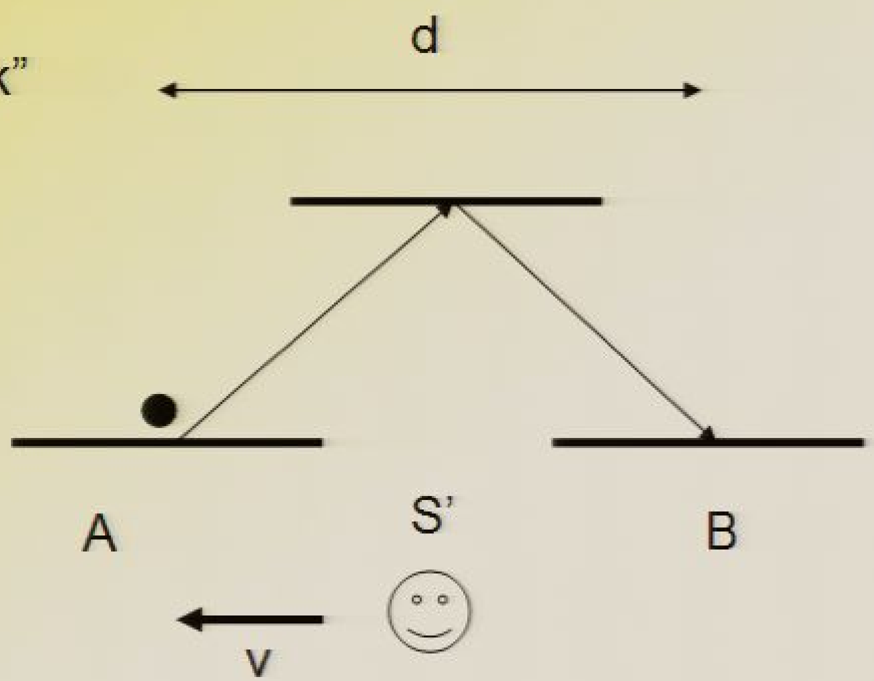

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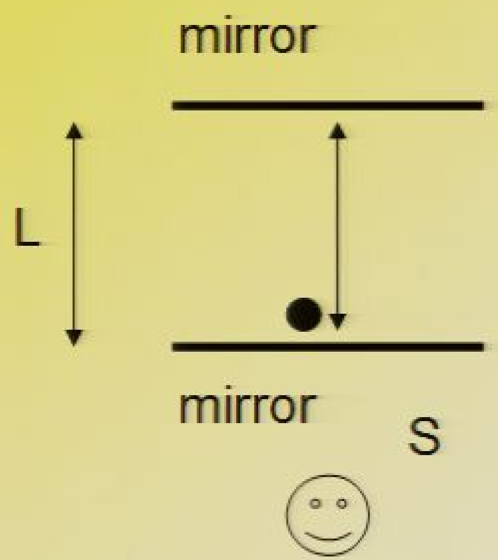

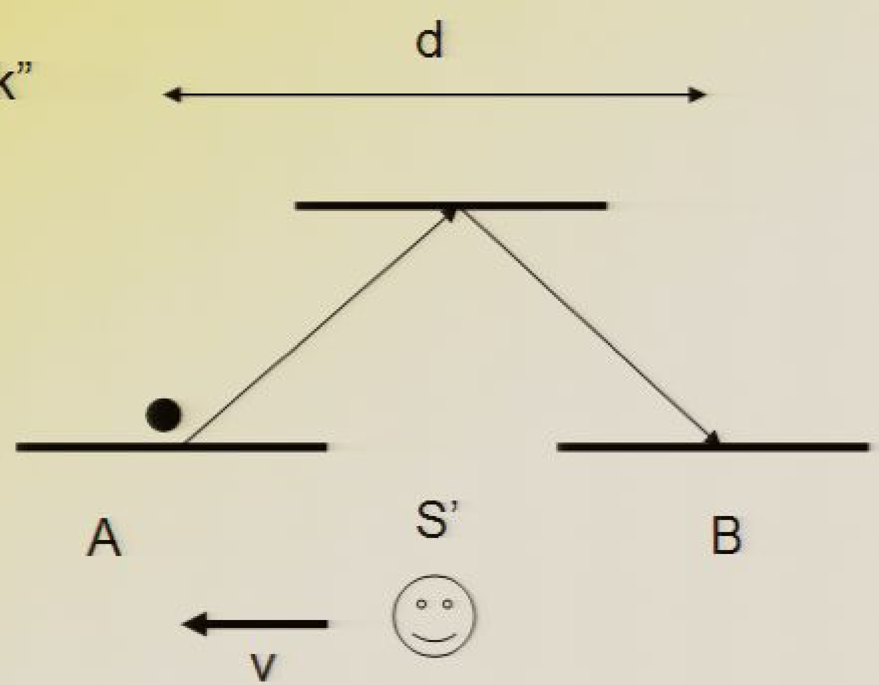

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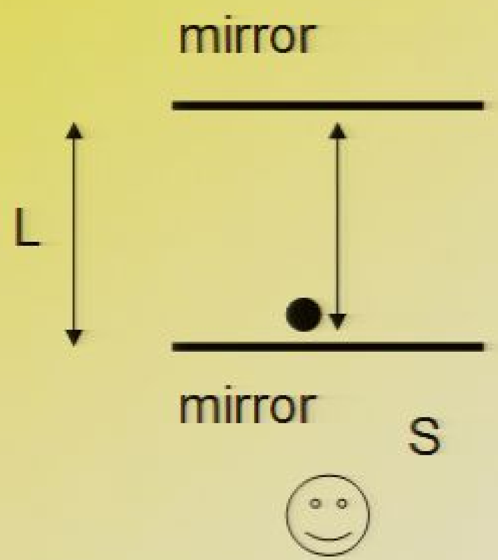

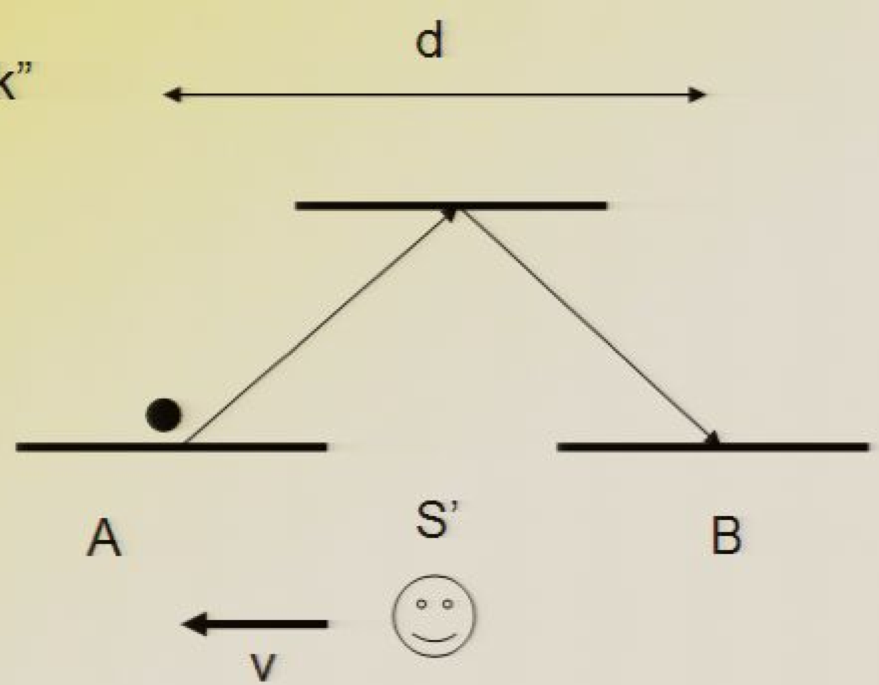

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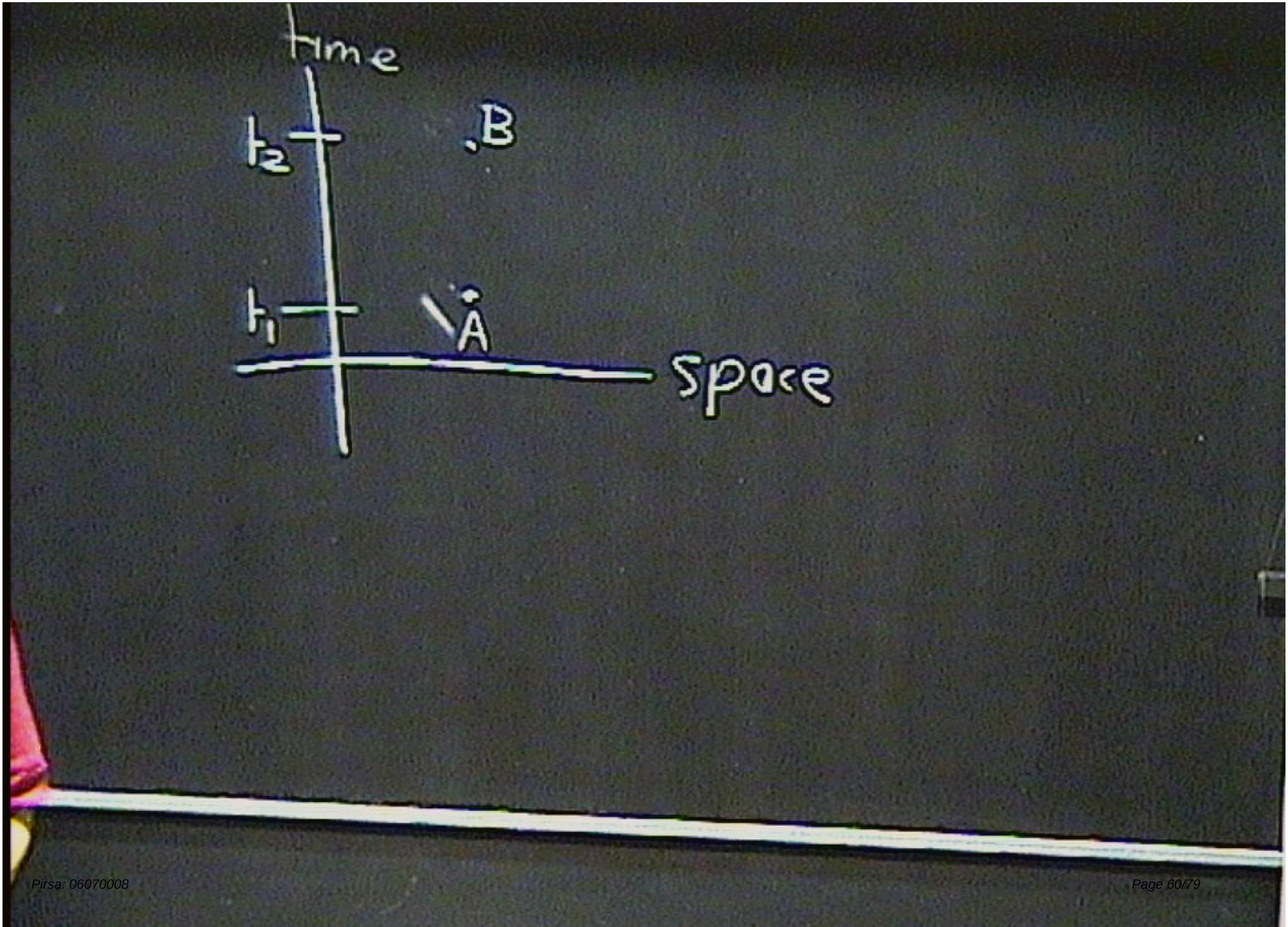
time
t_2
.B
t_1
A
space

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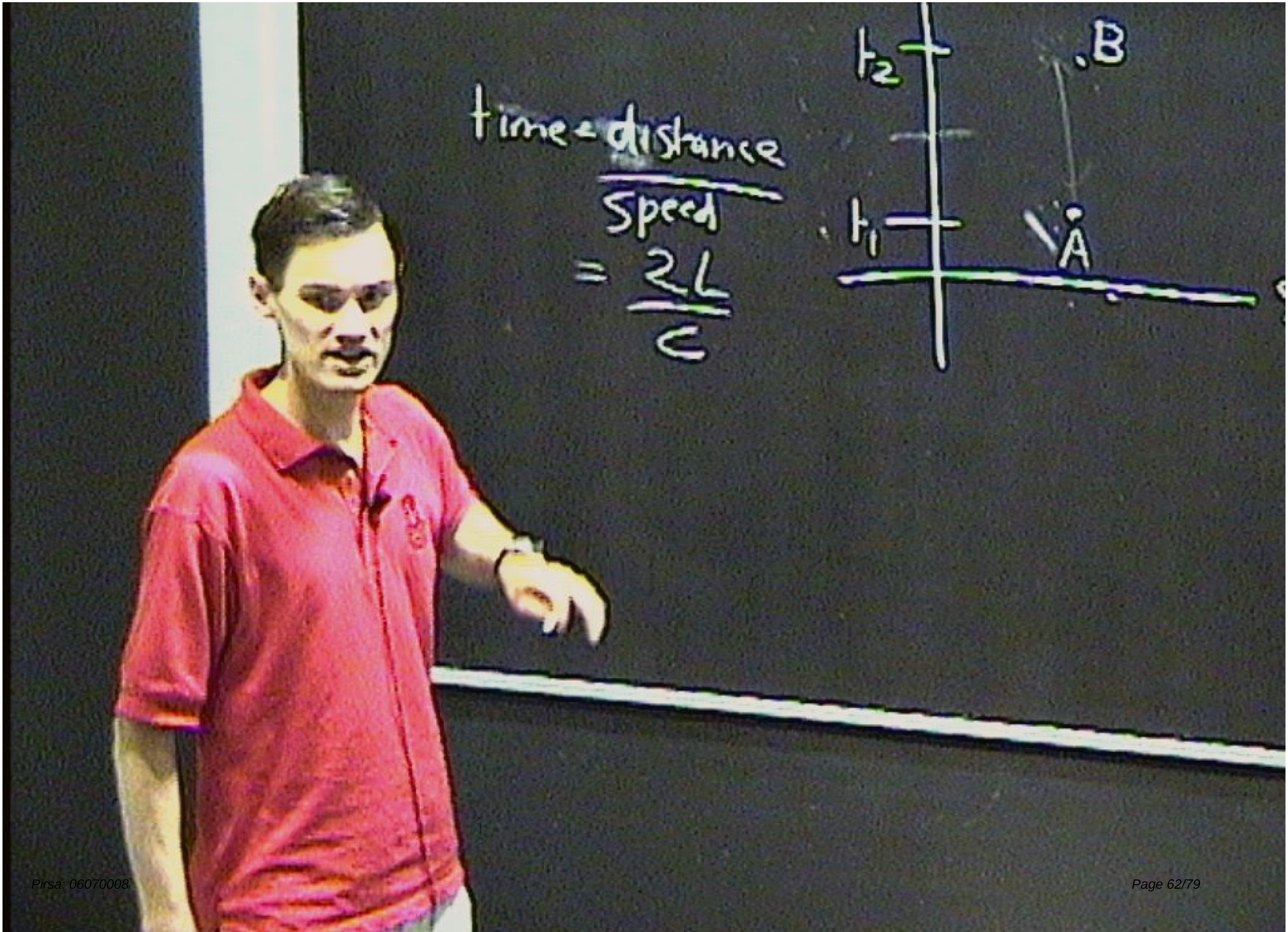
time = distance / speed
= 2L / c
t_2
t_1
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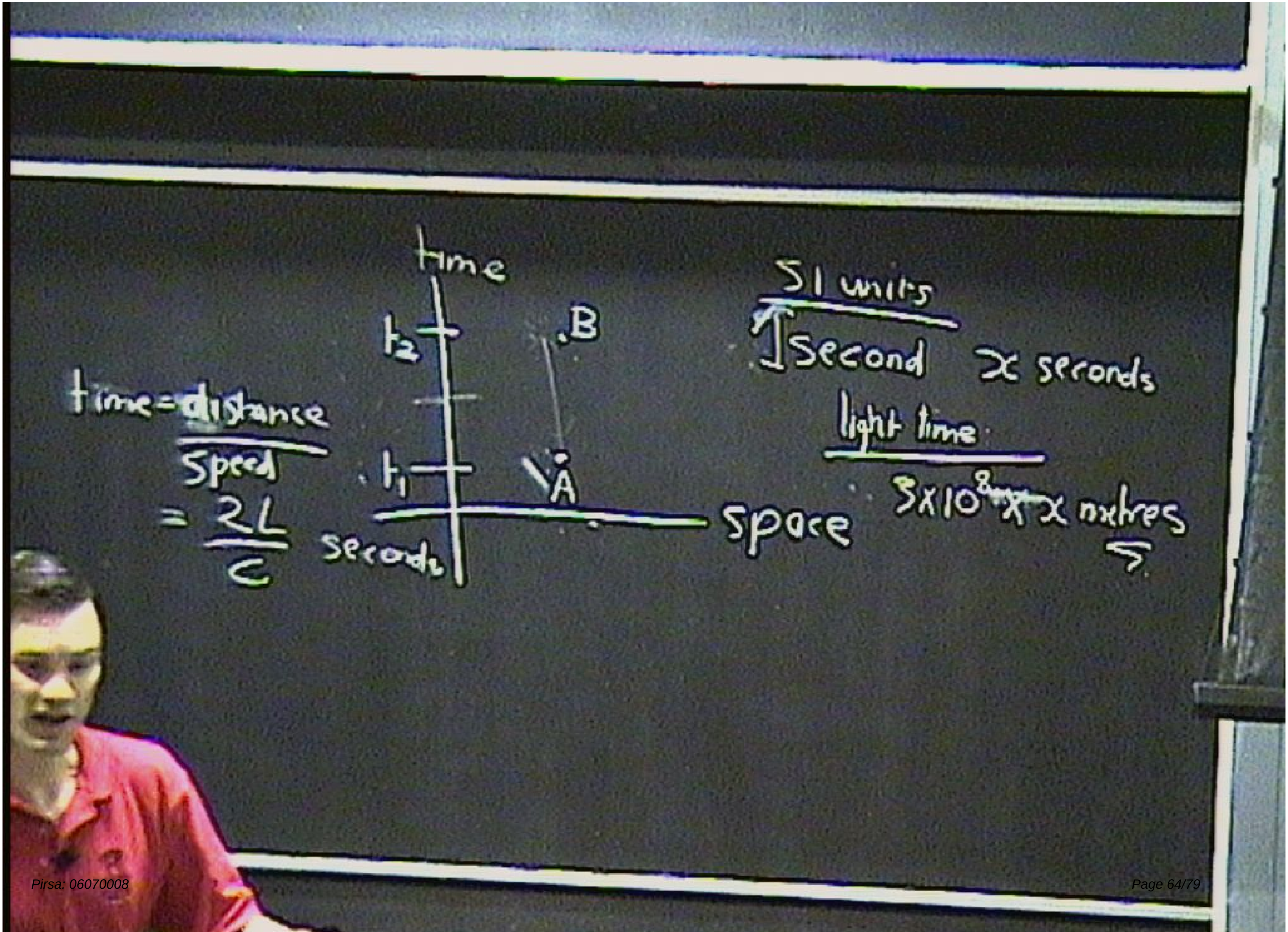
time
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SI units
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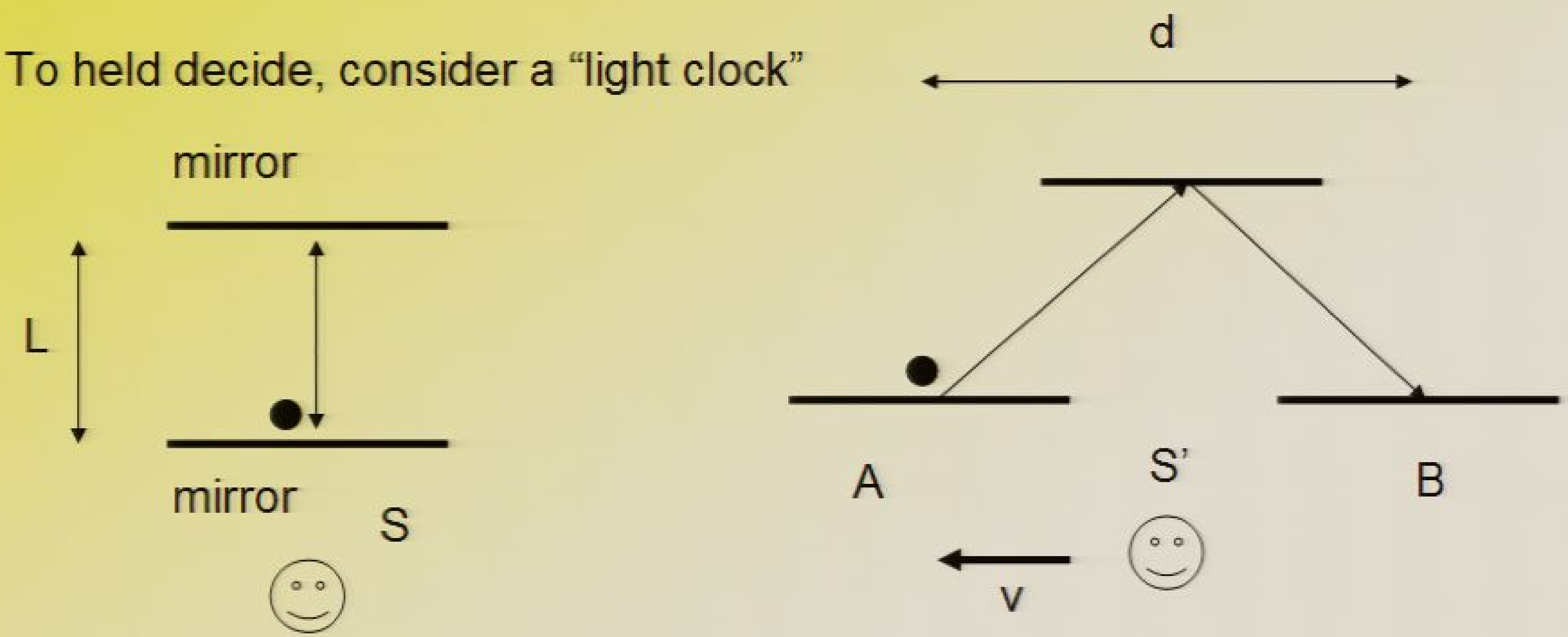

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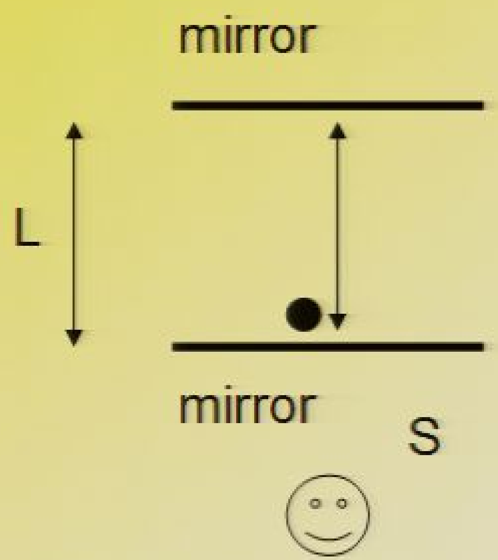

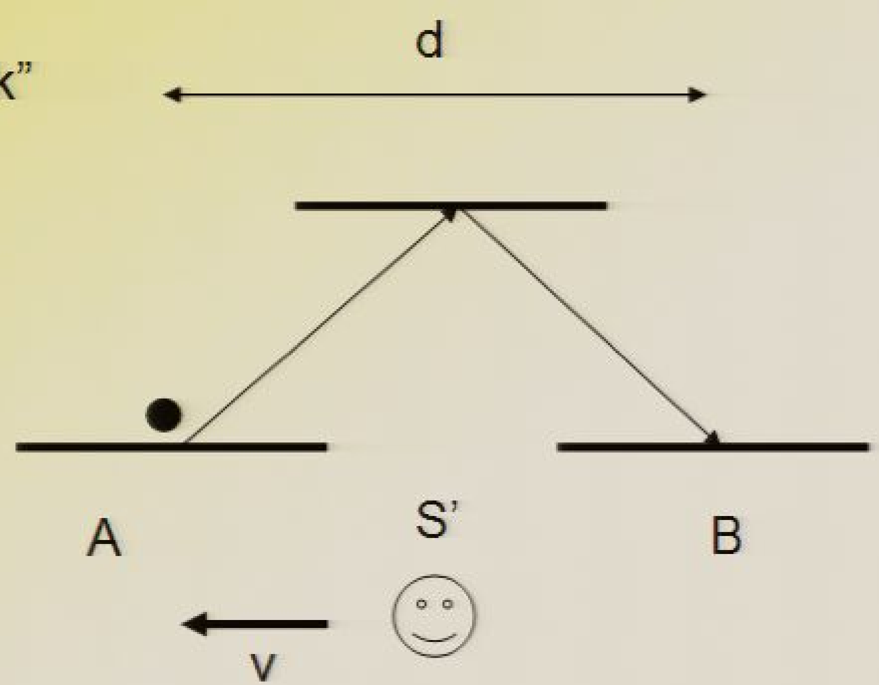

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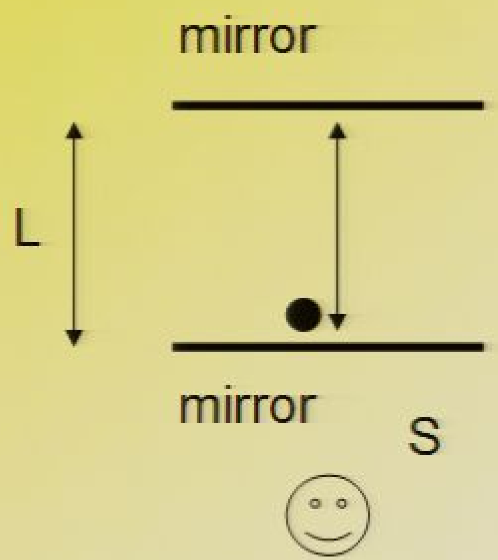

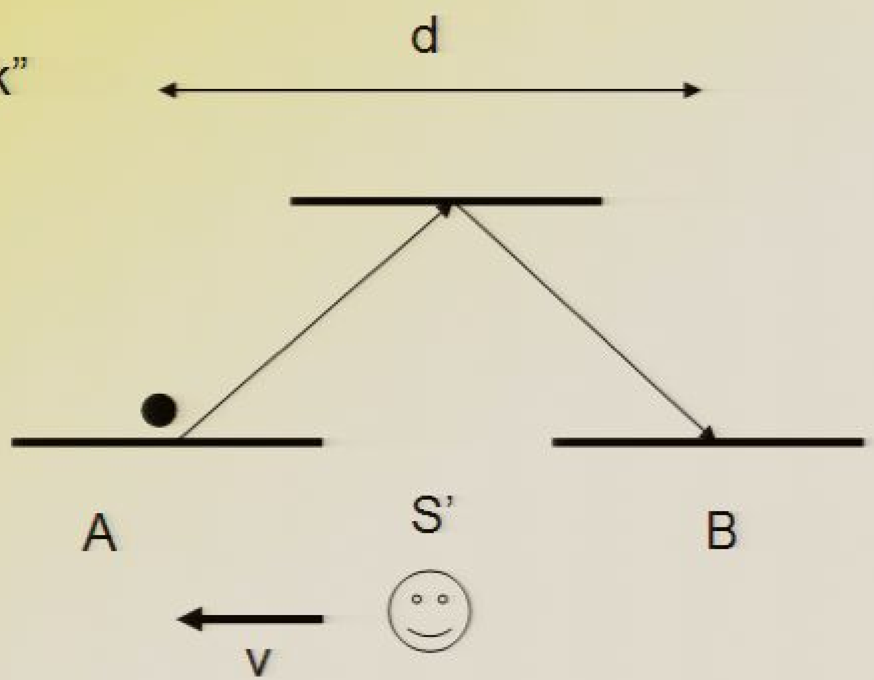

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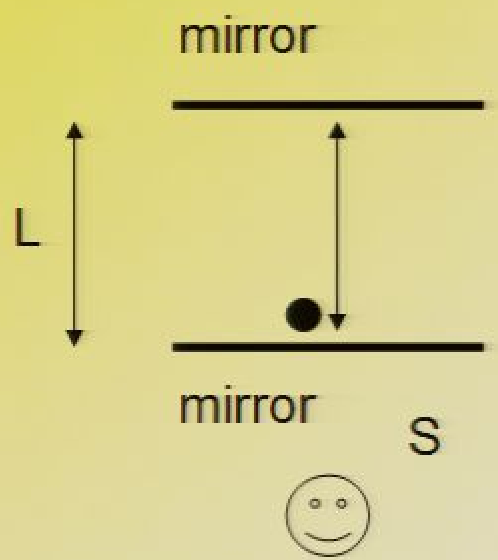

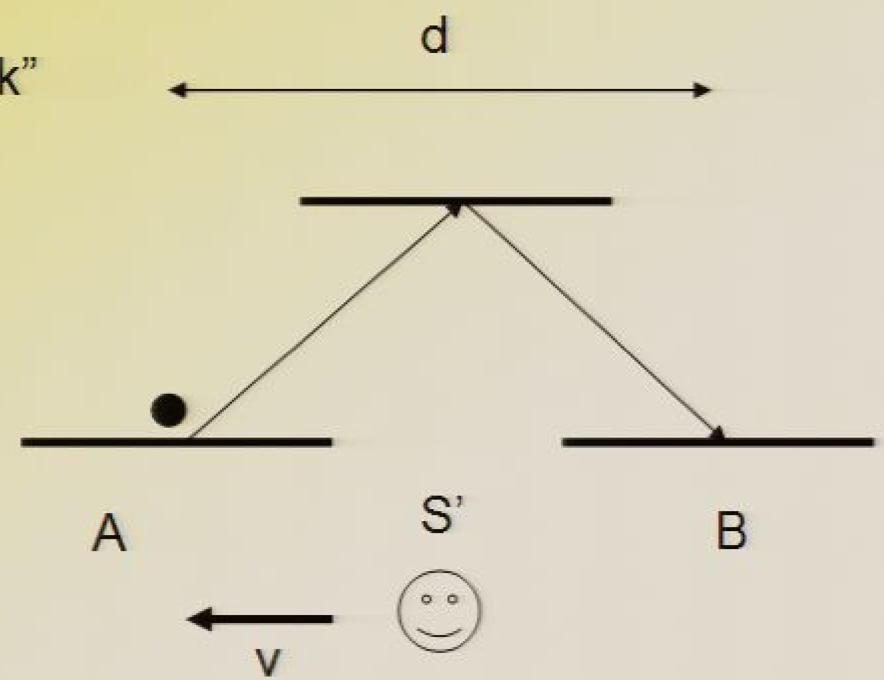

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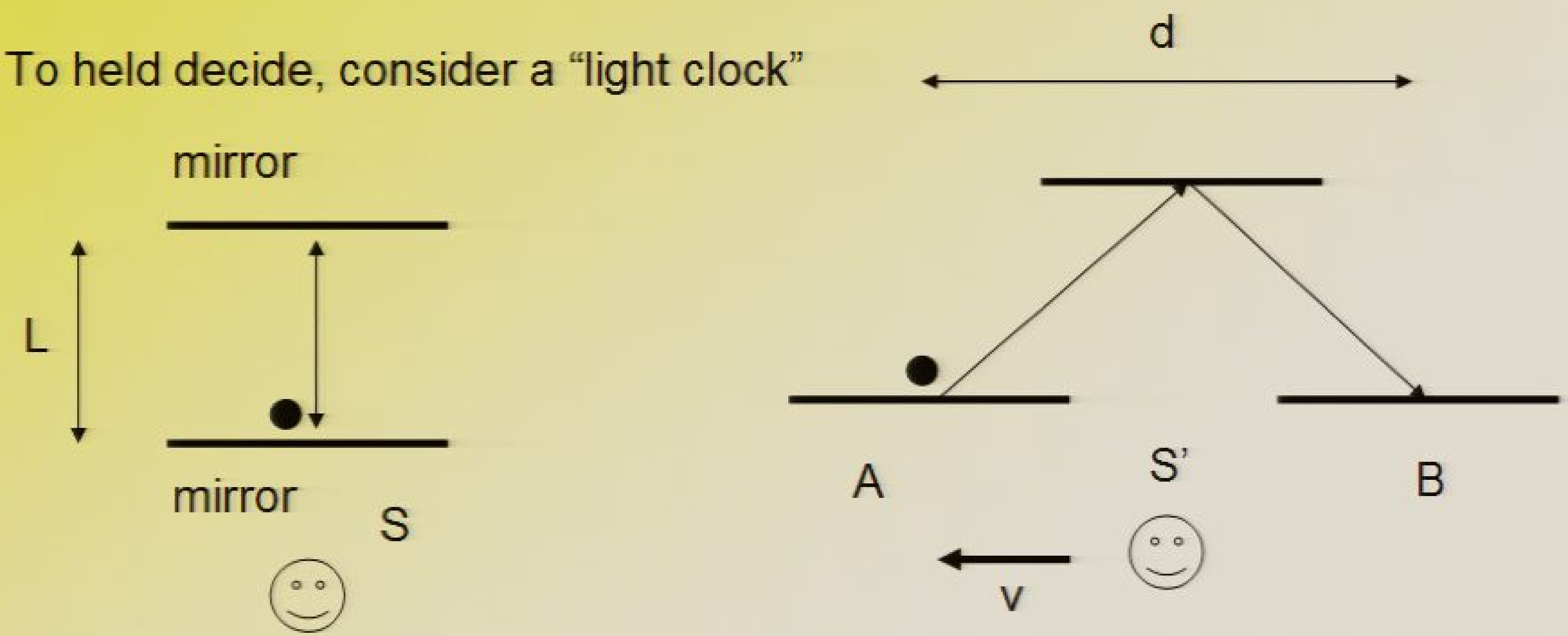

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The metric of space and time

- Imagine that we would like to calculate the distance between points A and B on the map below.

- Use the Pythagorean theorem $d^2 = \Delta x^2 + \Delta y^2$ (nelgecting the earth's curvature)

This is called a *metric equation*

metric = technical term for distance

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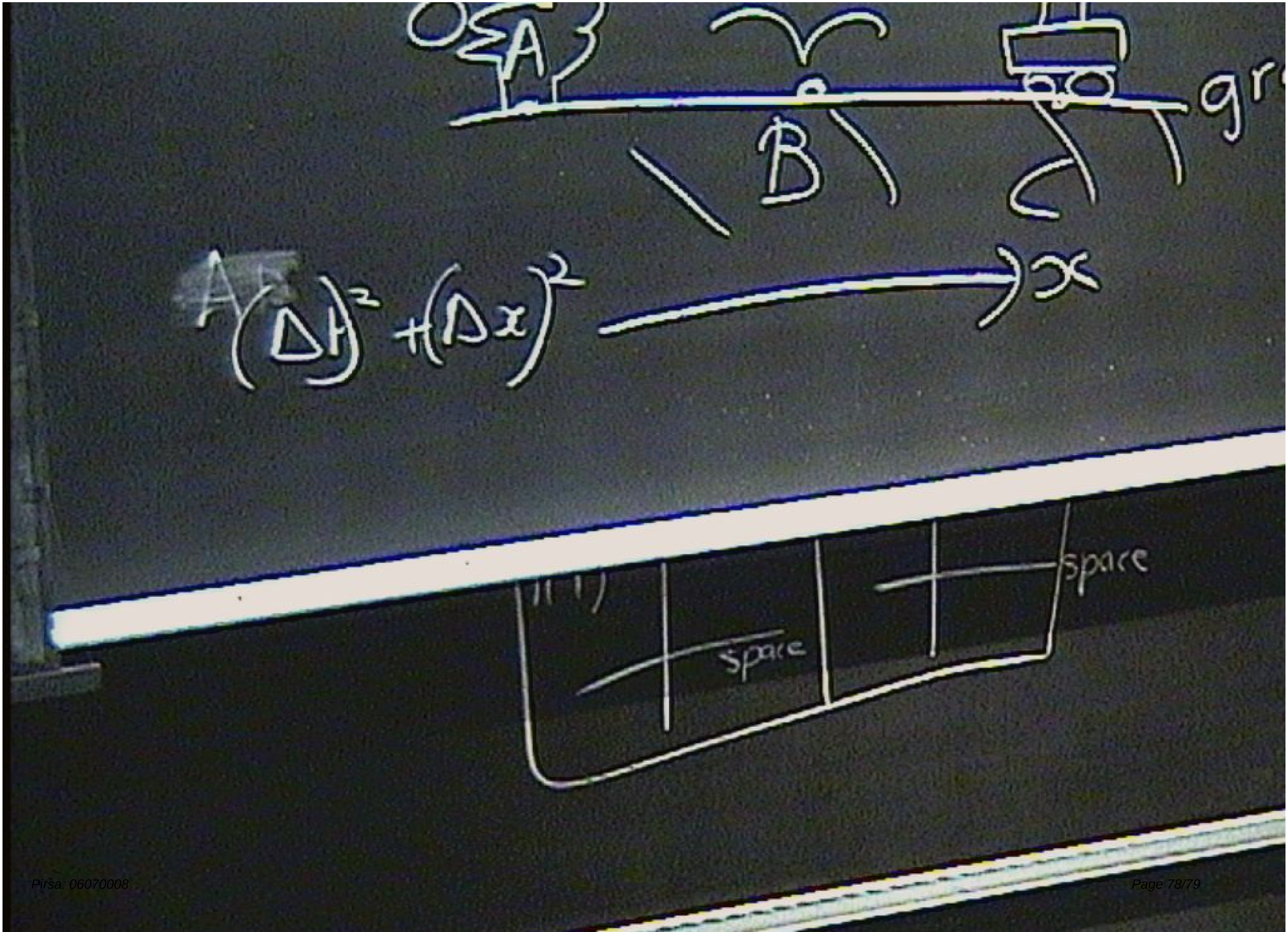
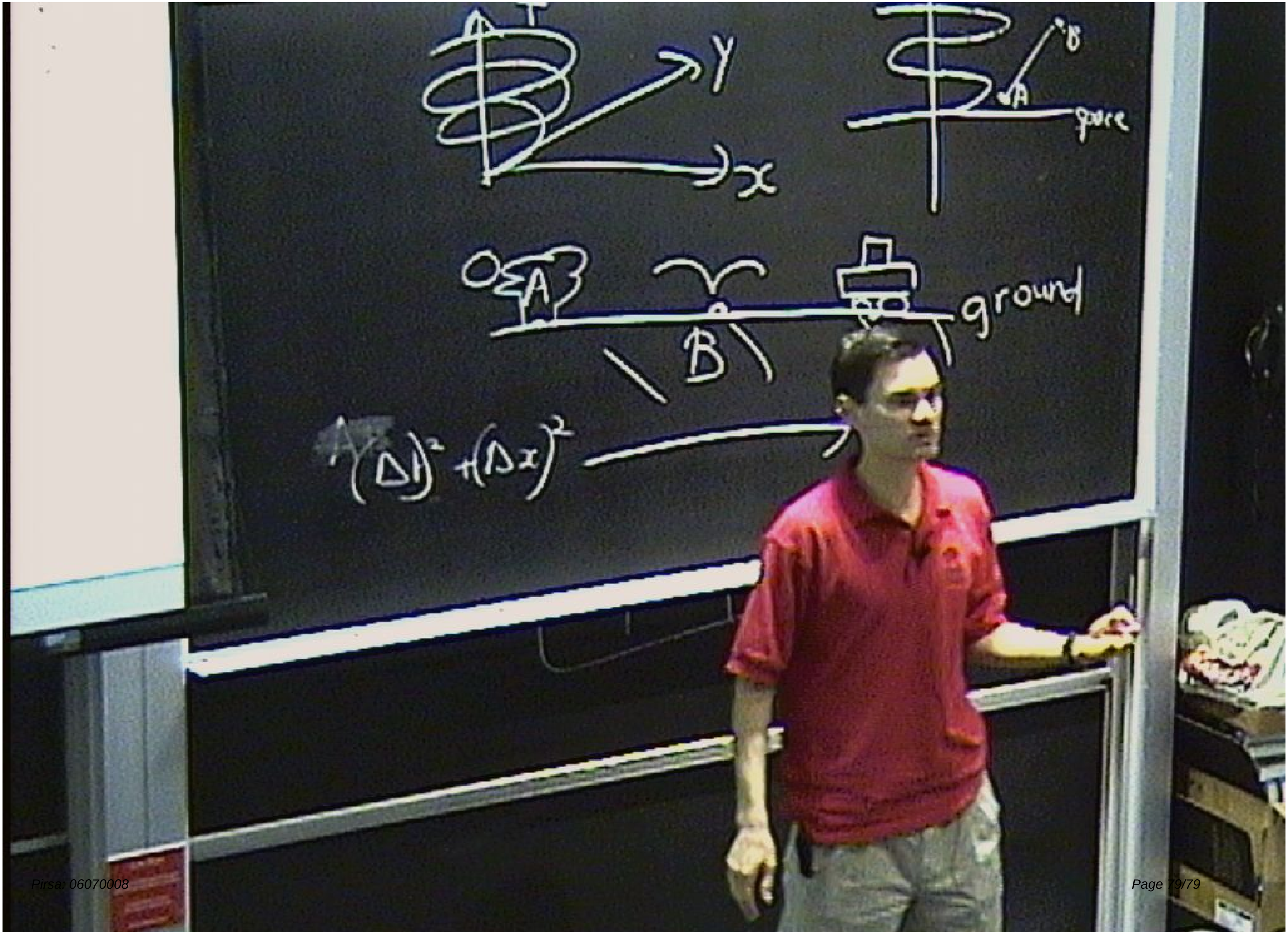

A
B
gr
(Δt)² + (Δx)²
x
space
space


y
x
A
B
ground
A
B
(Δt)^2 +(Δx)^2