Title: Relativity 2

Date: Jul 25, 2008 09:00 AM

URL: http://pirsa.org/08070037

Abstract:

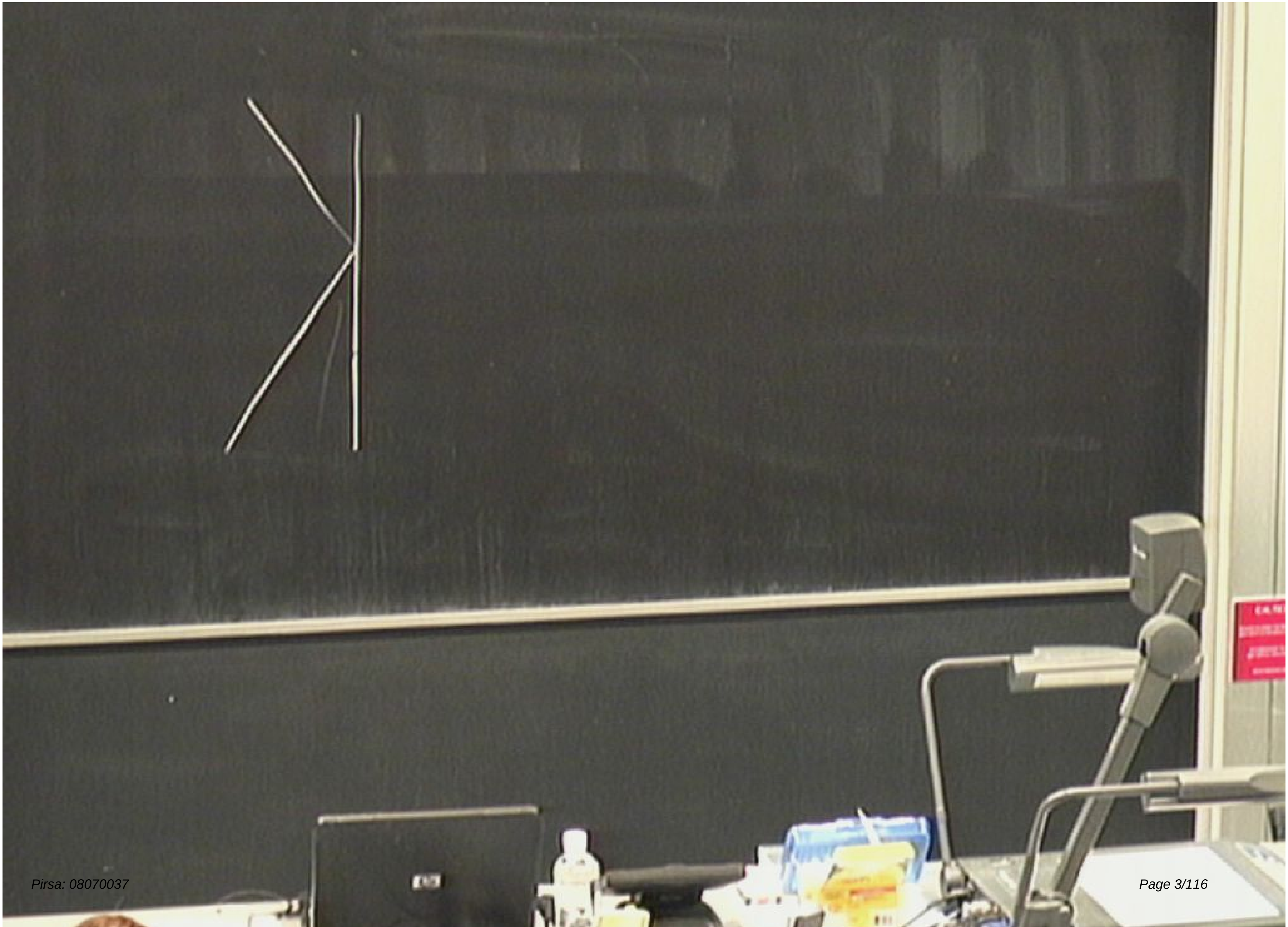
P2: (Speed of light)

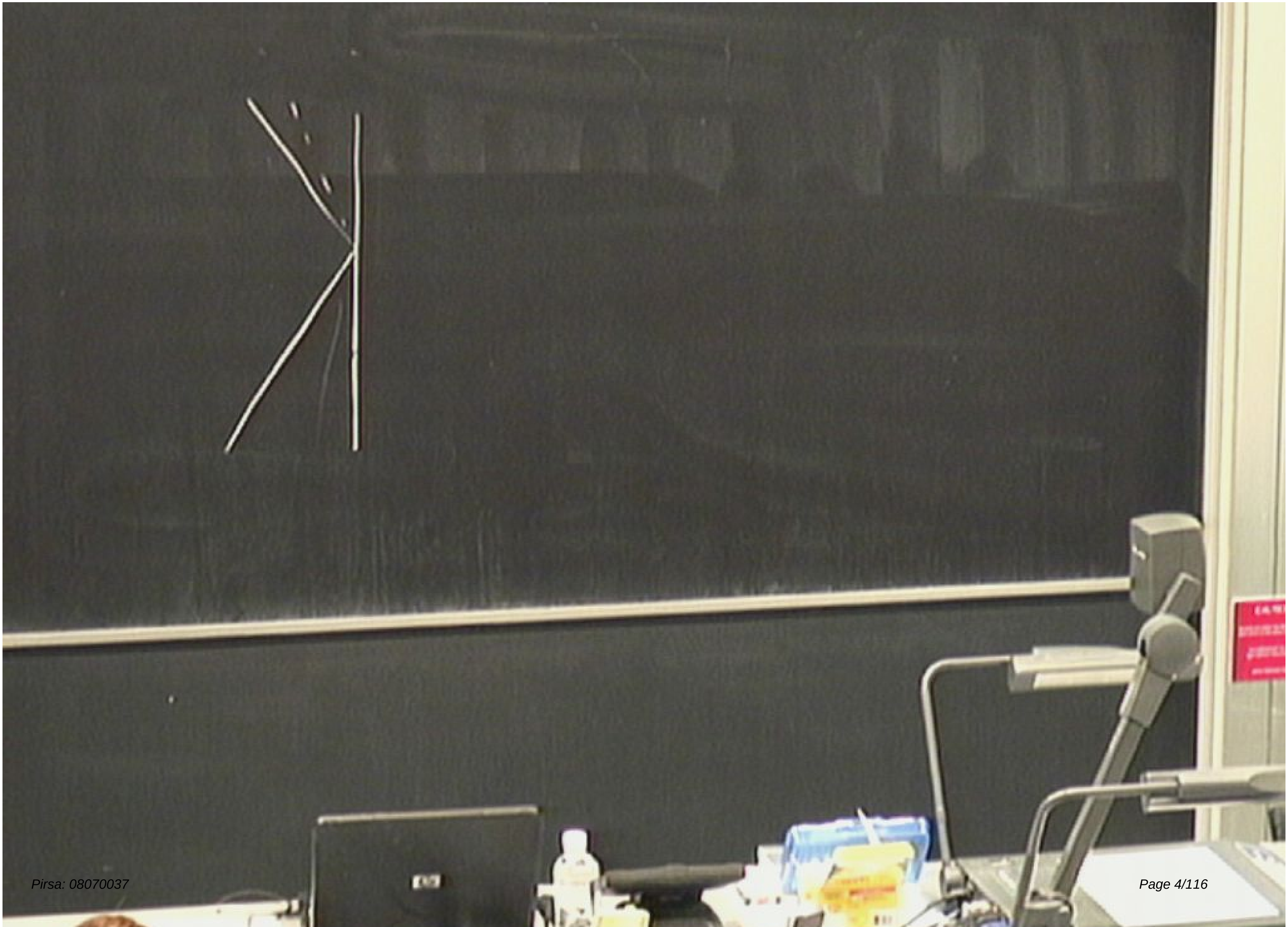
For an observer "at rest", speed is c,
independent of motion of source.

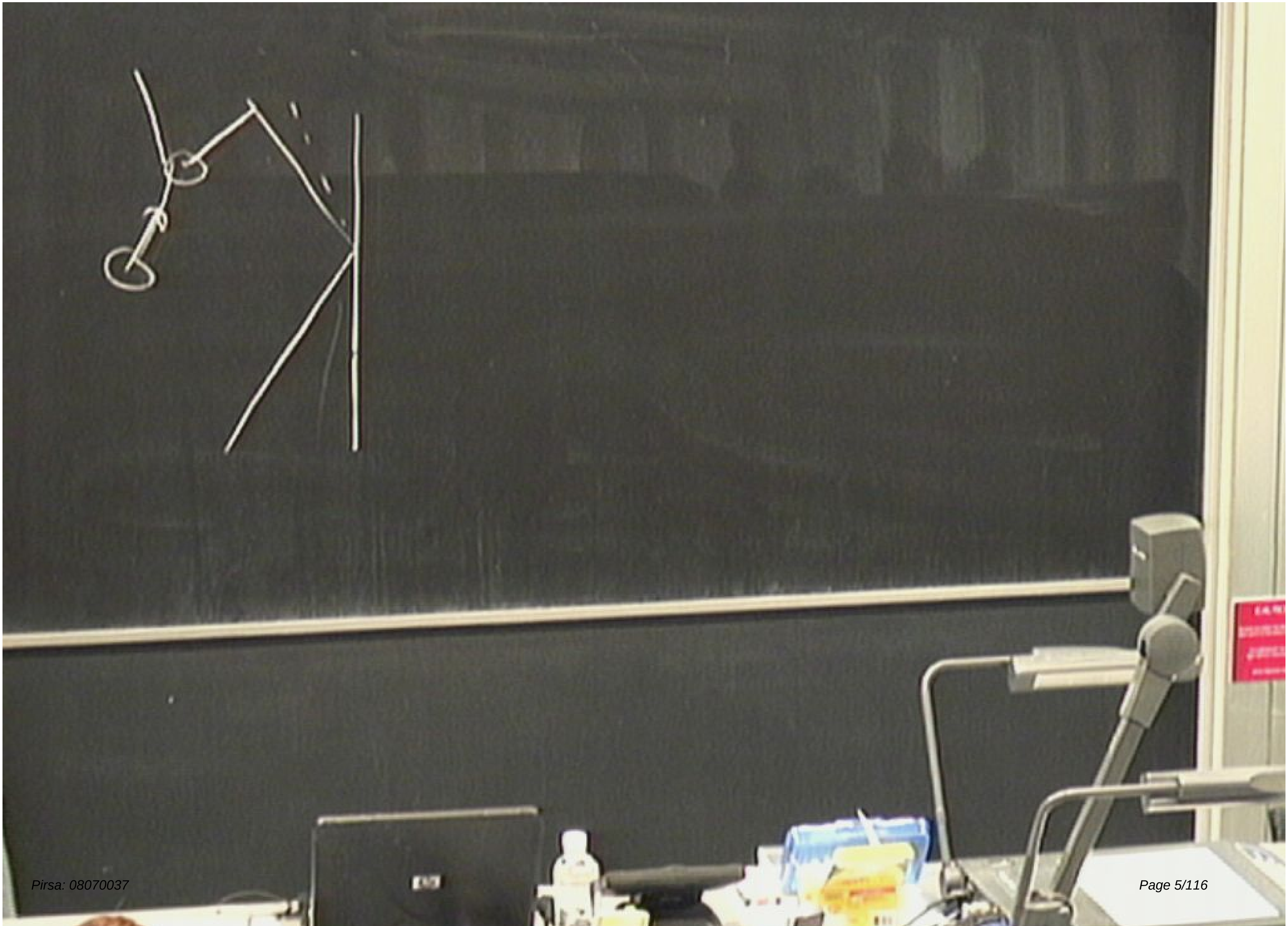
P2′: (Not Einstein)

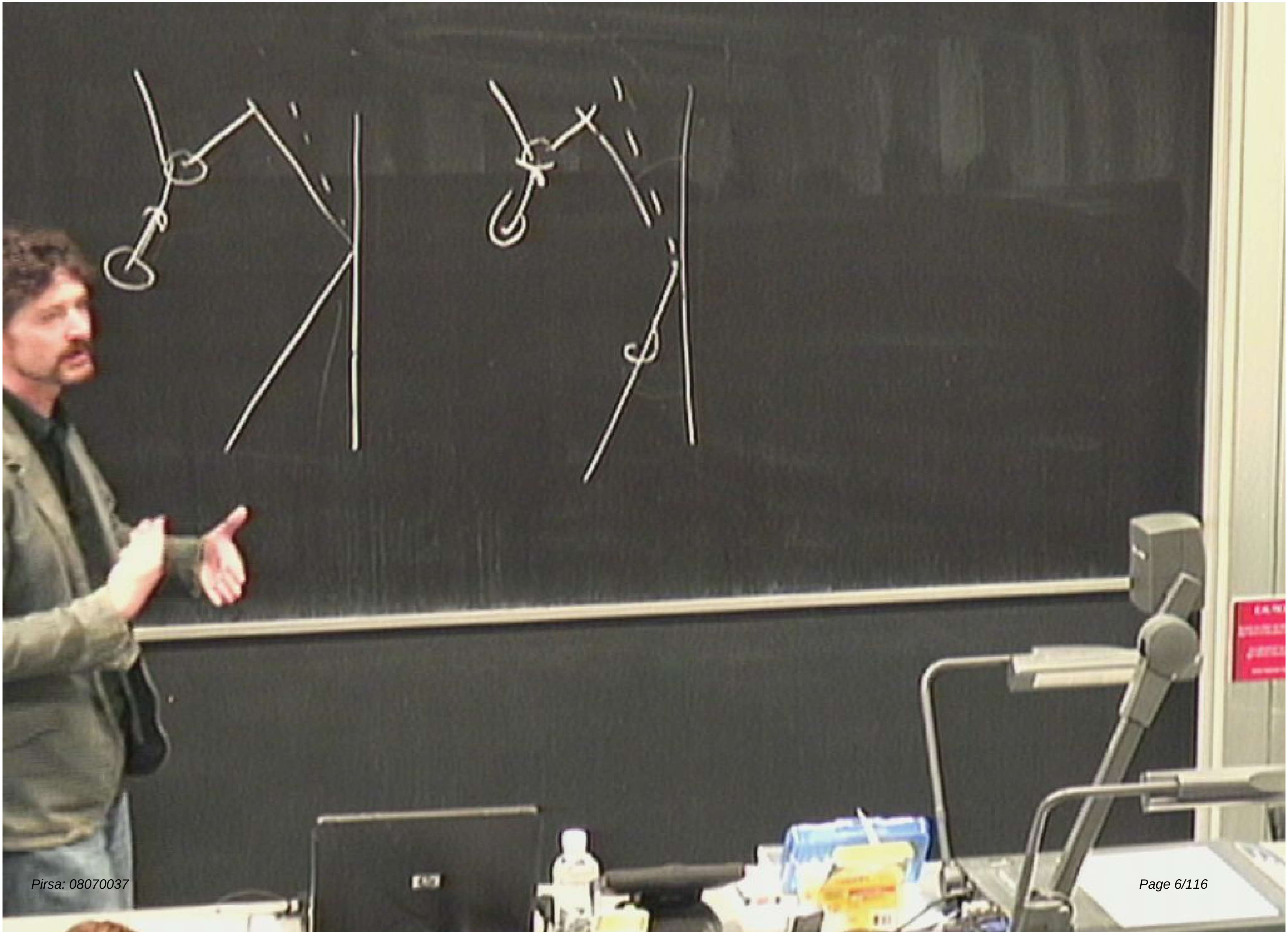
source

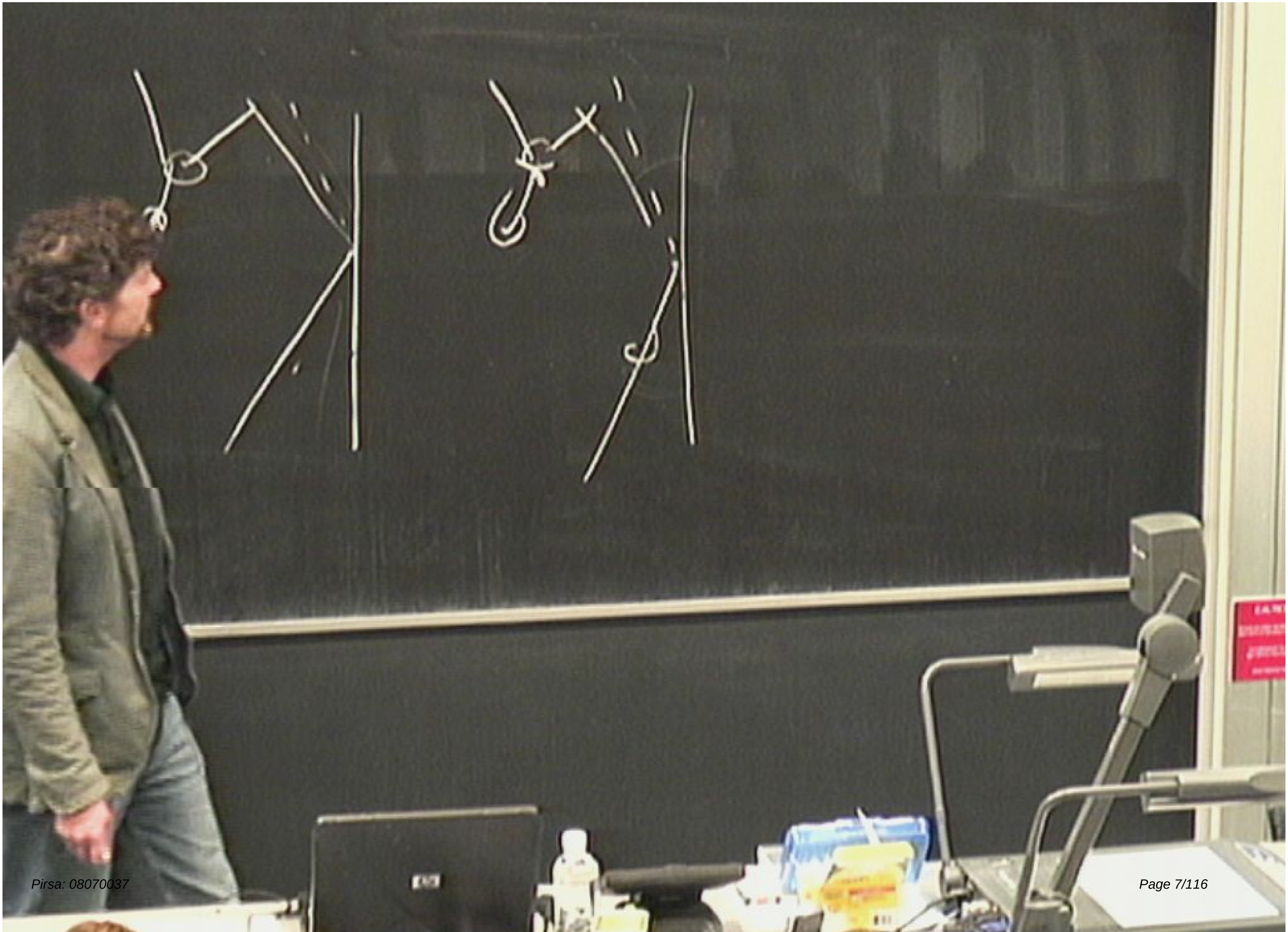
observer











P1 : (Relativity)

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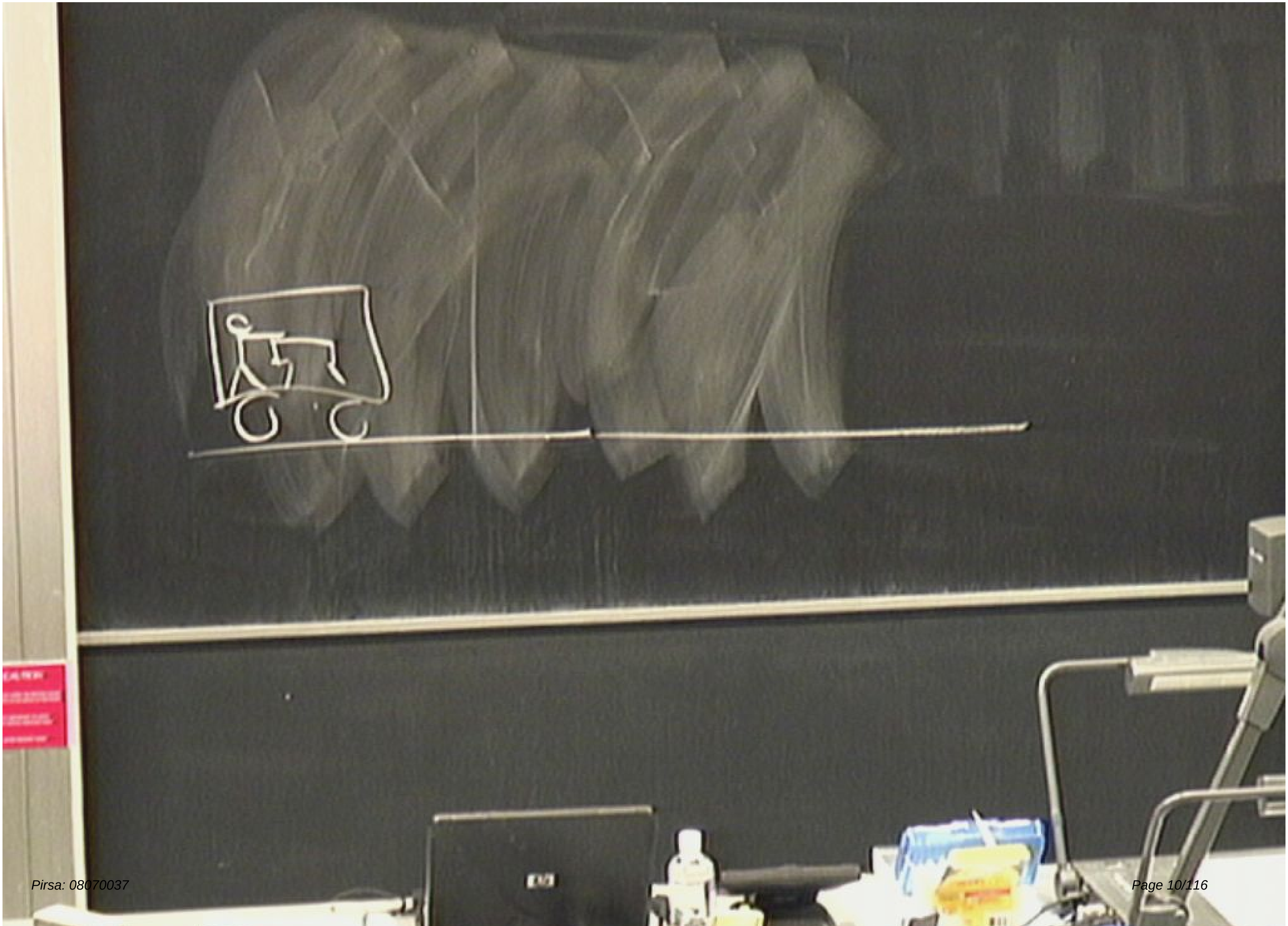
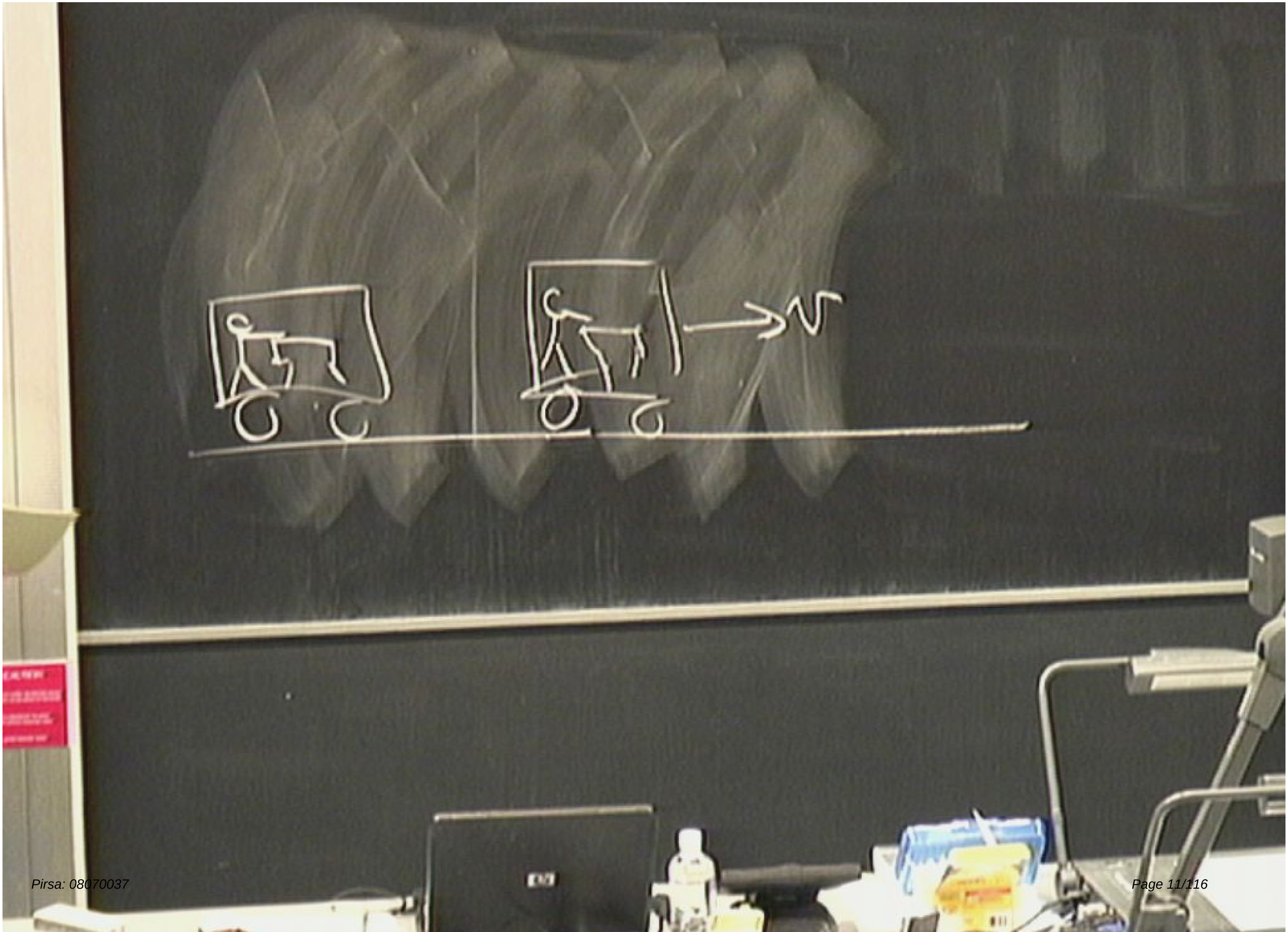
Given two inertial observers in uniform relative motion, both are equally entitled to consider themselves to be "at rest"

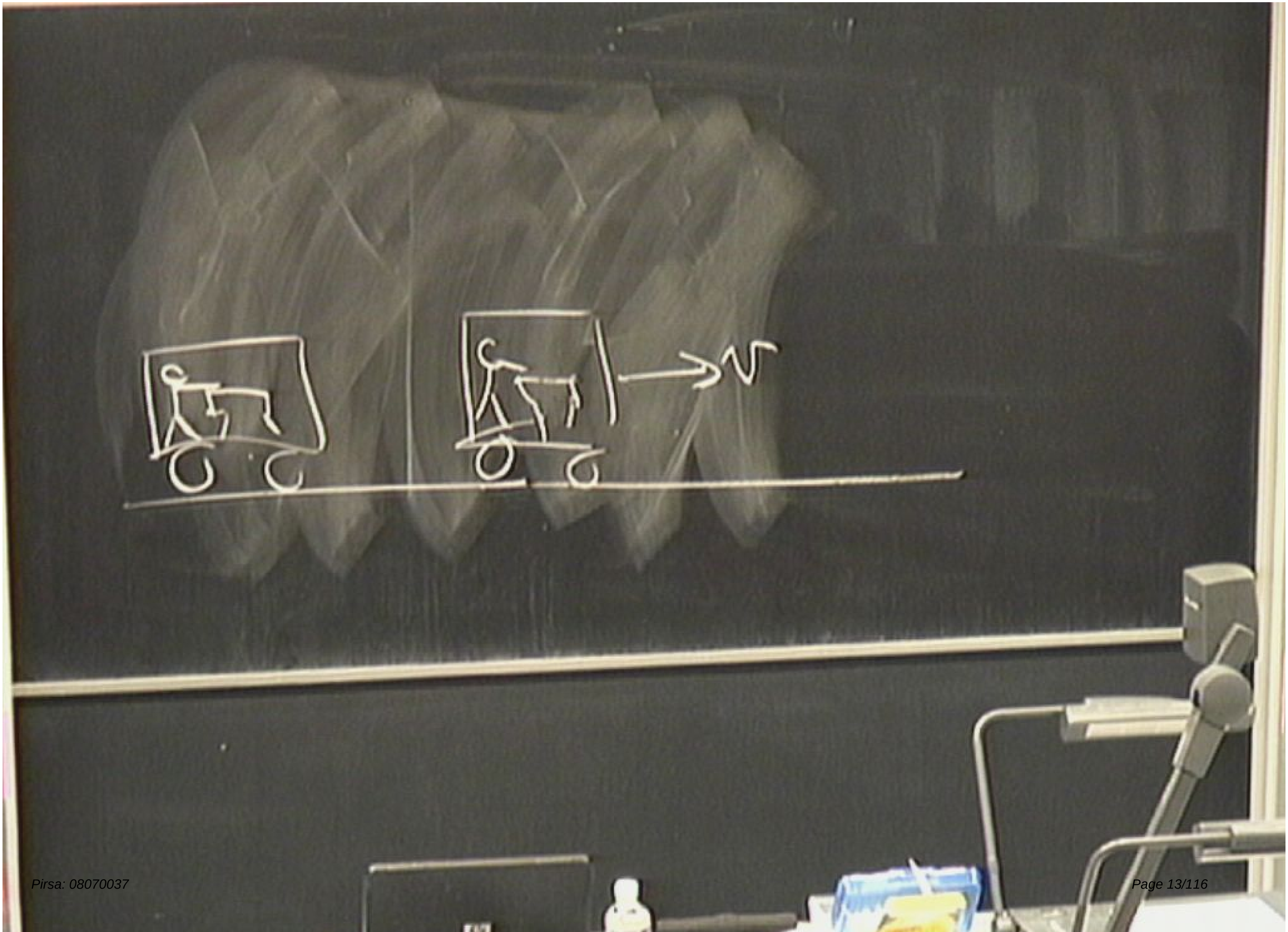


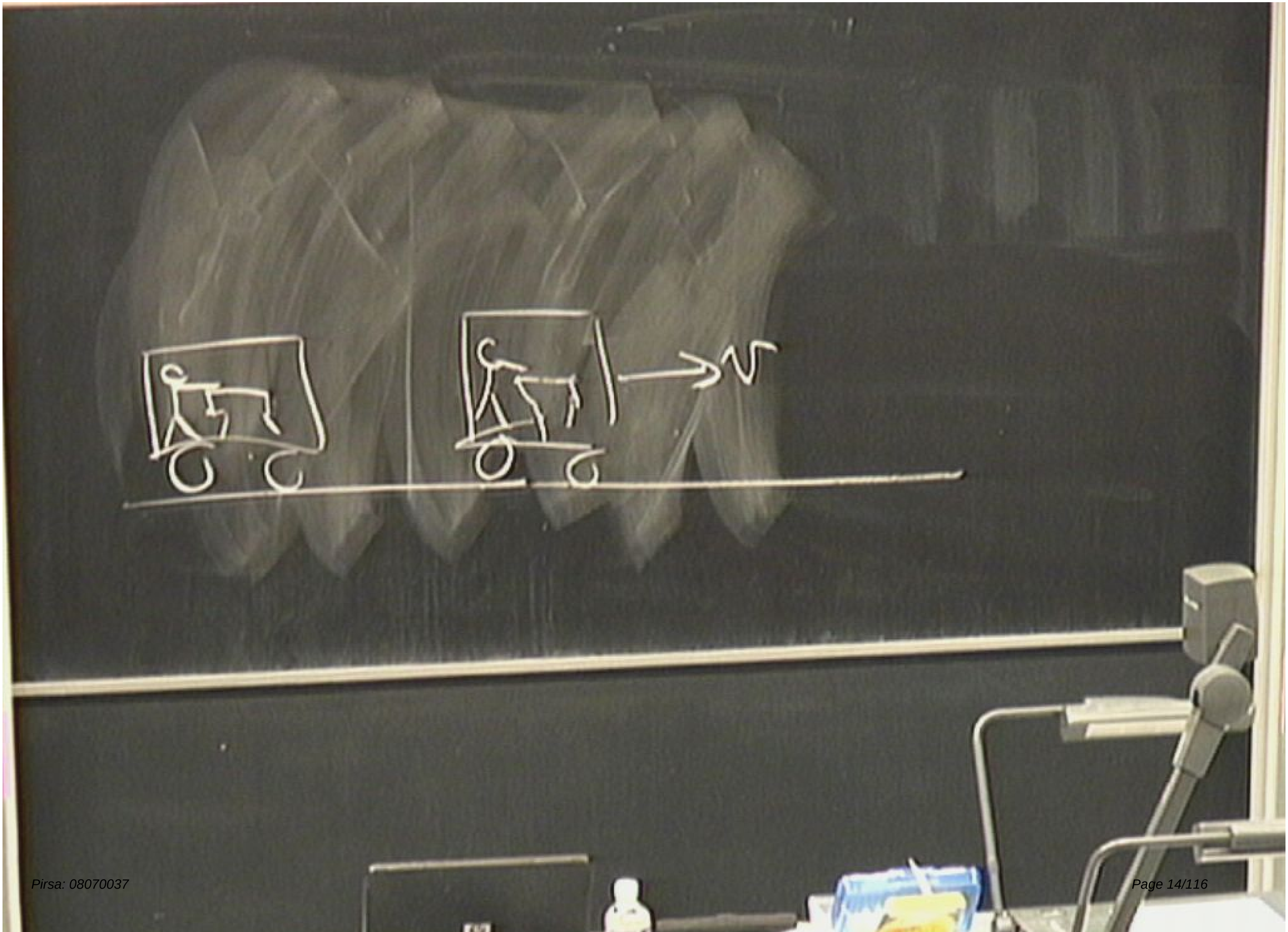

v

not accelerating (or rotating)

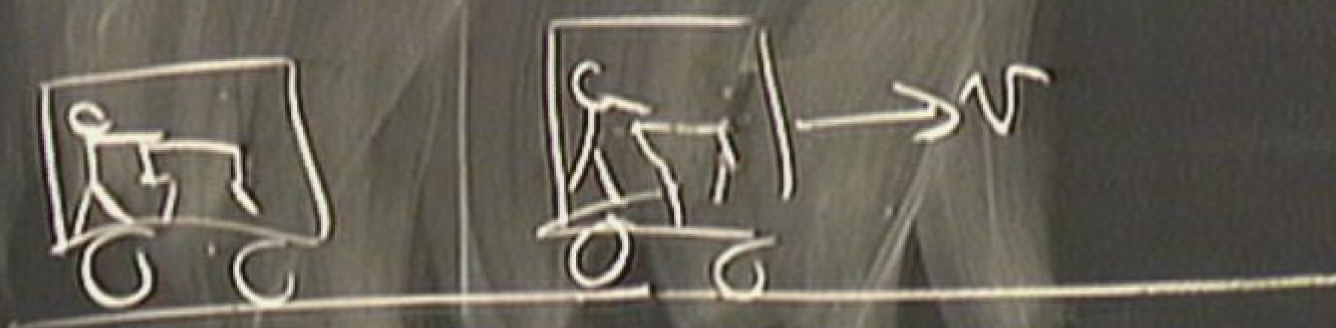
P1 : (Relativity)

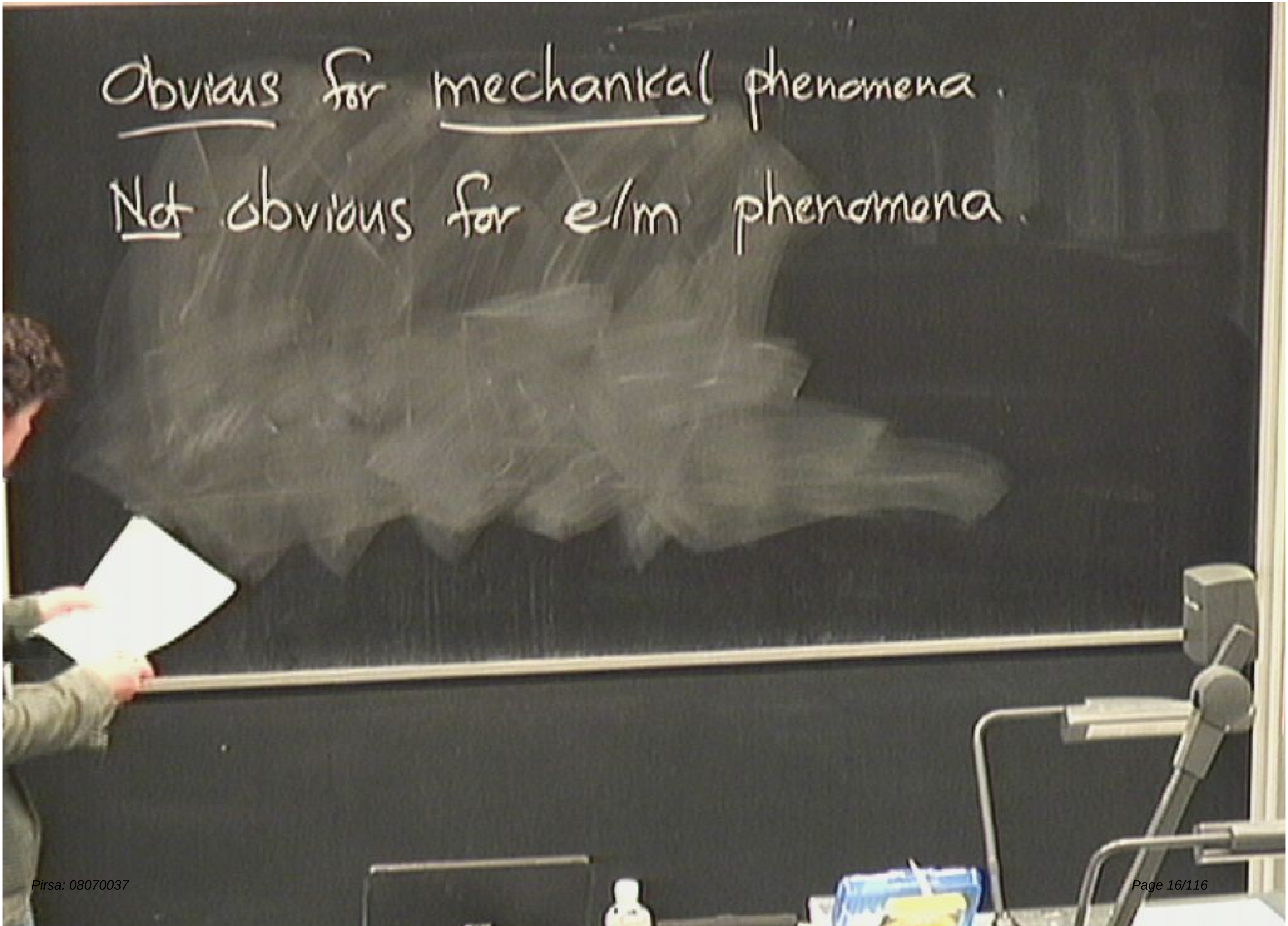
Given two inertial observers in uniform relative motion, both are equally entitled to consider themselves to be "at rest"

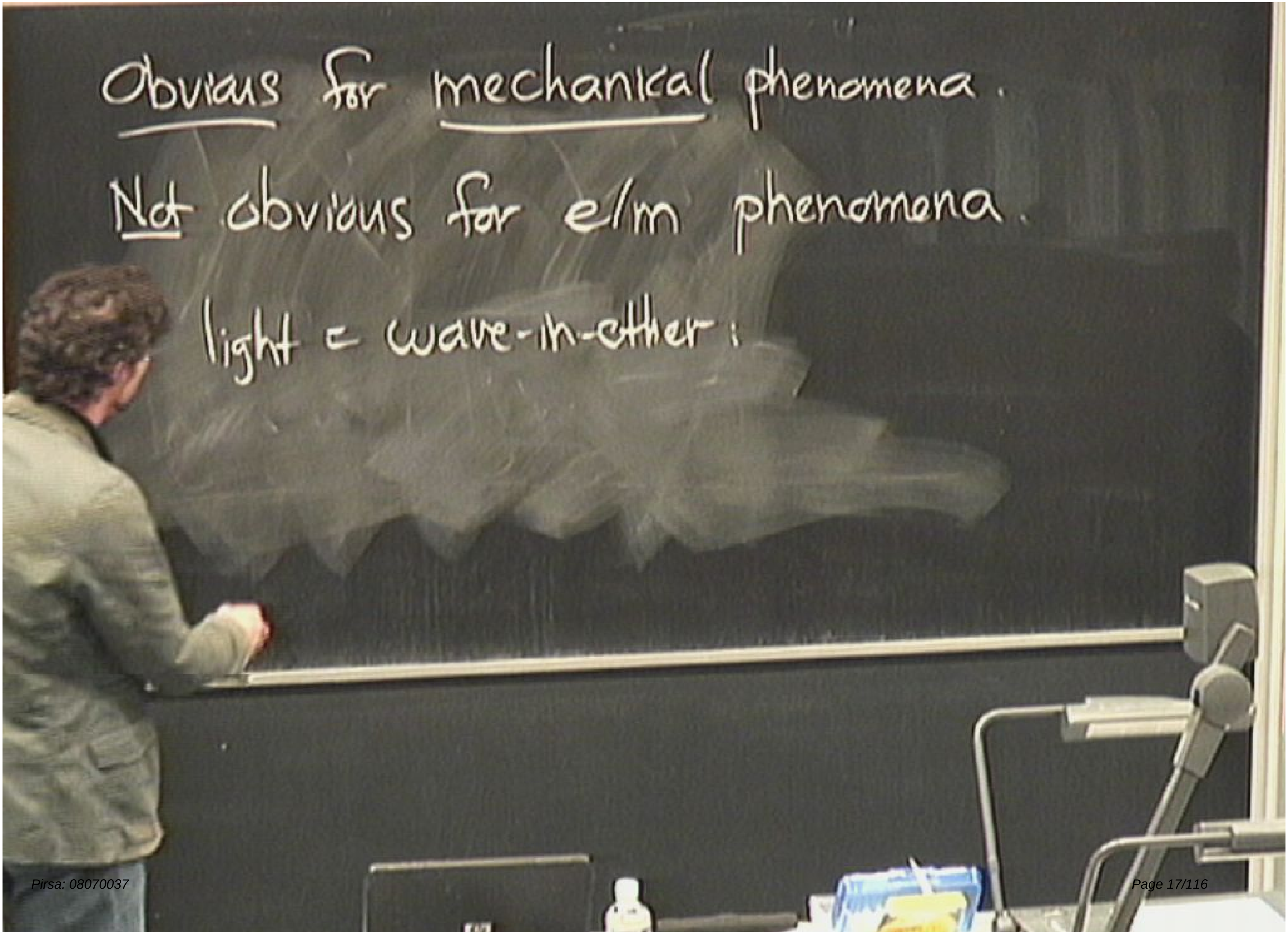

v


v

Obvious for mechanical phenomena.




Obvious for mechanical phenomena.
Not obvious for e/m phenomena.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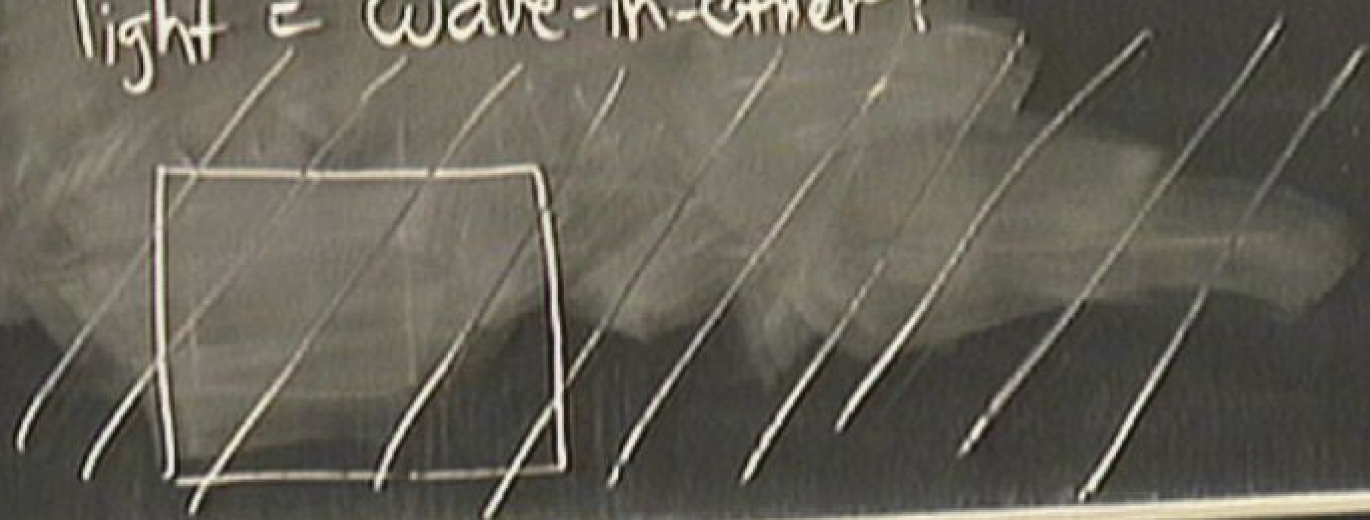
light = wave-in-ether :

Obvious for mechanical phenomena.

Not obvious for e/m phenomena.

e.g. light = wave-in-ether:



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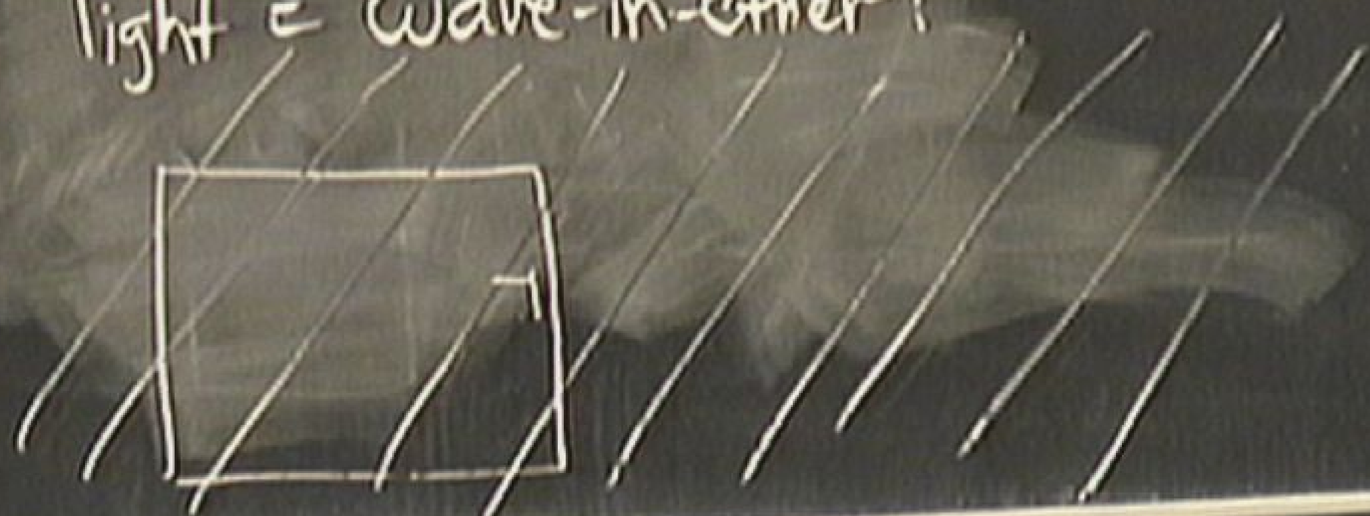

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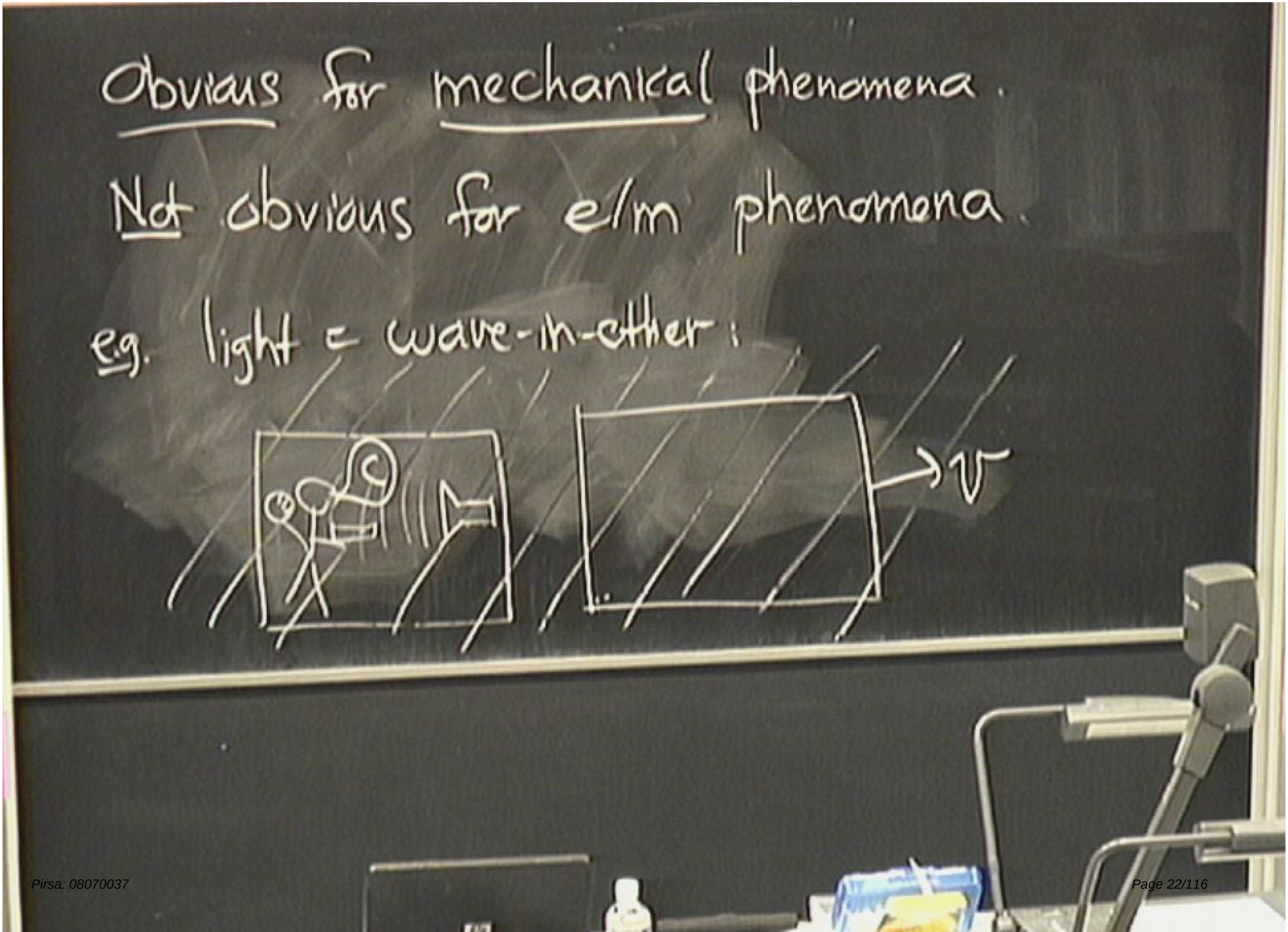
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v

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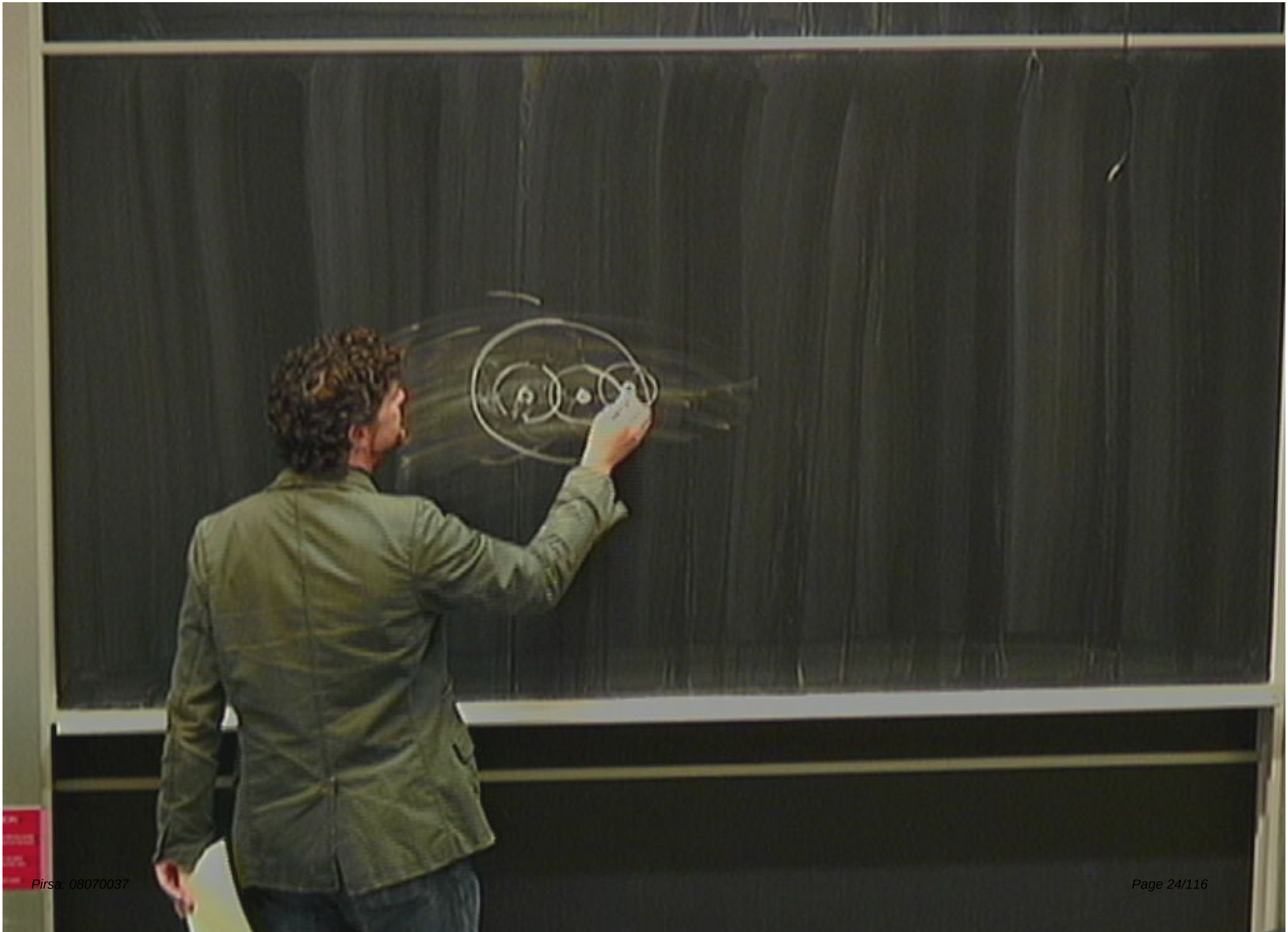

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e.g. light = wave-in-ether :

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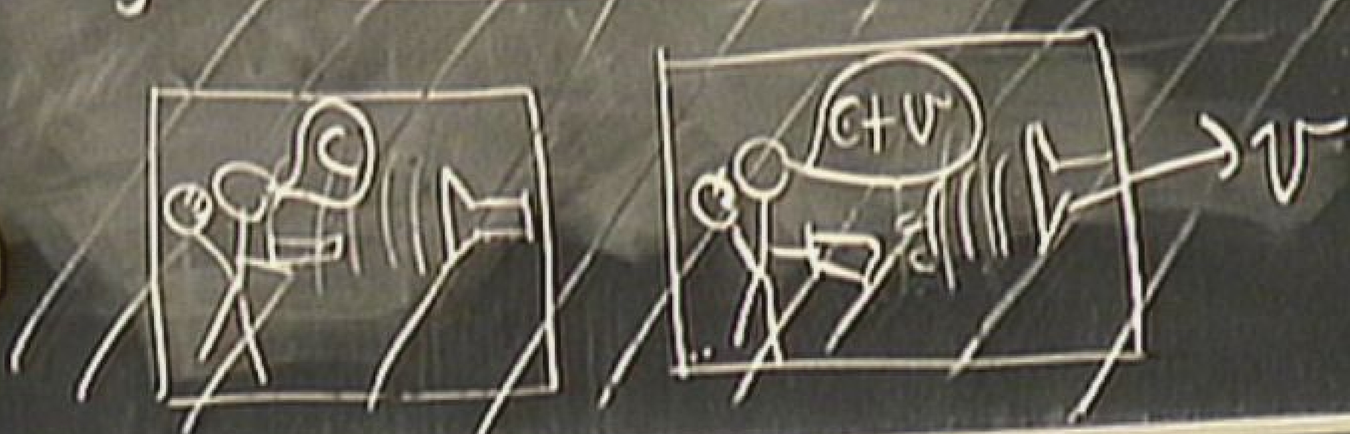
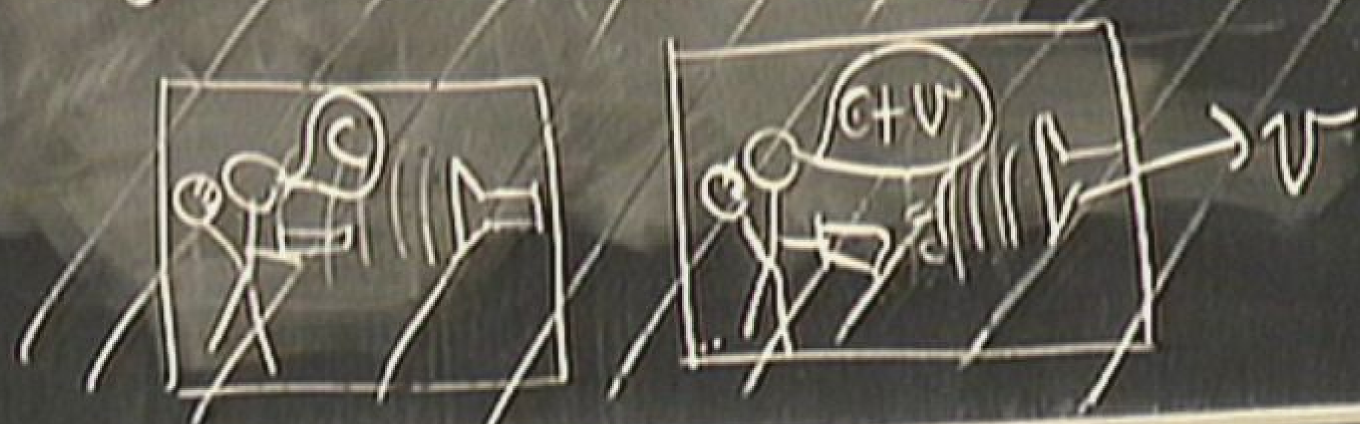
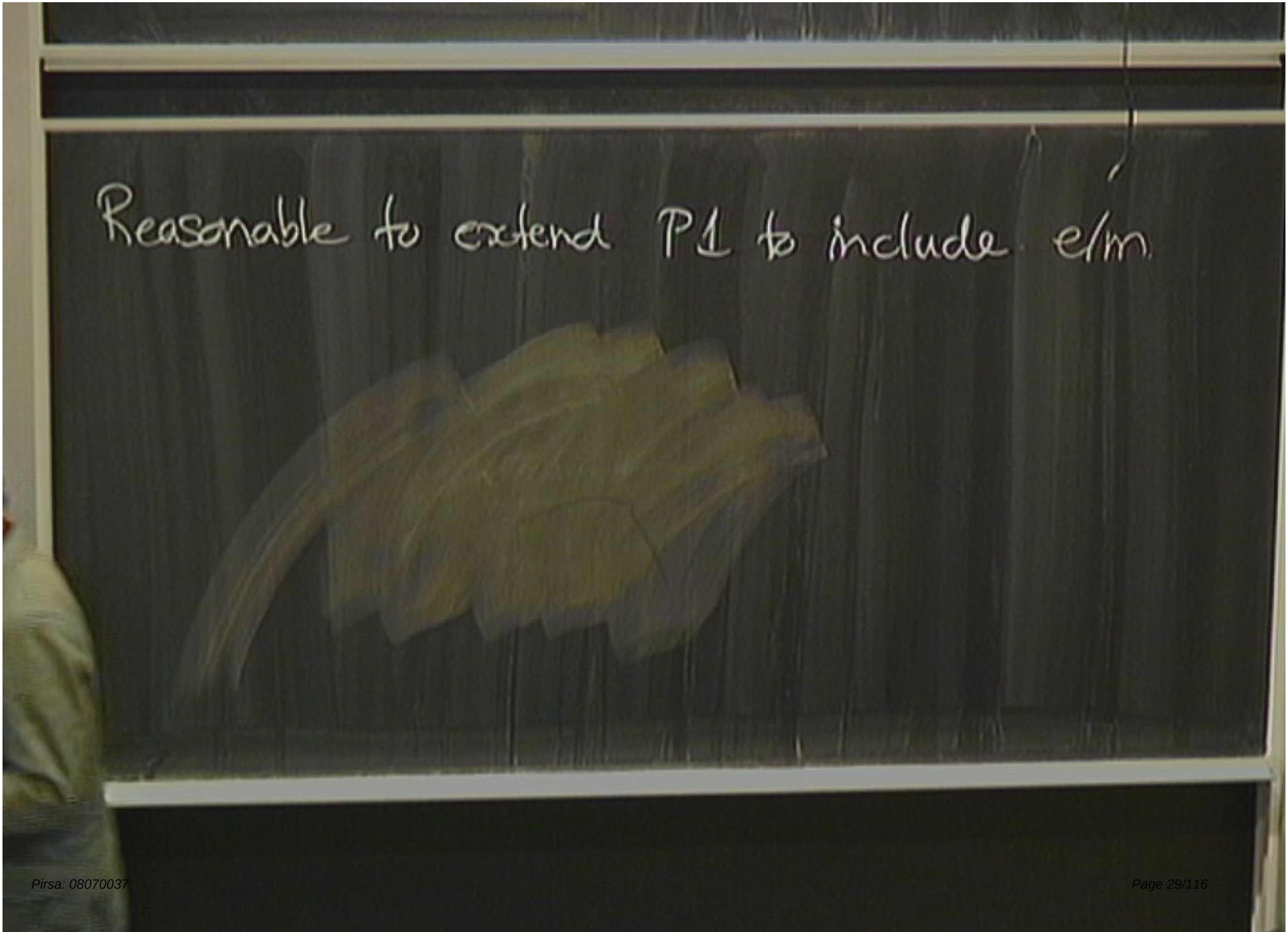


<u>Obvious</u> for <u>mechanical</u> phenomena.

<u>Not</u> obvious for e/m phenomena.

<u>e.g.</u> light = ~~wave in ether~~:

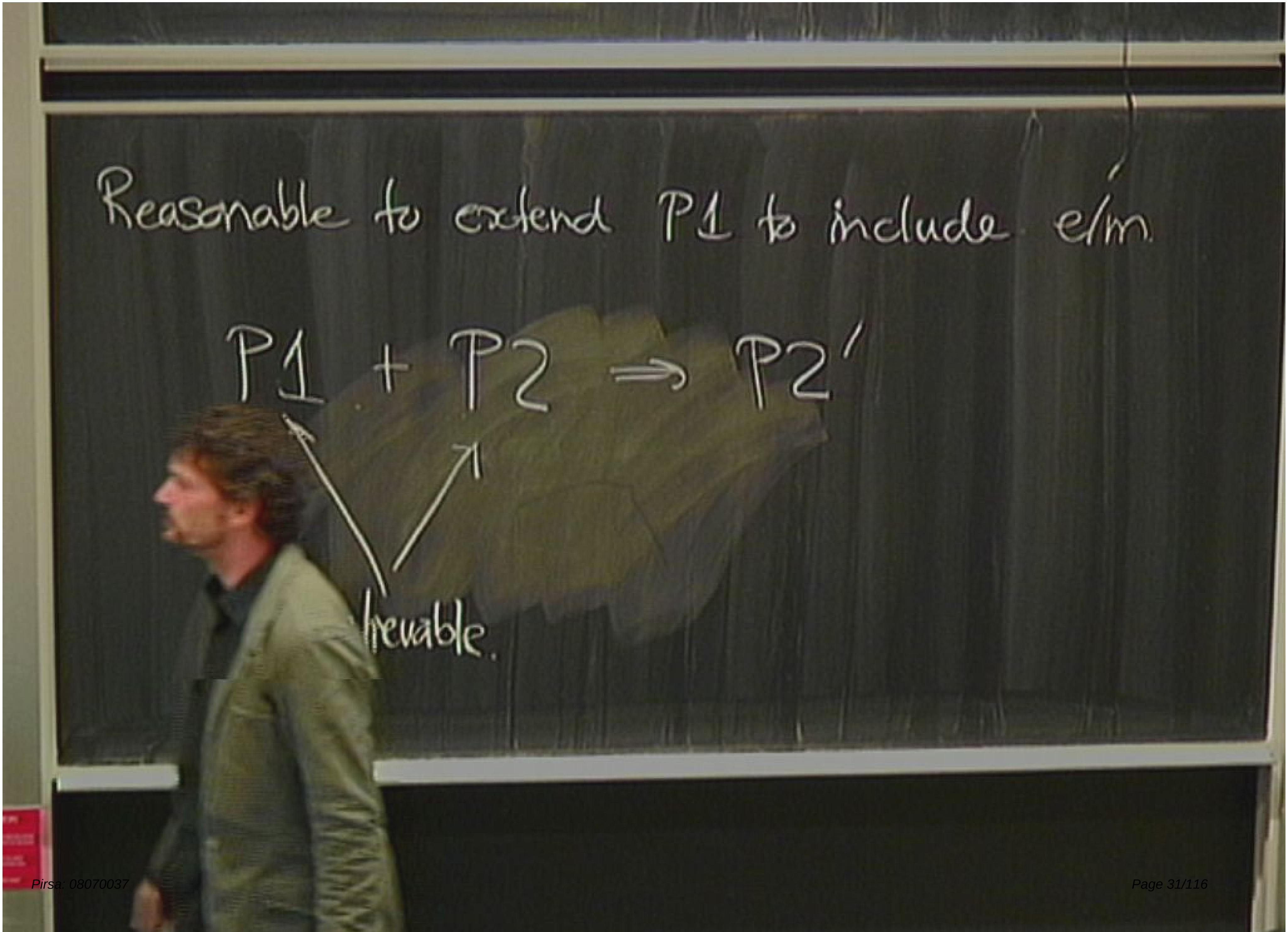



Reasonable to extend P1 to include e/m.

Reasonable to extend P1 to include e/m.

P1 P2

believable.


Reasonable to extend P1 to include e/m
P1 + P2 ⇒ P2′

Reasonable to extend P1 to include e/m.

$$P1 + P2 \Rightarrow P2'$$

believable.

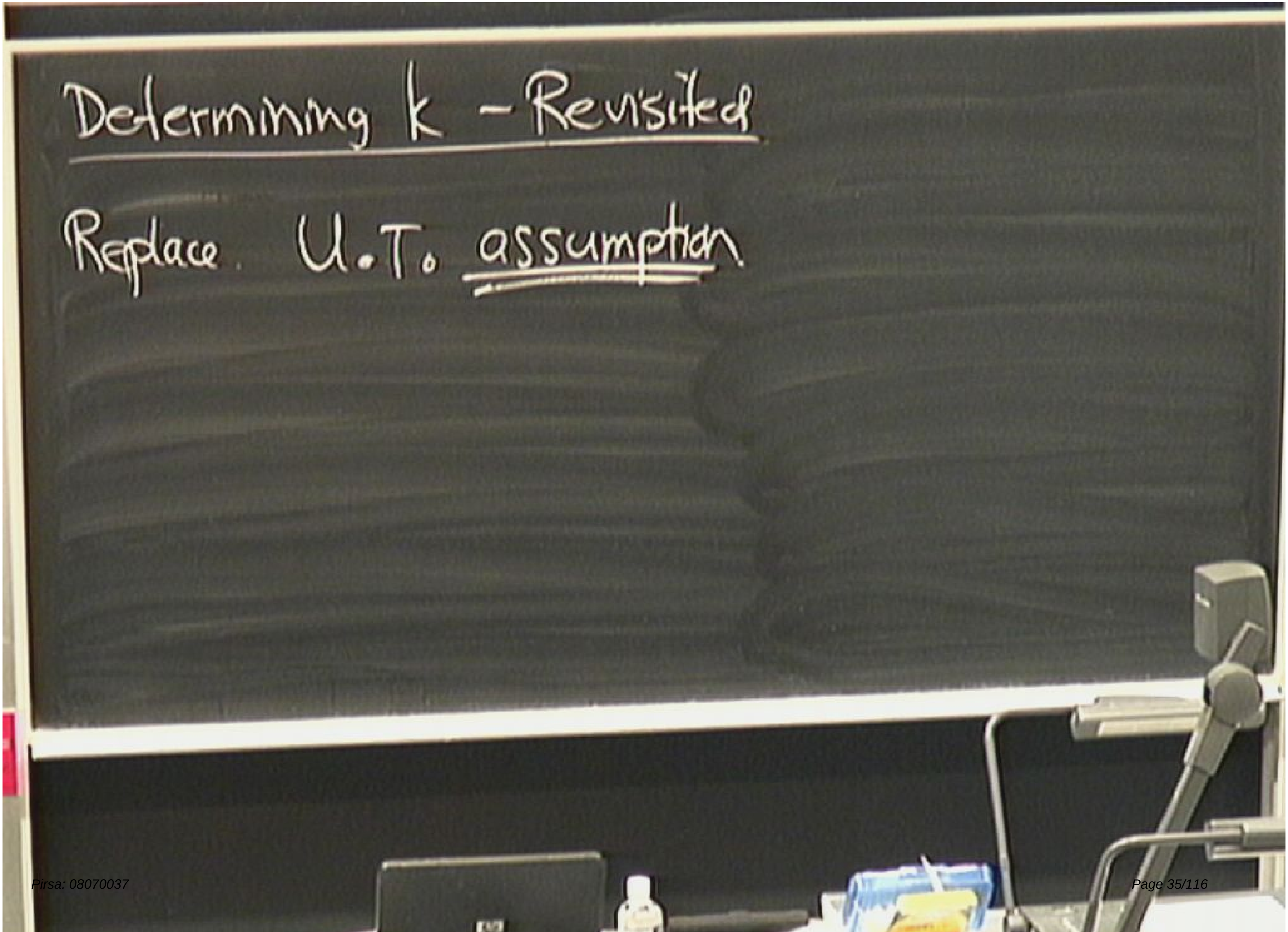
Reasonable to extend P1 to include e/m.

$$P1 + P2 \Rightarrow P2'$$

believable.

unbelievable !

Determining k - Revisited


Determining k - Revisited
Replace U.T. assumption

Determining k – Revisited

Replace U.T. assumption with P1

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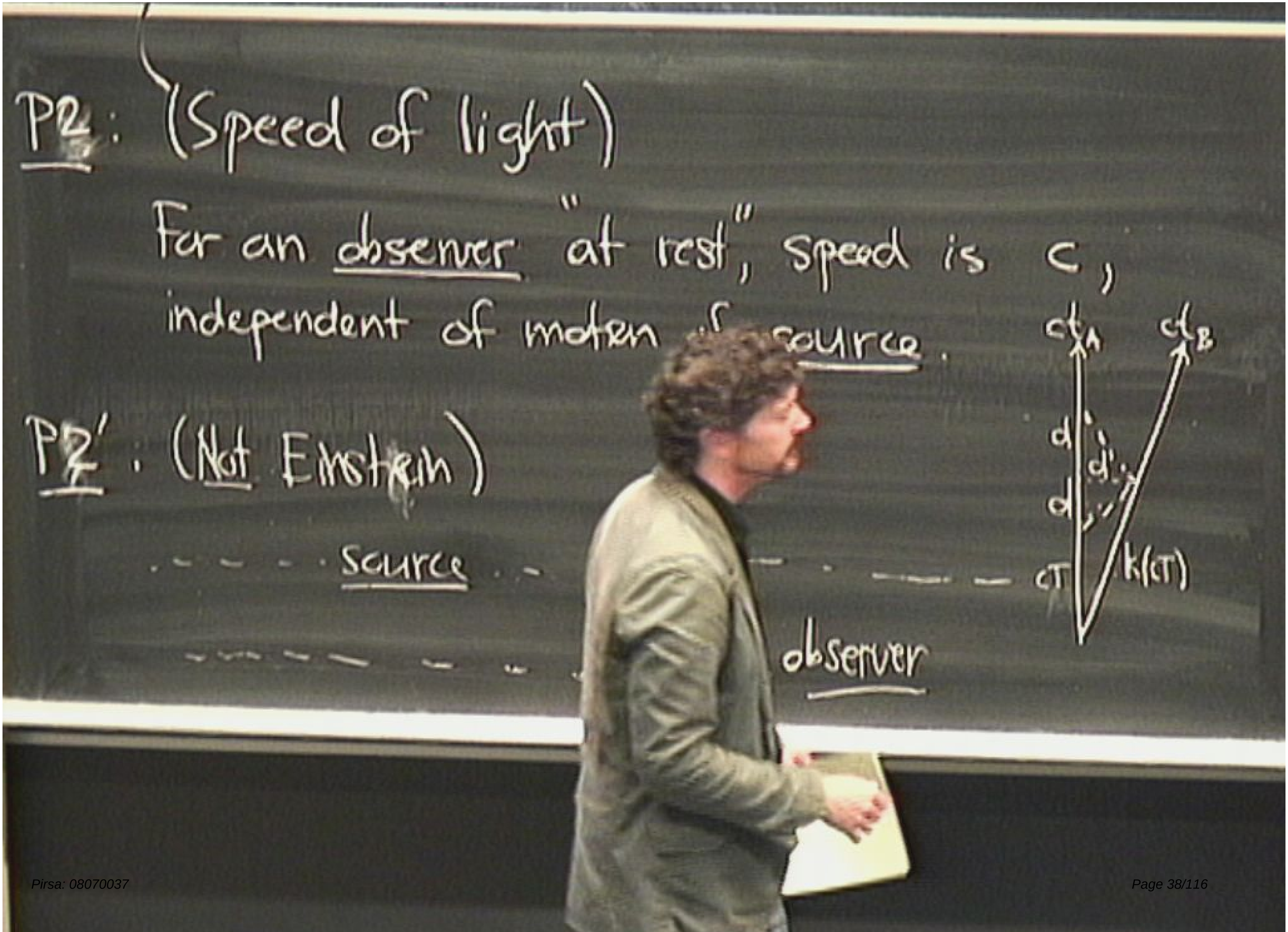
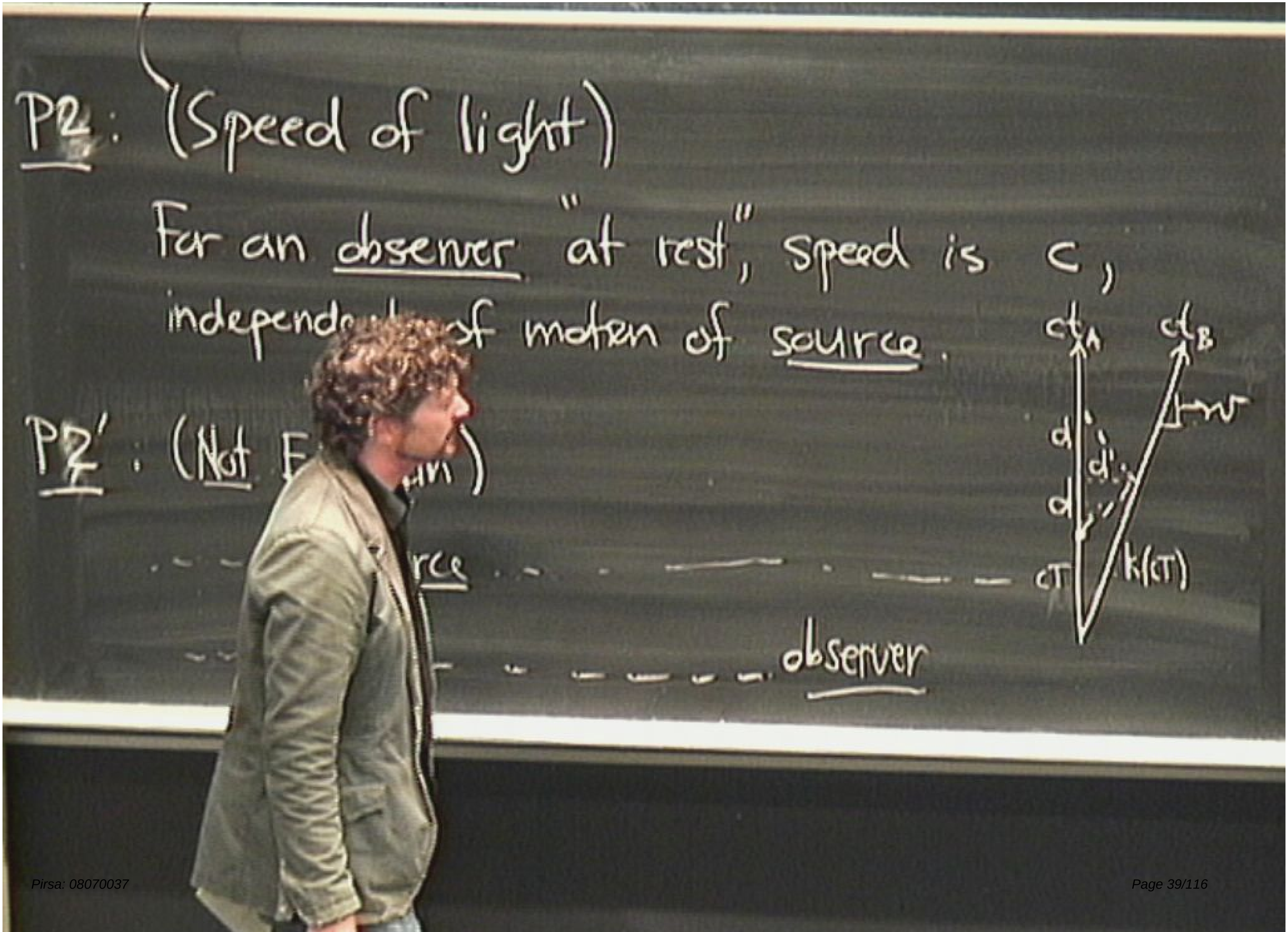

P2: (Speed of light)
For an observer "at rest", speed is c,
independent of moten of source.
ct_A
ct_B
P2': (Not Einstein)
source
cT
k(cT)
observer

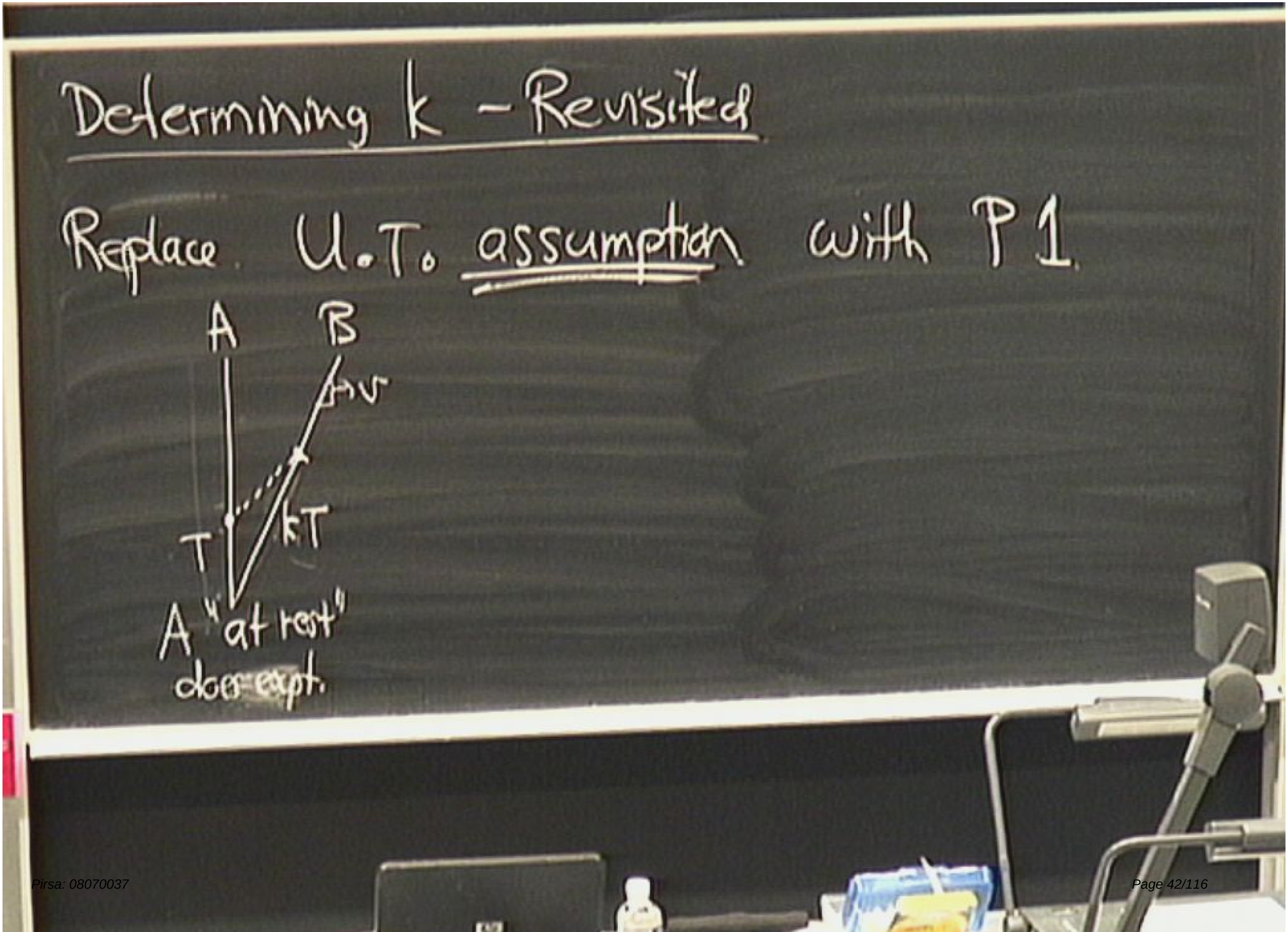

P2: (Speed of light)
For an observer "at rest", speed is c,
of moten of source.
ct_A
ct_B
v
d
d'
d
cT
k(cT)
P2': (Not
observer

Determining k – Revisited

Replace U.T. assumption with P 1

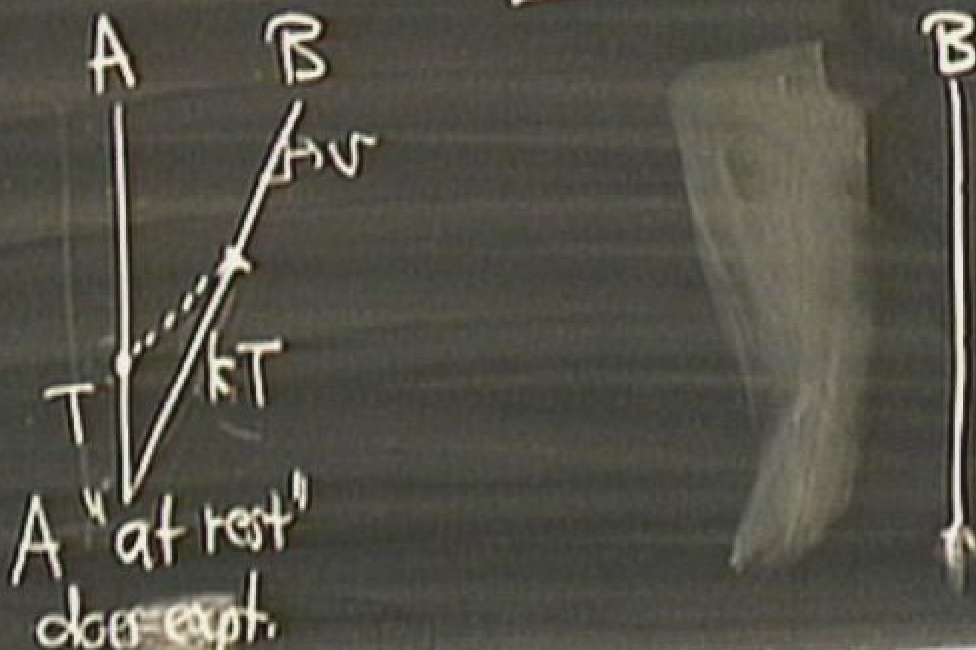
Determining k - Revisited

Replace U.T. assumption with P1


Determining k - Revisited
Replace U.T. assumption with P 1
A
B
v
T
kT
A "at rest"
does expt.

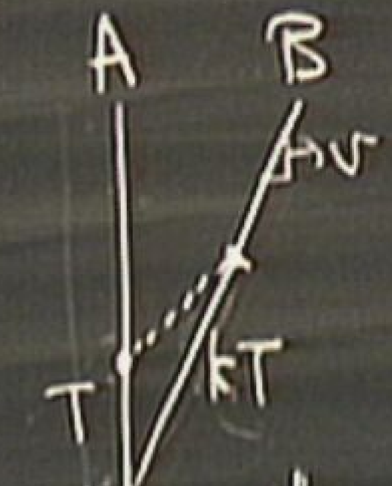
Determining k – Revisited

Replace U.T. assumption with P1

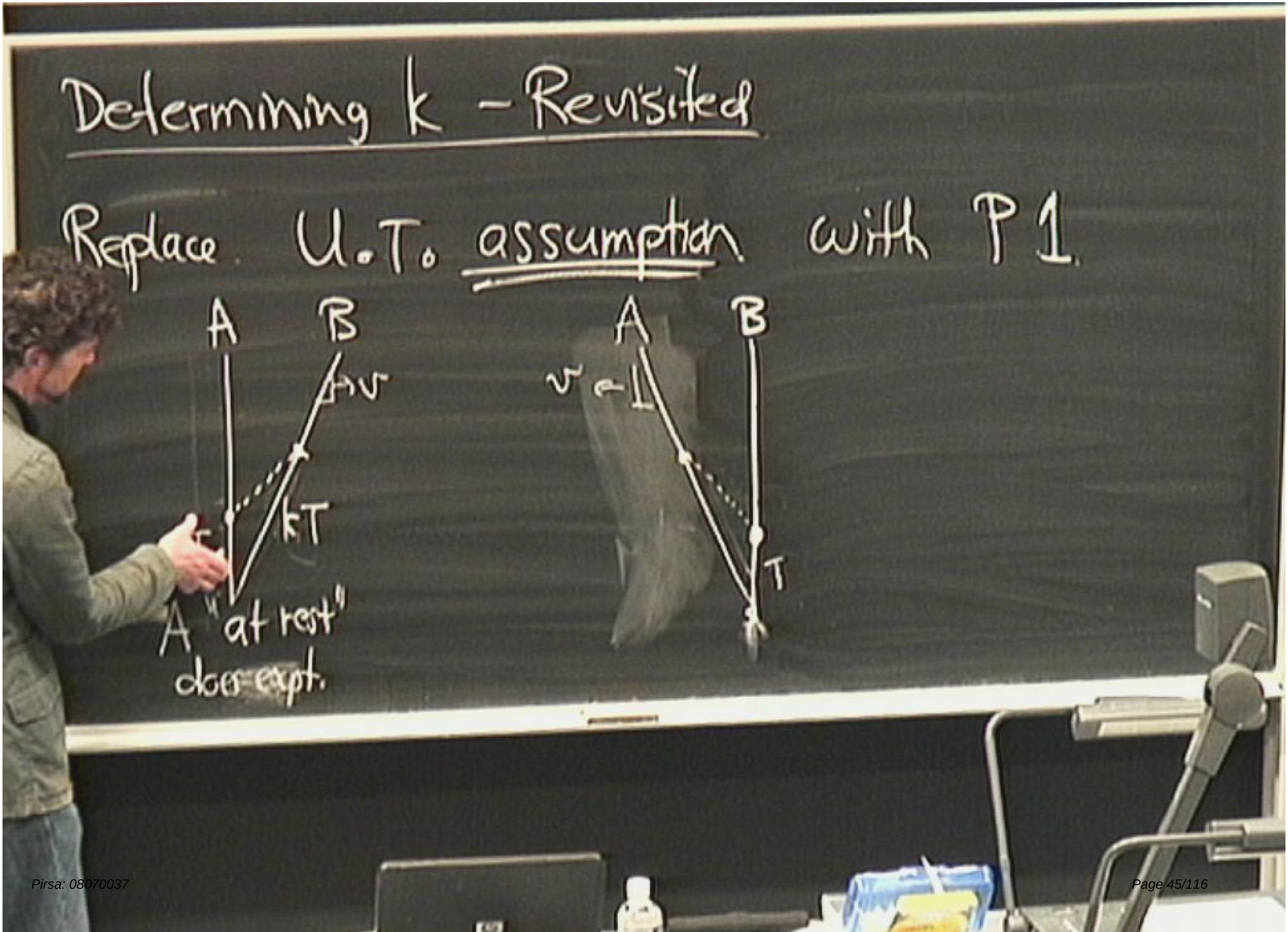


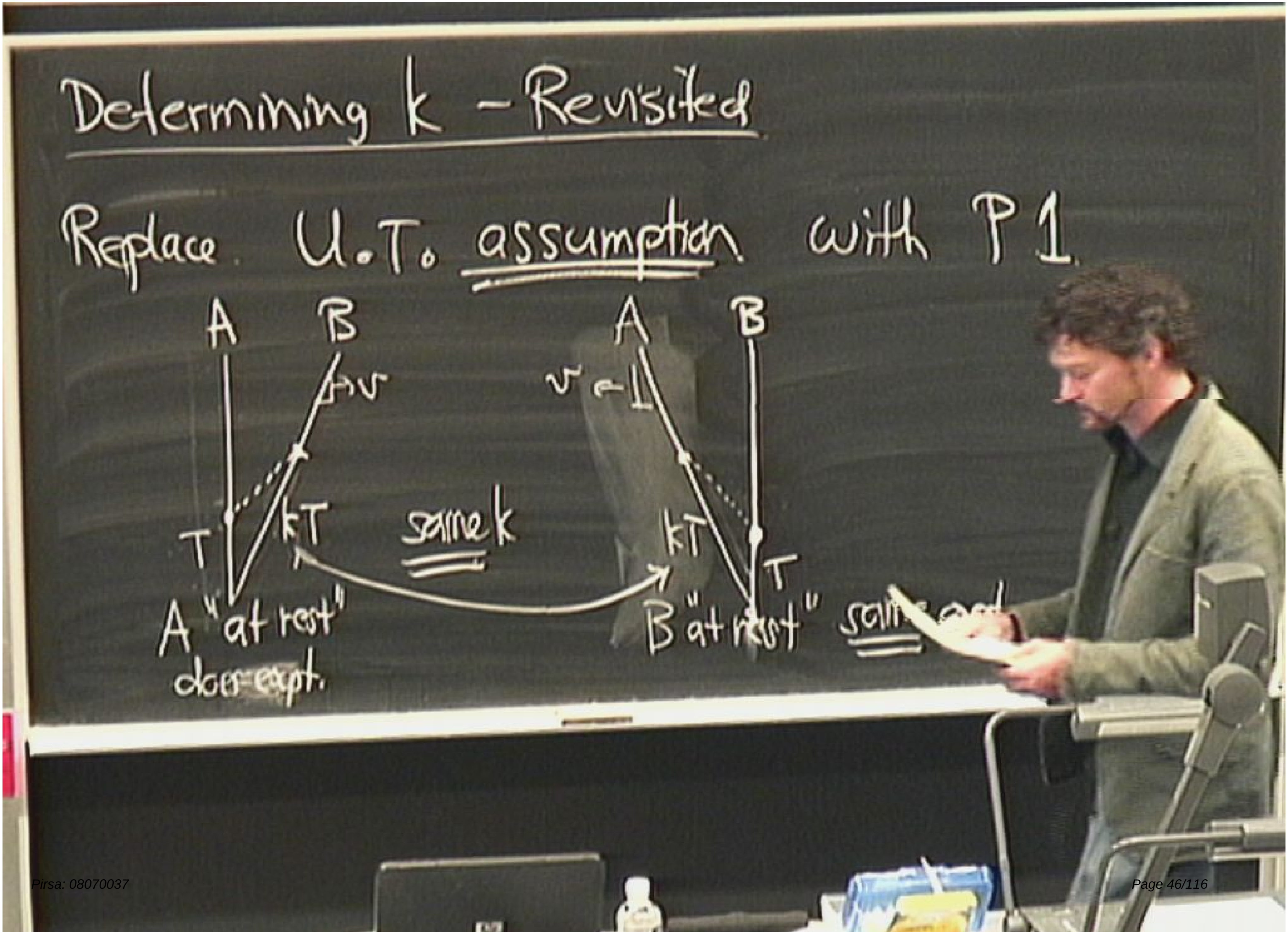
Determining k – Revisited

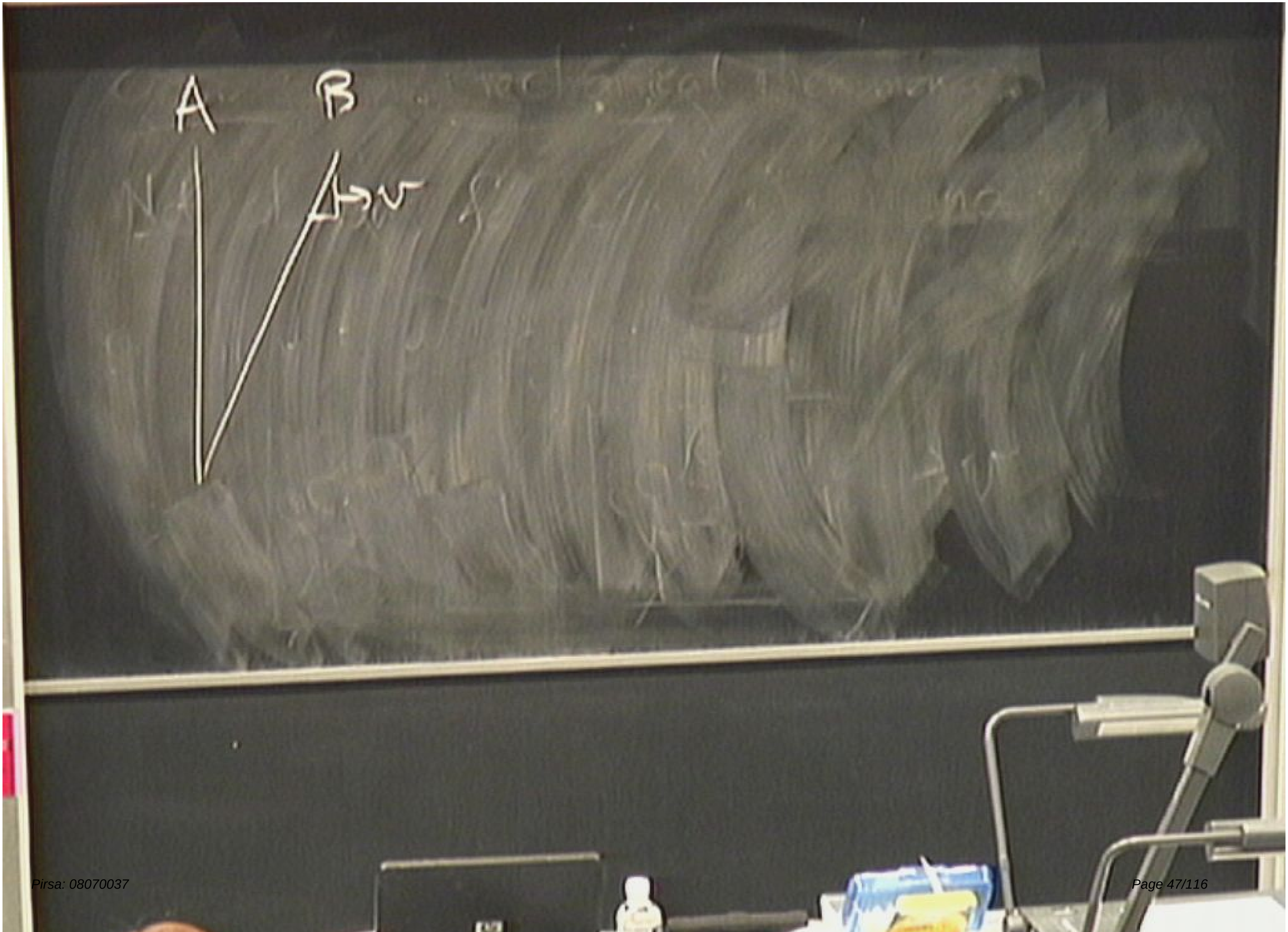
Replace U.T. assumption with P1

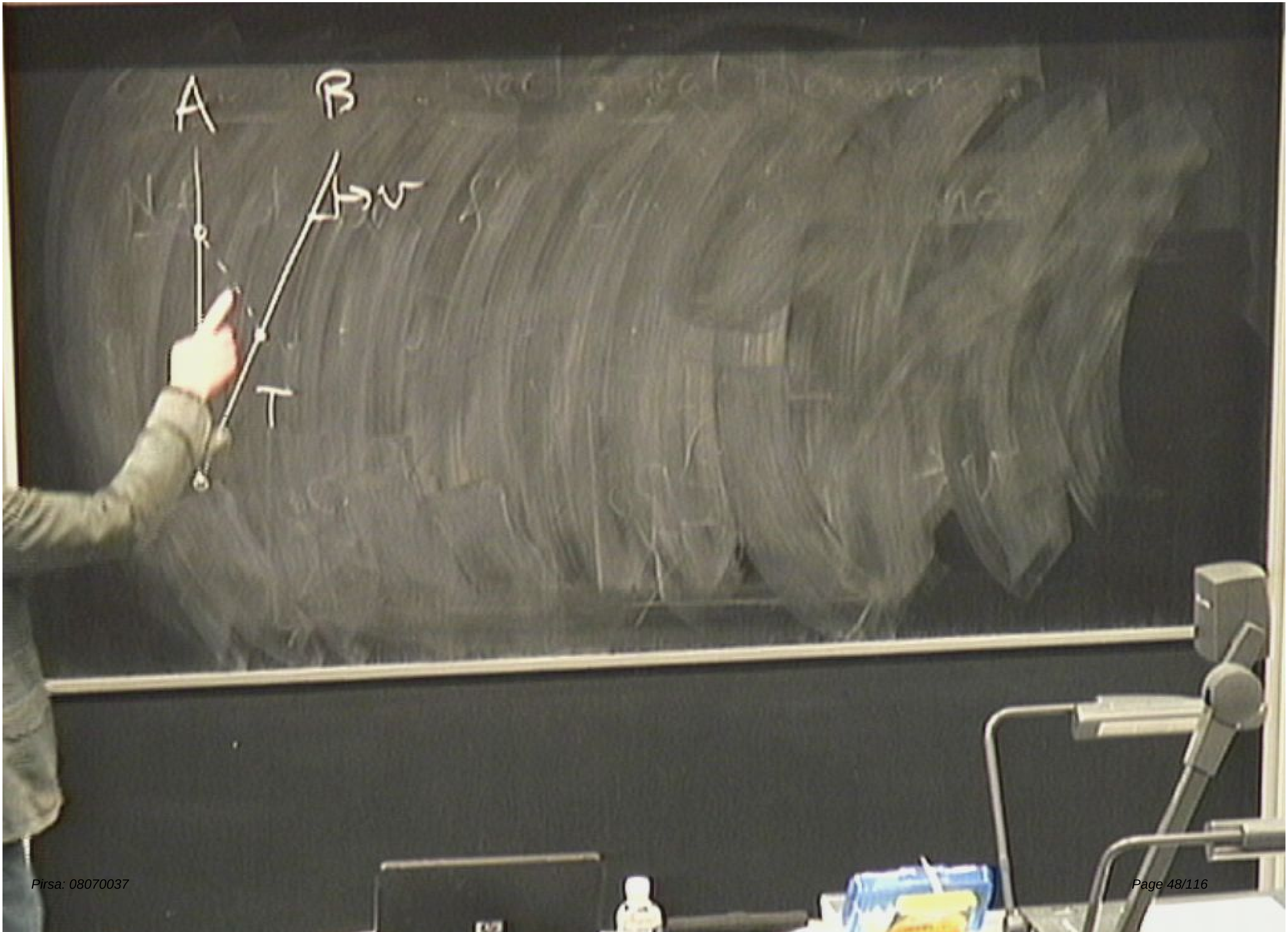


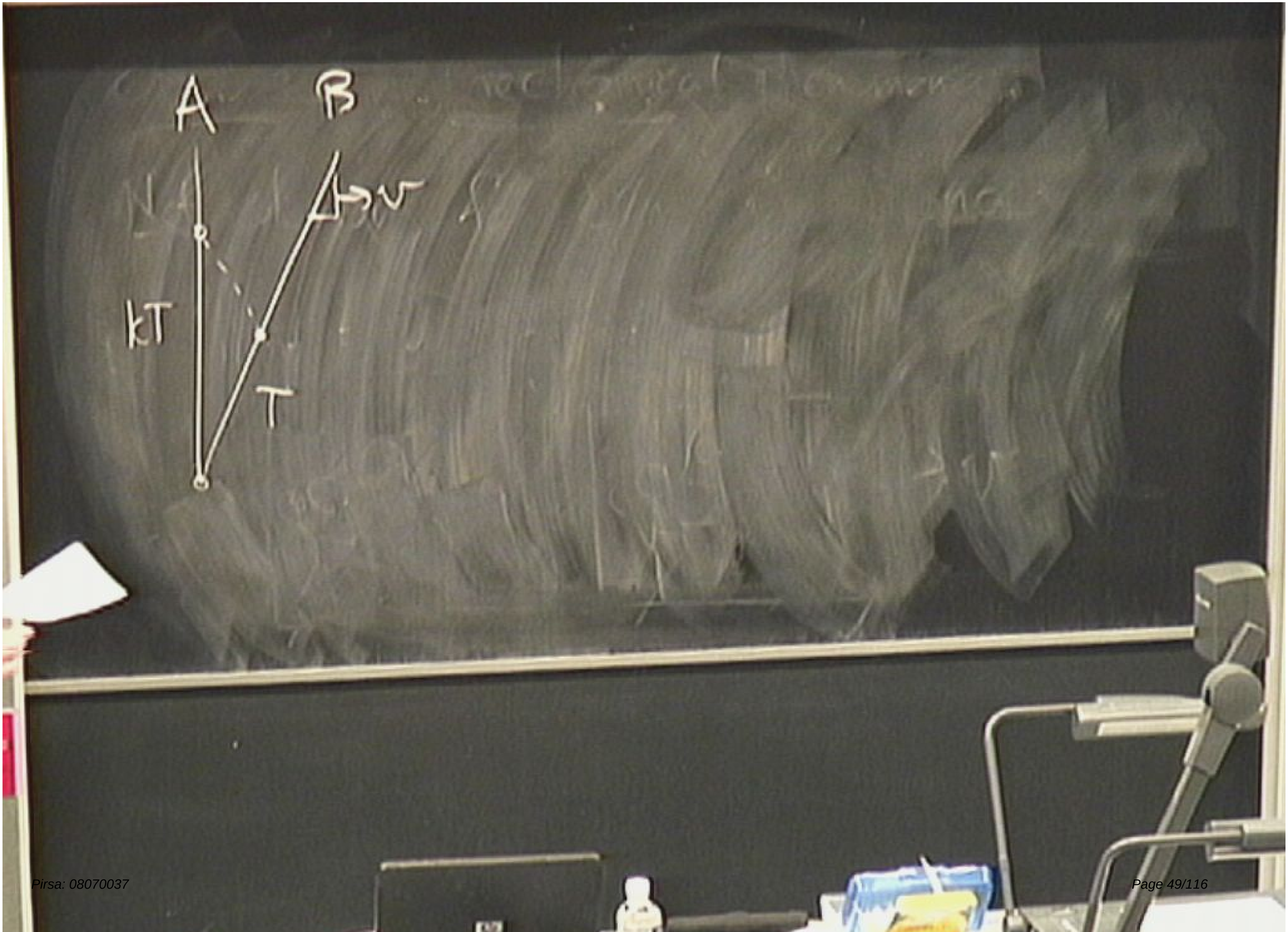
A "at rest"

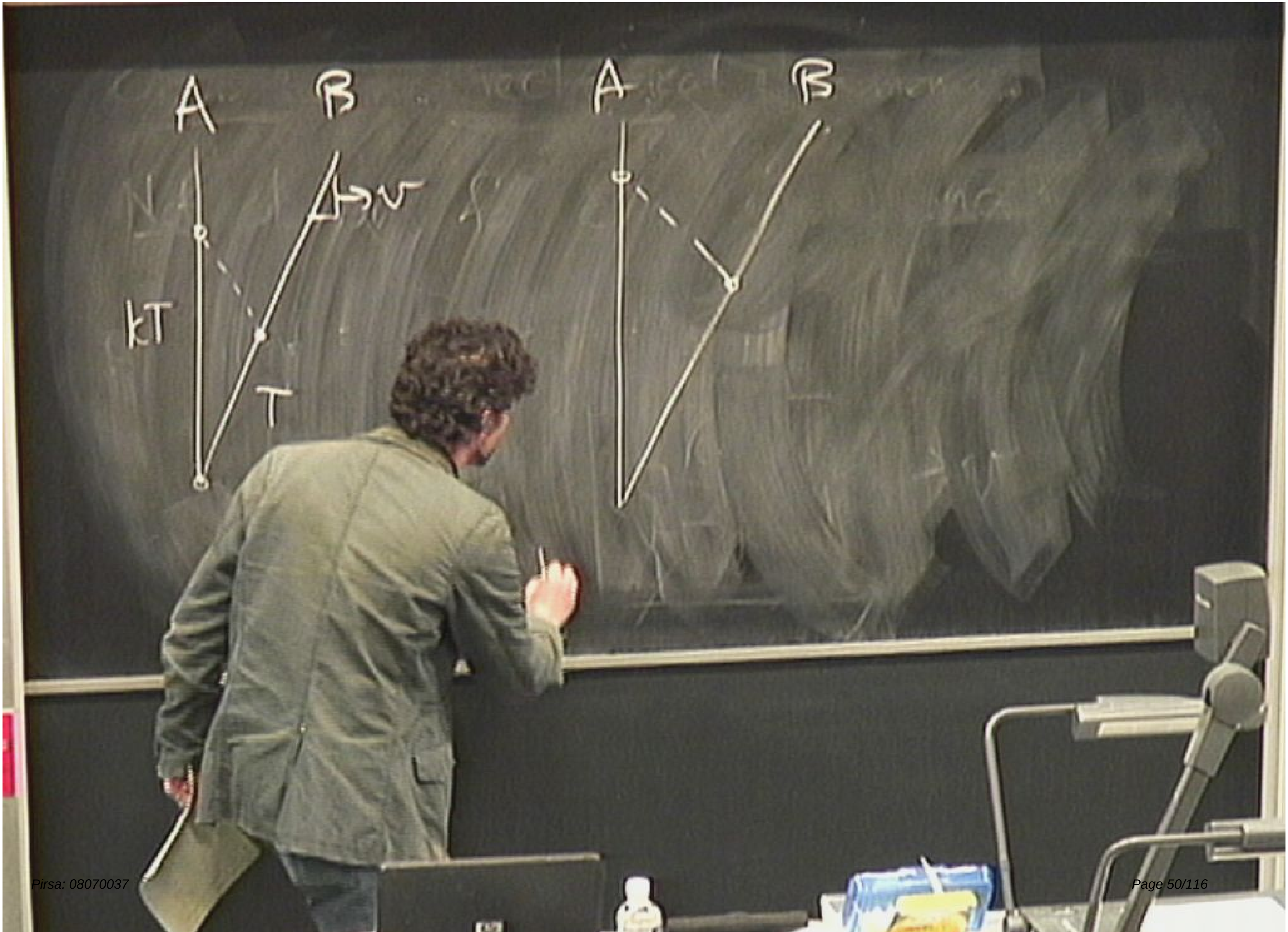

Determining k - Revisited
Replace U.T. assumption with P 1
A
B
+v
kT
A "at rest"
does expt.
A
B
T

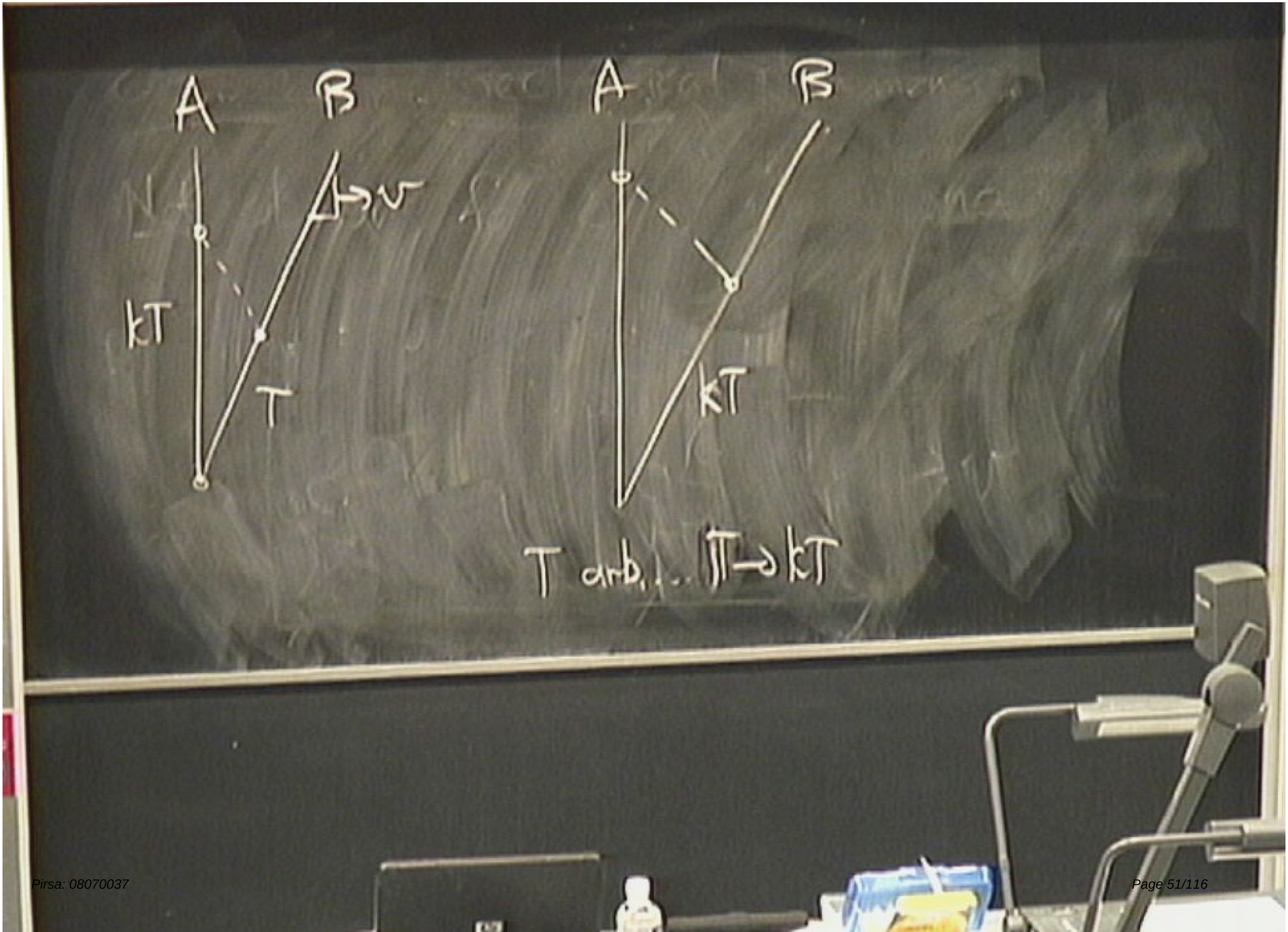

Determining k - Revisited
Replace U.T. assumption with P 1
A
B
T
kT
same k
A "at rest"
does expt.
A
B
kT
T
B "at rest"

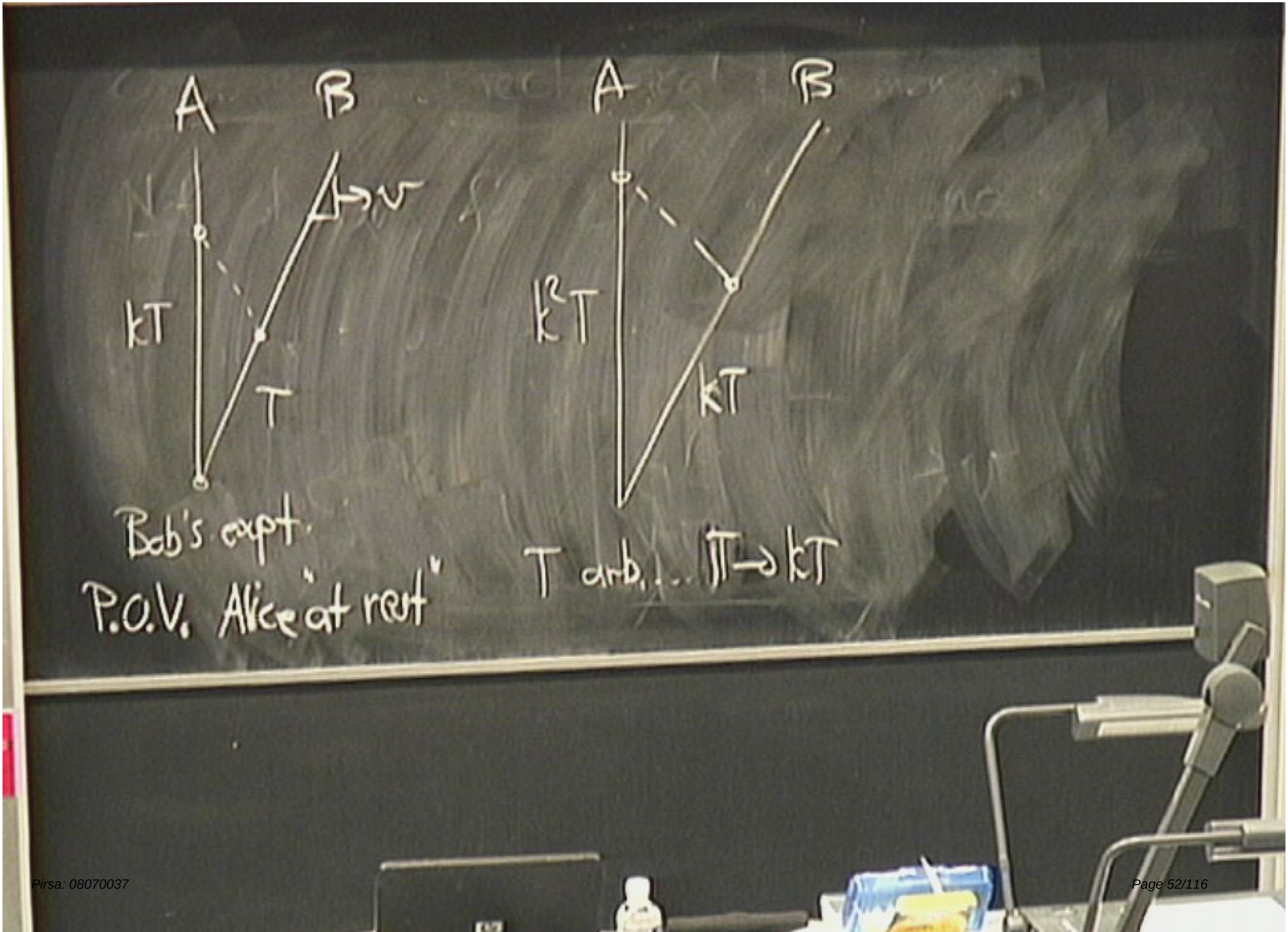

A
B

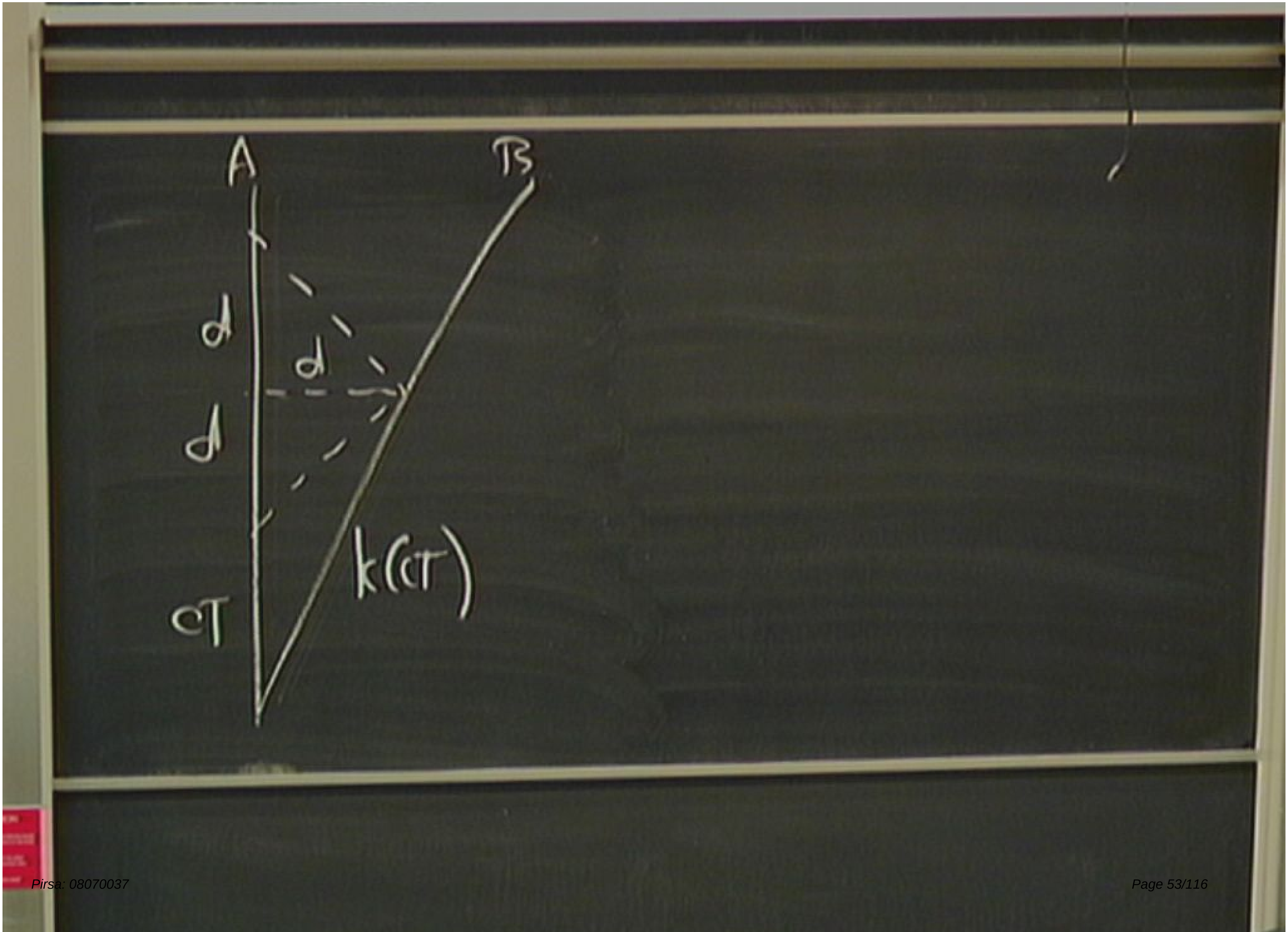

A
B
Δν
T

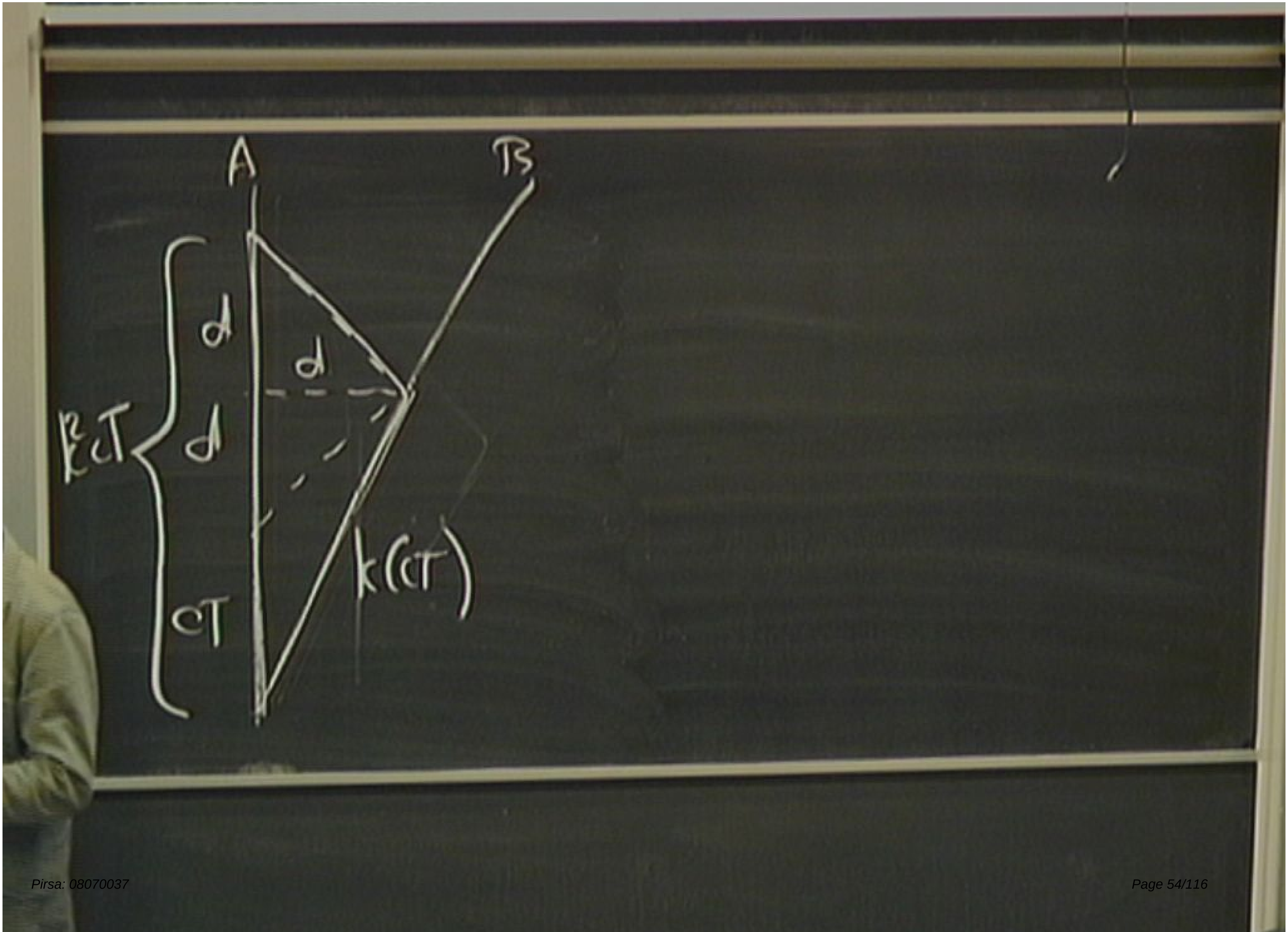

A
B
$h\nu$
kT
T

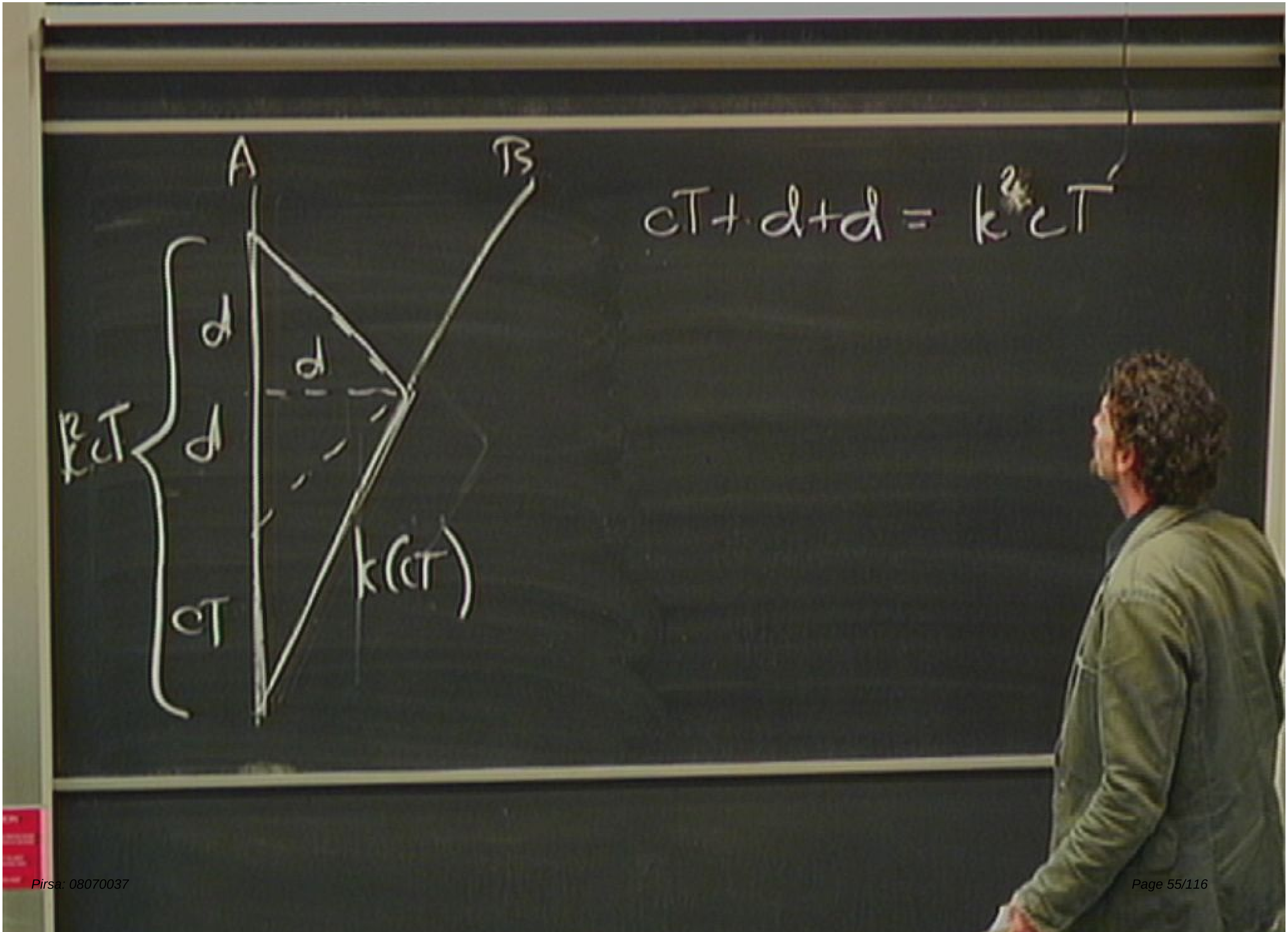

A
B
A
B
$\Delta h\nu$
kT
T

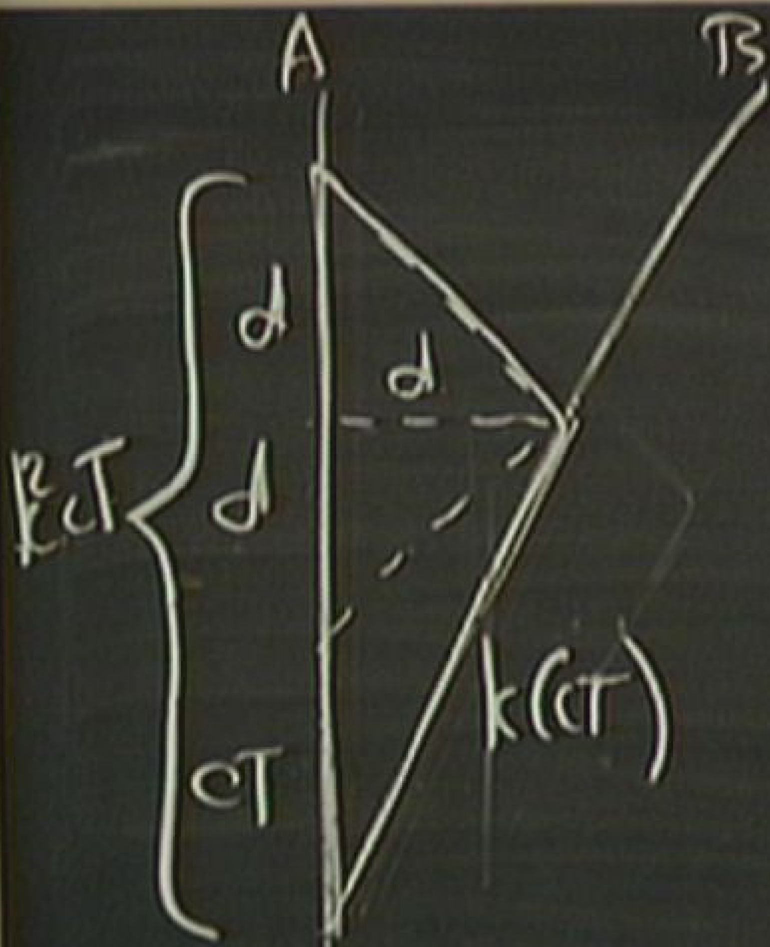

A
B
$\Delta h\nu$
kT
T
A
B
kT
T arb. ... $T \to kT$


A
B
Δv
kT
T
Bob's expt.
P.O.V. Alice "at rest"
A
B
k²T
kT
T arb. ... T→kT


A
B
d
d
d
k(cT)
cT

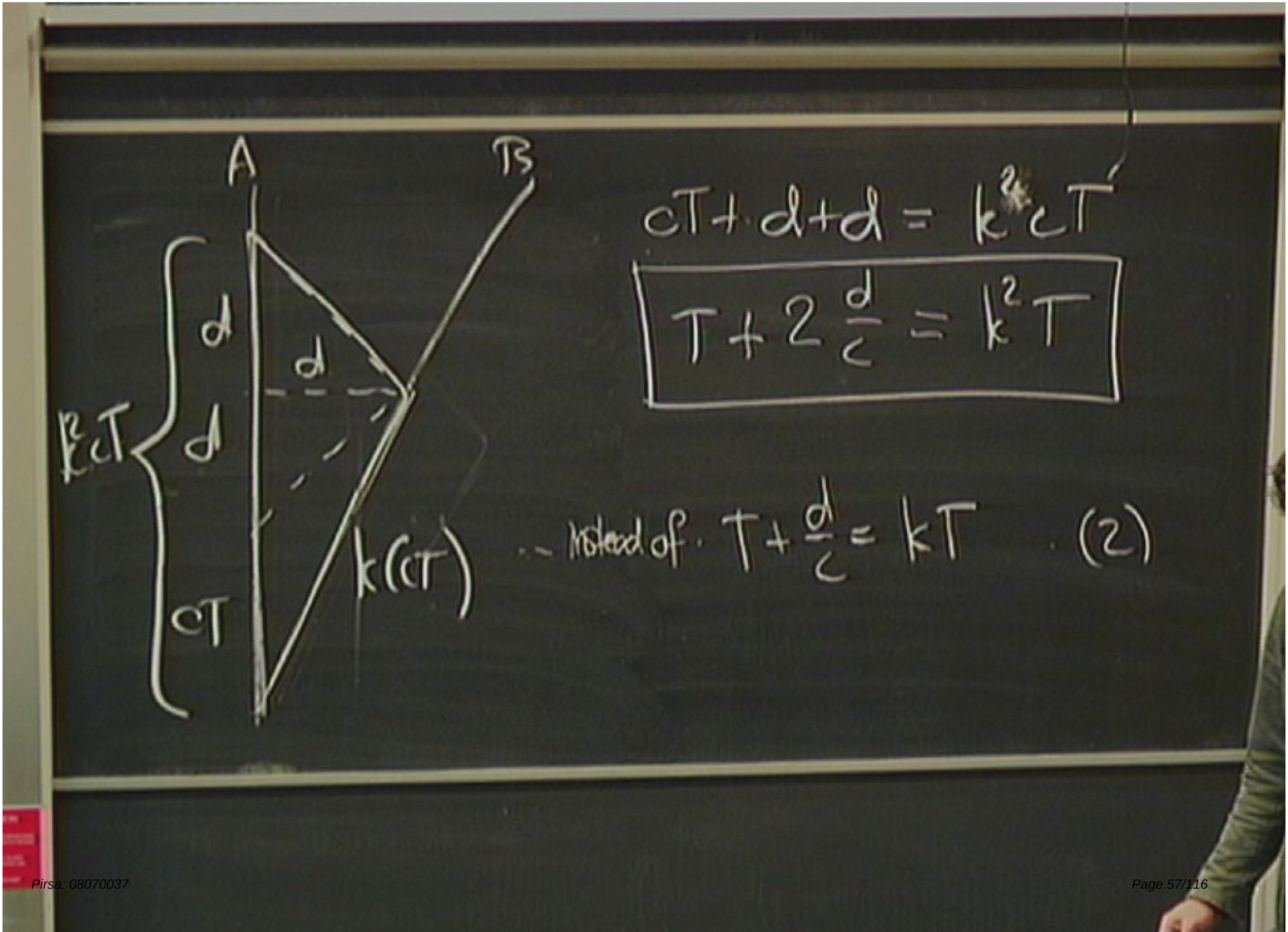

A
B
d
d
d
k^2cT
k(cT)
cT

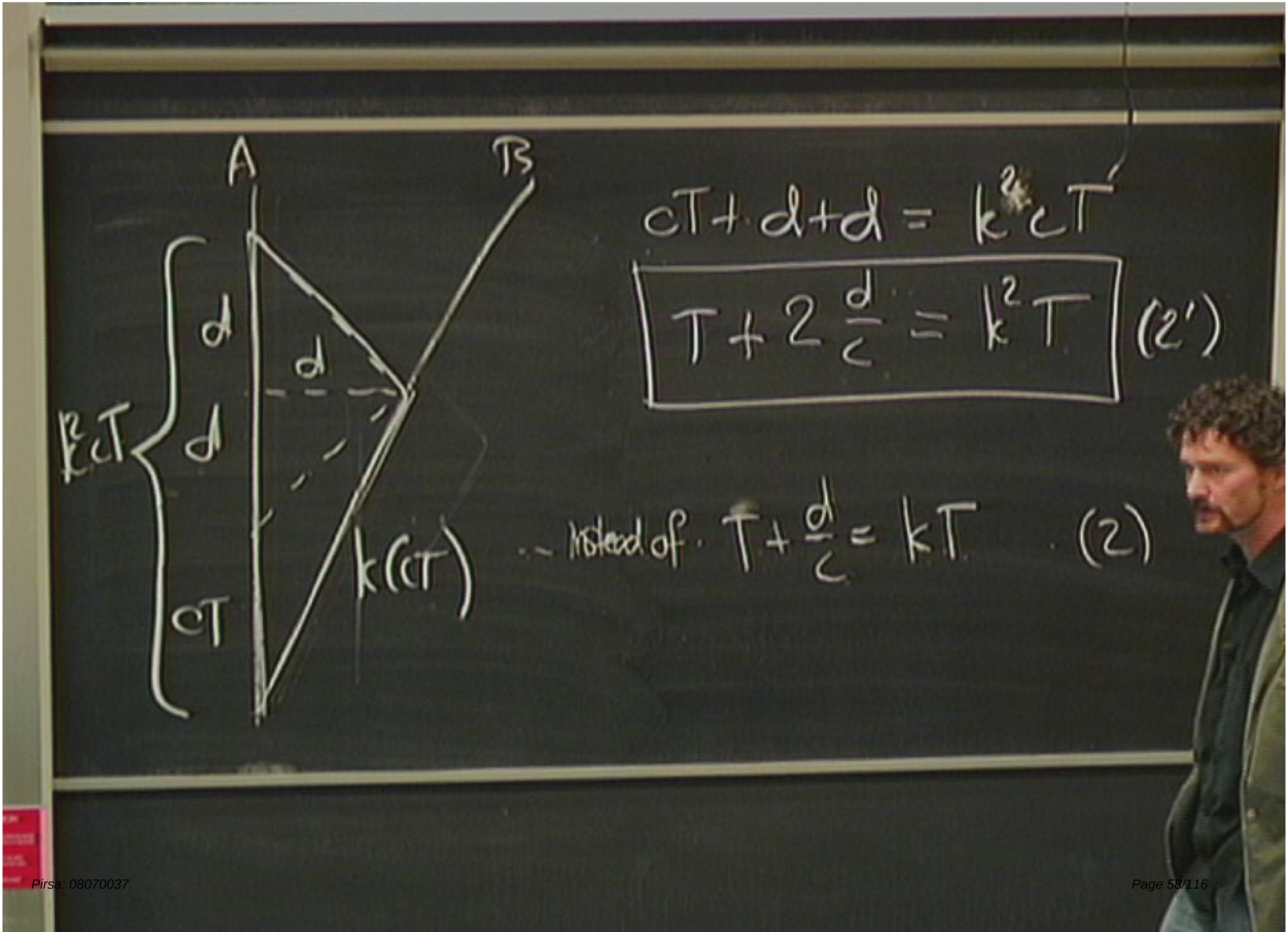

A
B
cT + d + d = k²cT
d
d
d
k²cT
k(cT)
cT

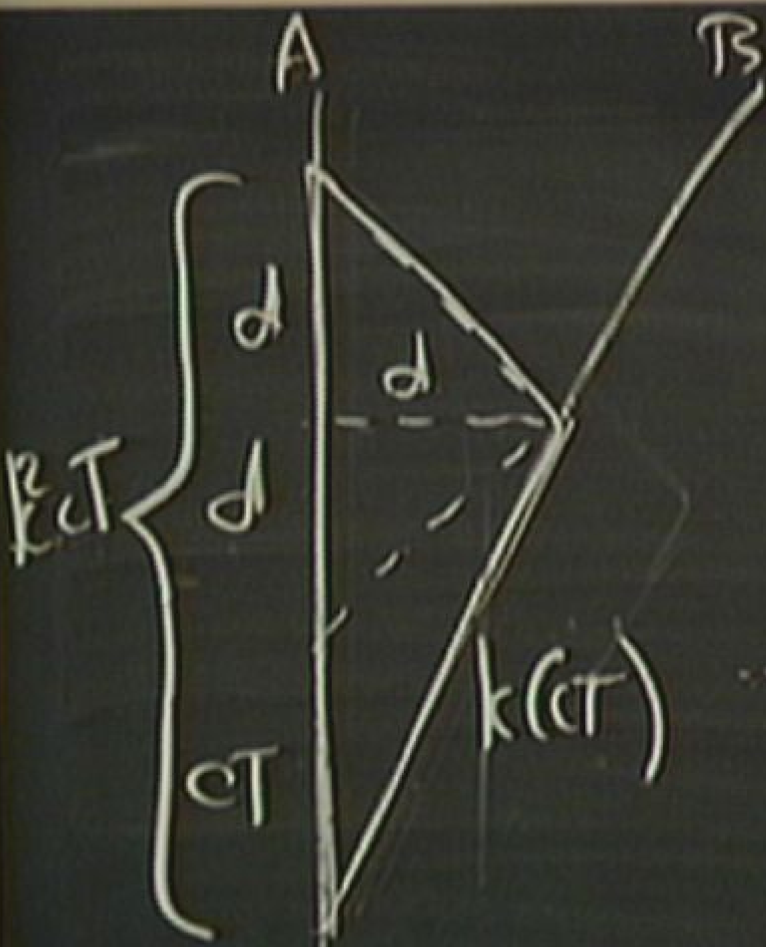


$$cT + d + d = k^2 cT$$

$$\boxed{T + 2\frac{d}{c} = k^2 T}$$


A
B
cT + d + d = k²cT
T + 2 d/c = k²T
k²cT
d
d
d
cT
k(cT)
instead of T + d/c = kT (2)

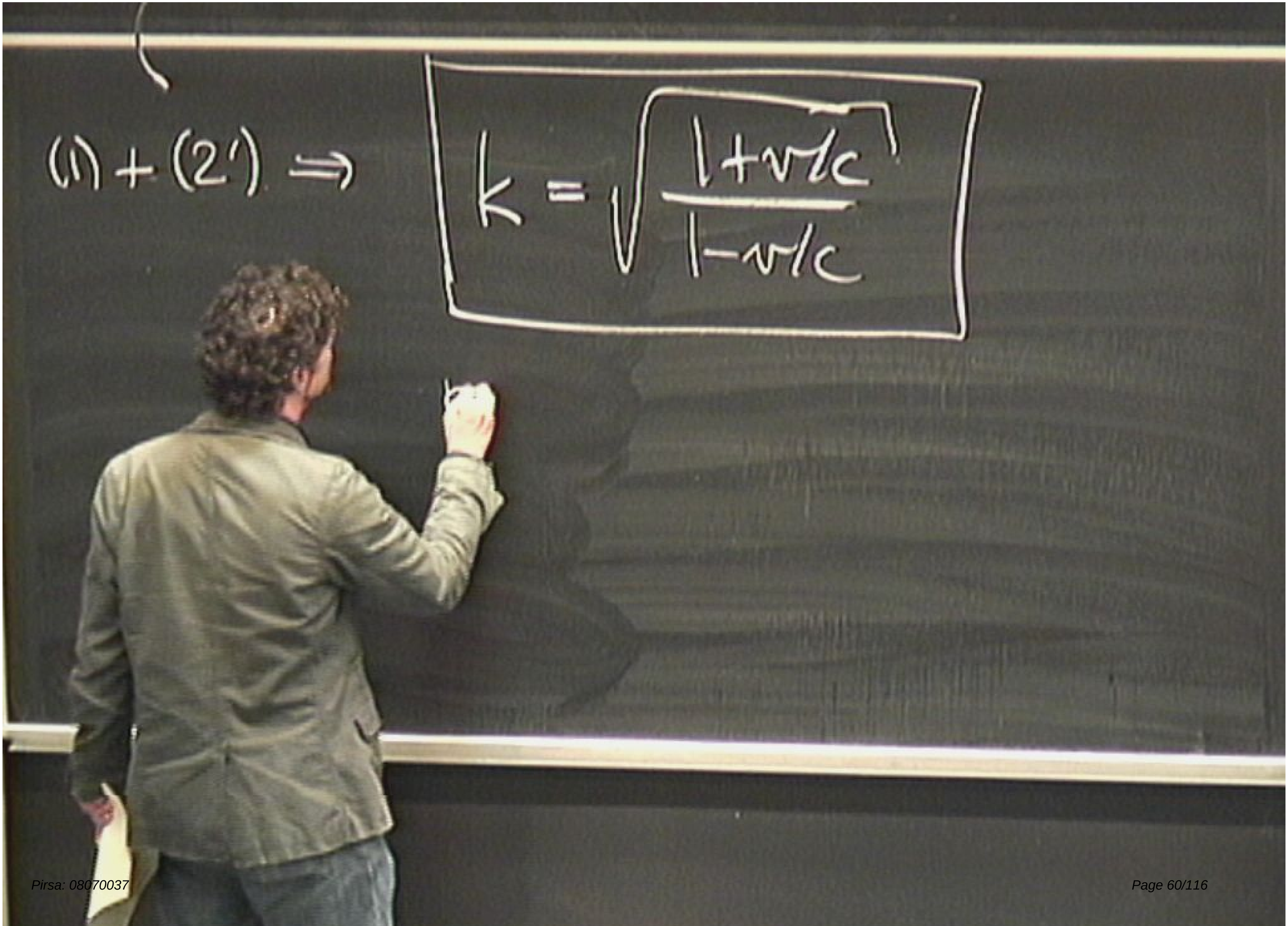

A
B
$cT + d + d = k^2 cT$
$\boxed{T + 2\frac{d}{c} = k^2 T}$ (2')
$k^2 cT$
d
d
d
cT
k(cT)
... instead of $T + \frac{d}{c} = kT$ (2)



$$cT + d + d = k^2 cT$$

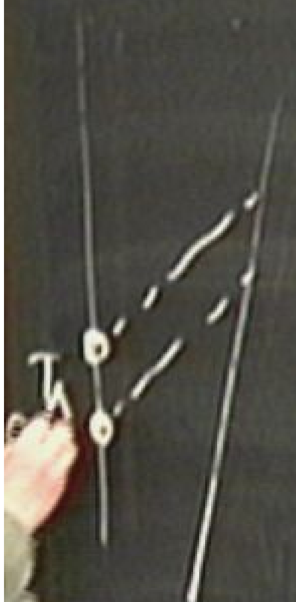
$$\boxed{T + 2\frac{d}{c} = k^2 T} \quad (2')$$

... instead of $T + \frac{d}{c} = kT \quad (2)$


(1) + (2') ⇒
k = √((1+v/c)/(1−v/c))

$$(1) + (2') \Rightarrow \boxed{k = \sqrt{\frac{1+v/c}{1-v/c}}}$$

relativistic Doppler shift.



$(1) + (2') \Rightarrow$ $$\boxed{k = \sqrt{\frac{1+v/c}{1-v/c}}}$$

relativistic Doppler shift.

$$(1) + (2') \Rightarrow \boxed{k = \sqrt{\frac{1+v/c}{1-v/c}}}$$

relativistic Doppler shift.

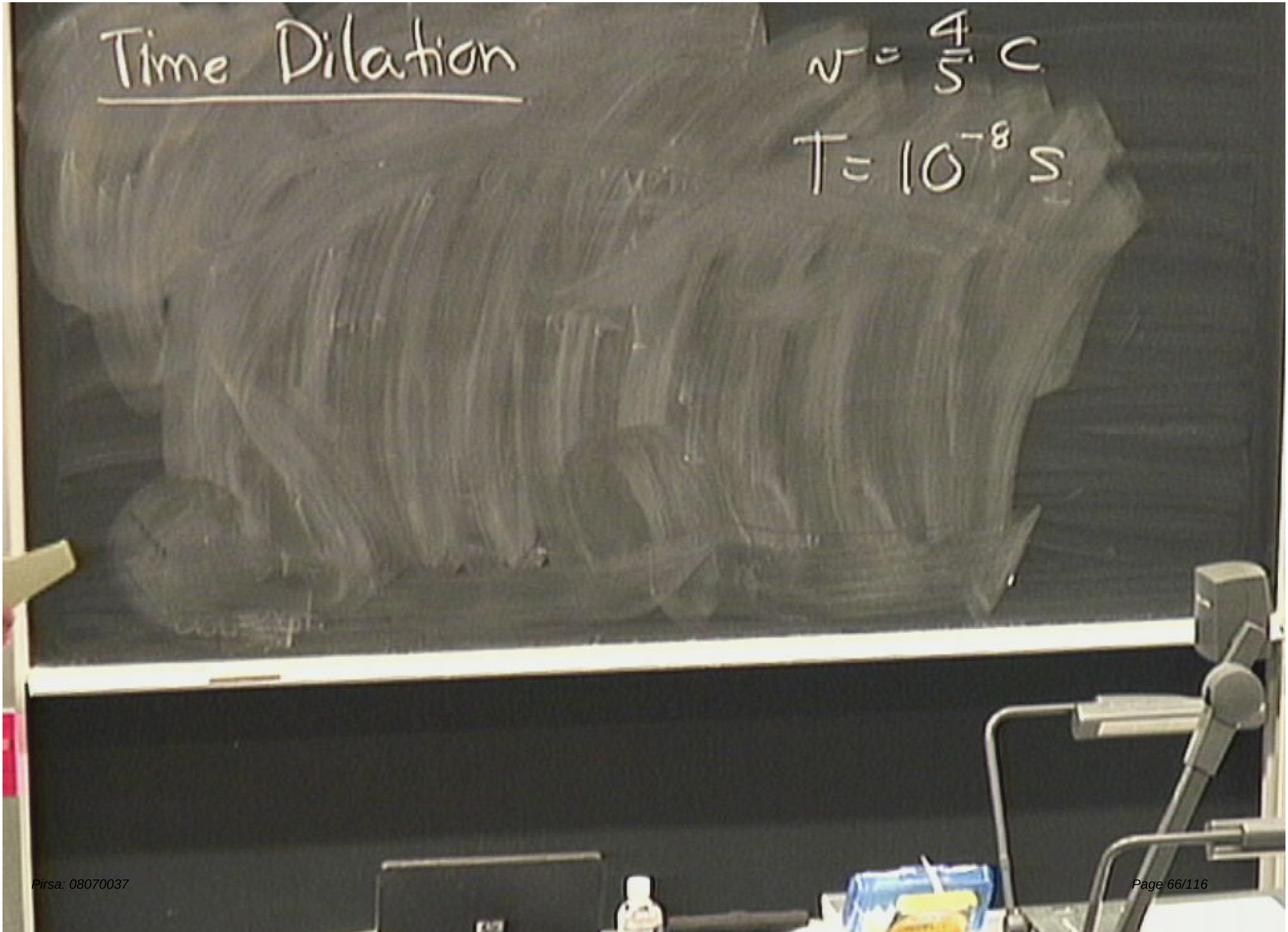
$$(1) + (2') \Longrightarrow \boxed{k = \sqrt{\frac{1+v/c}{1-v/c}}}$$

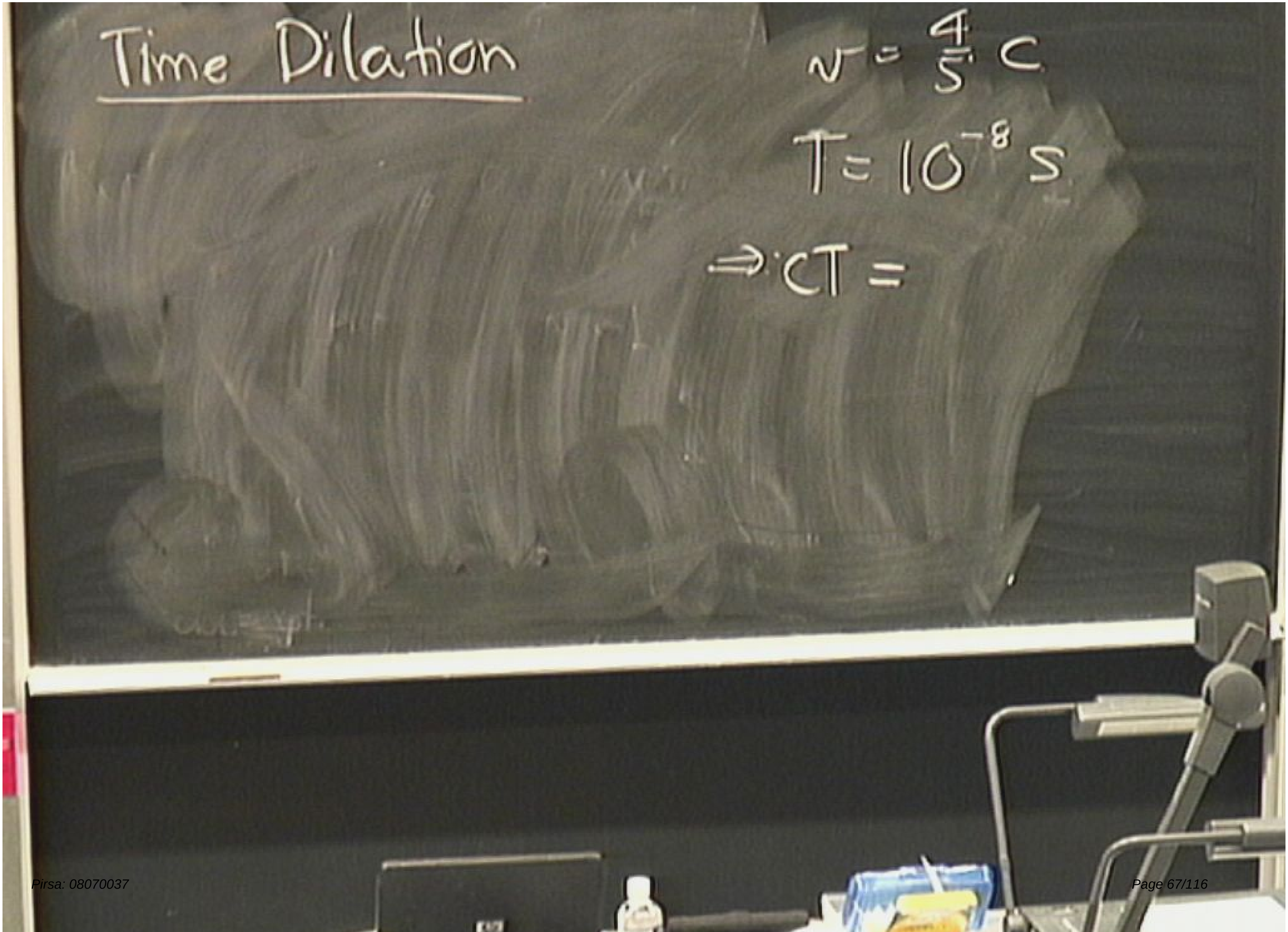
relativistic Doppler shift.

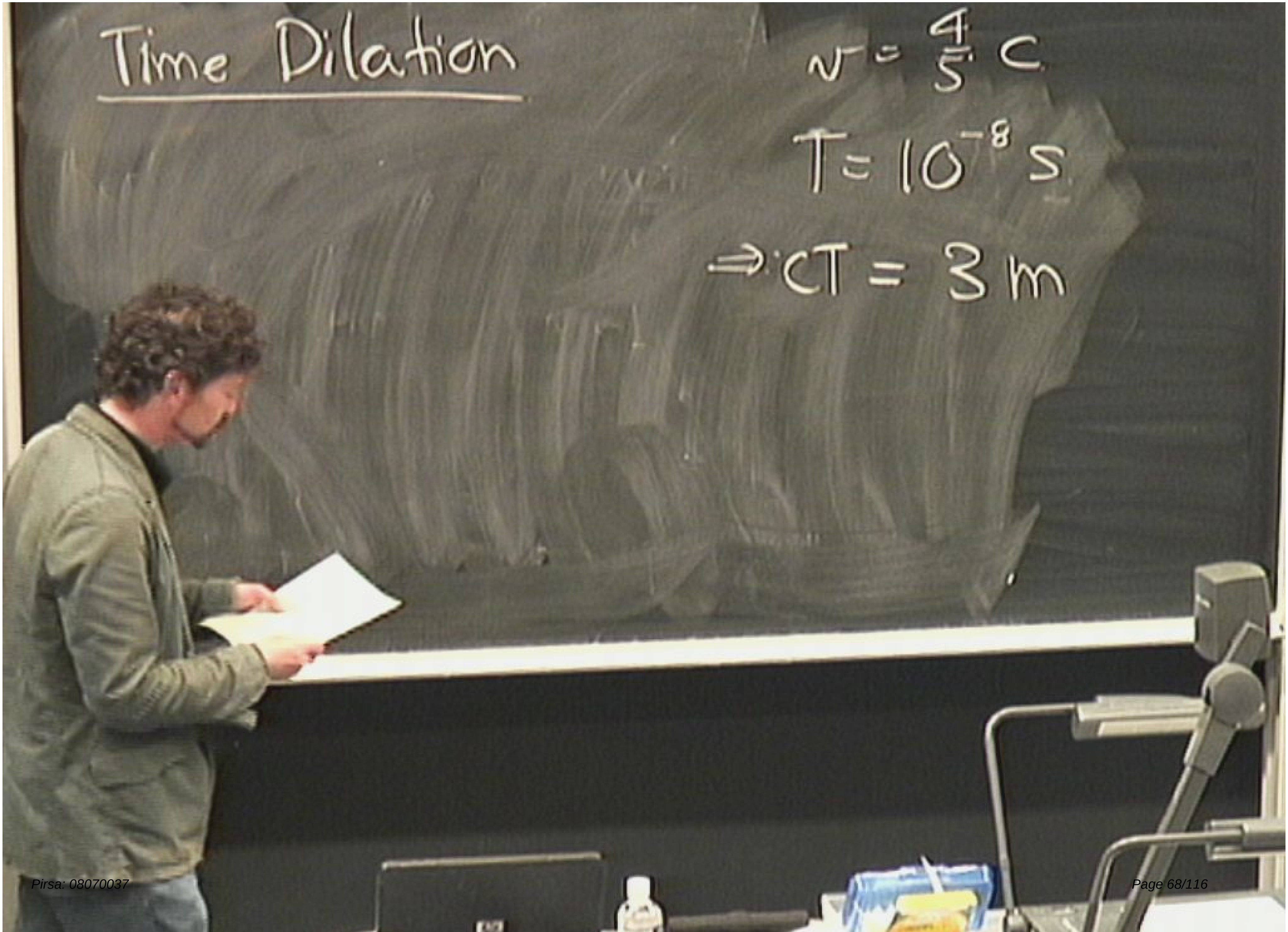
$$(1) + (2') \Rightarrow \quad \boxed{k = \sqrt{\frac{1+v/c}{1-v/c}}}$$

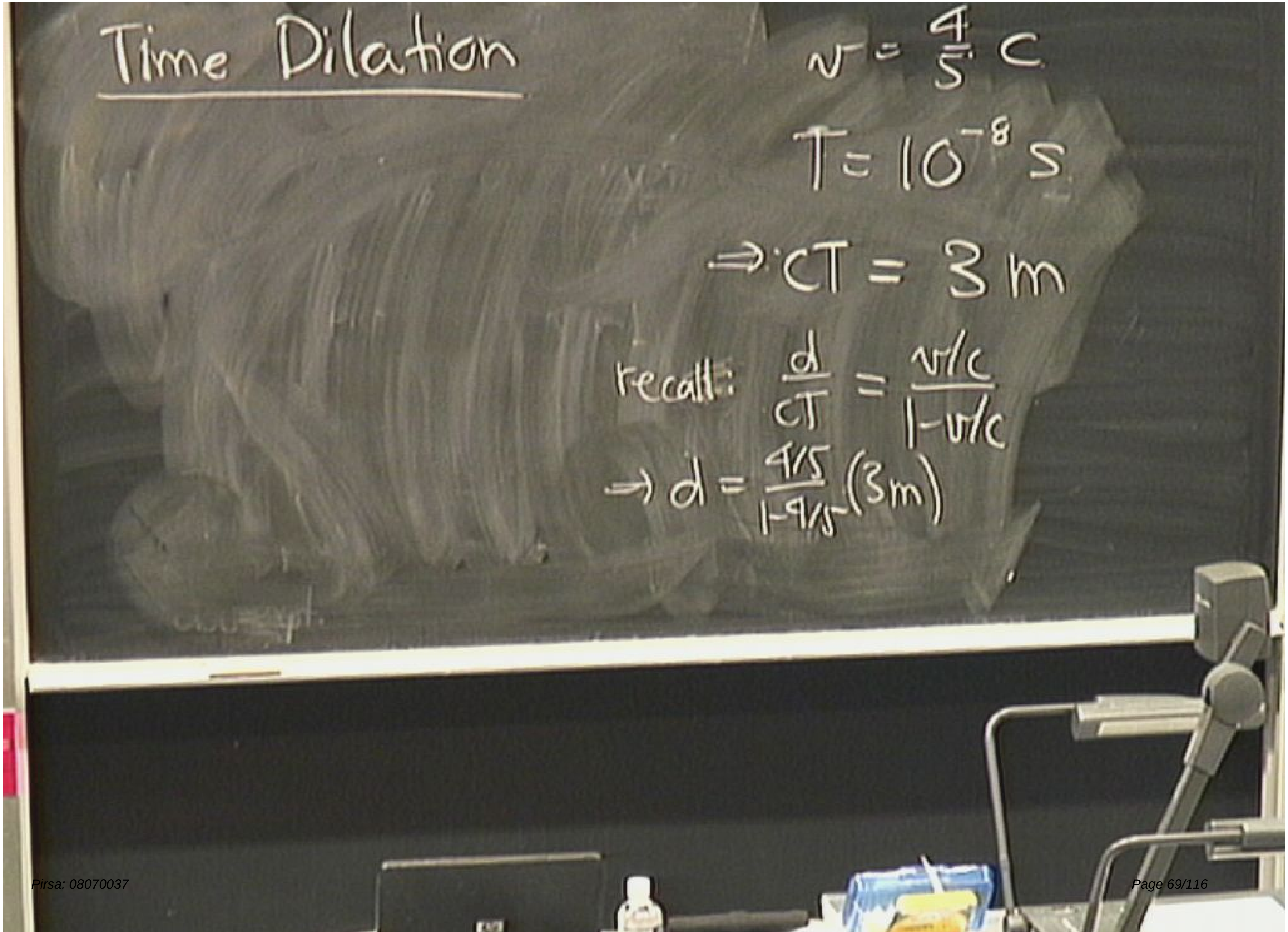
relativistic Doppler shift.

$\rightarrow$ true nature of time


Time Dilation
v = 4/5 c
T = 10^-8 s


Time Dilation
v = 4/5 c
T = 10^-8 s
⇒ cT =


Time Dilation
$v = \frac{4}{5} c$
$T = 10^{-8}$ s
$\Rightarrow cT = 3$ m


Time Dilation
$v = \frac{4}{5} c$
$T = 10^{-8}$ s
$\Rightarrow cT = 3$ m
recall: $\frac{d}{cT} = \frac{v/c}{1-v/c}$
$\rightarrow d = \frac{4/5}{1-4/5}(3\text{m})$

Time Dilation

$v = \frac{4}{5} c$

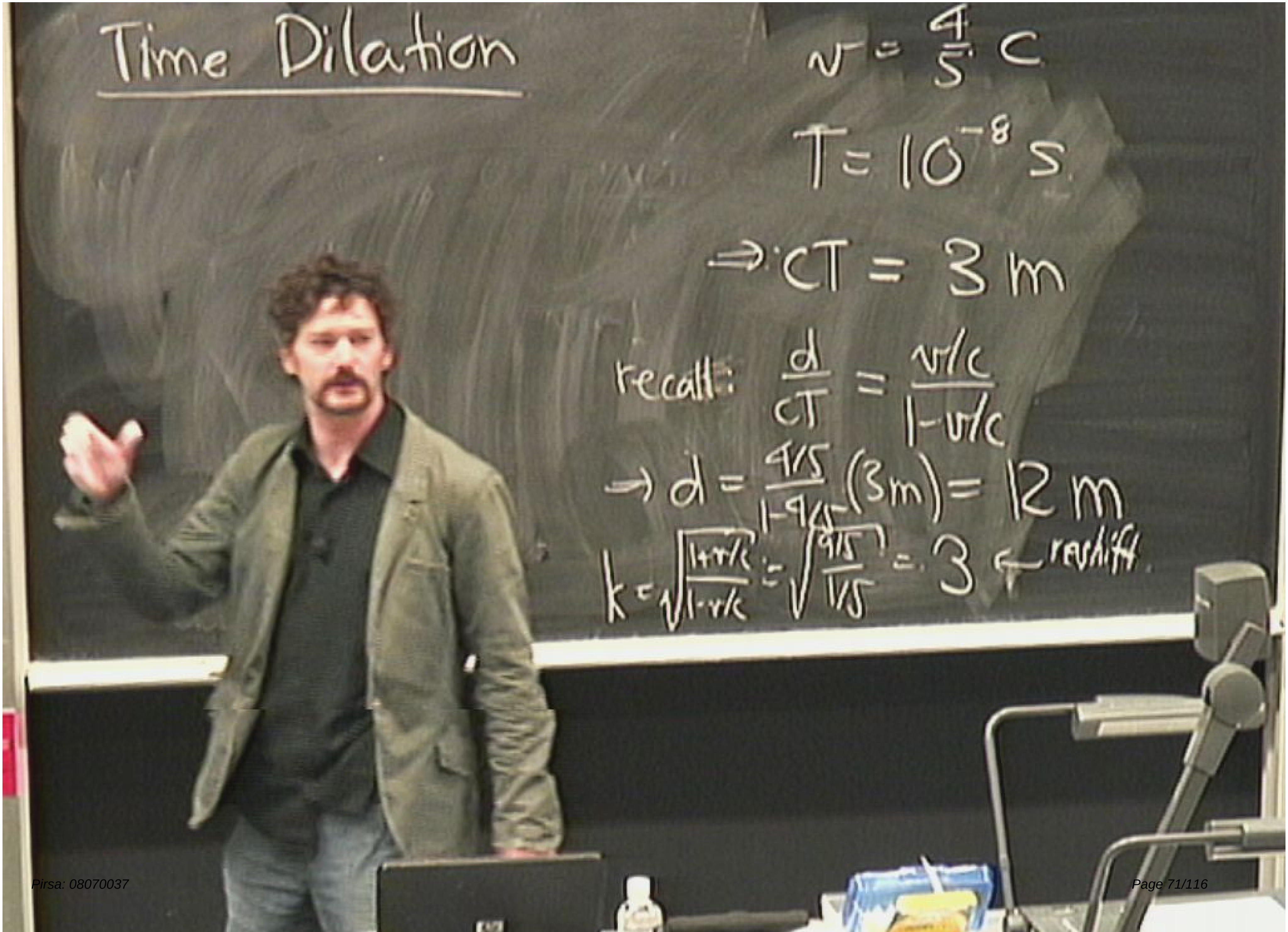
$T = 10^{-8}\,s$

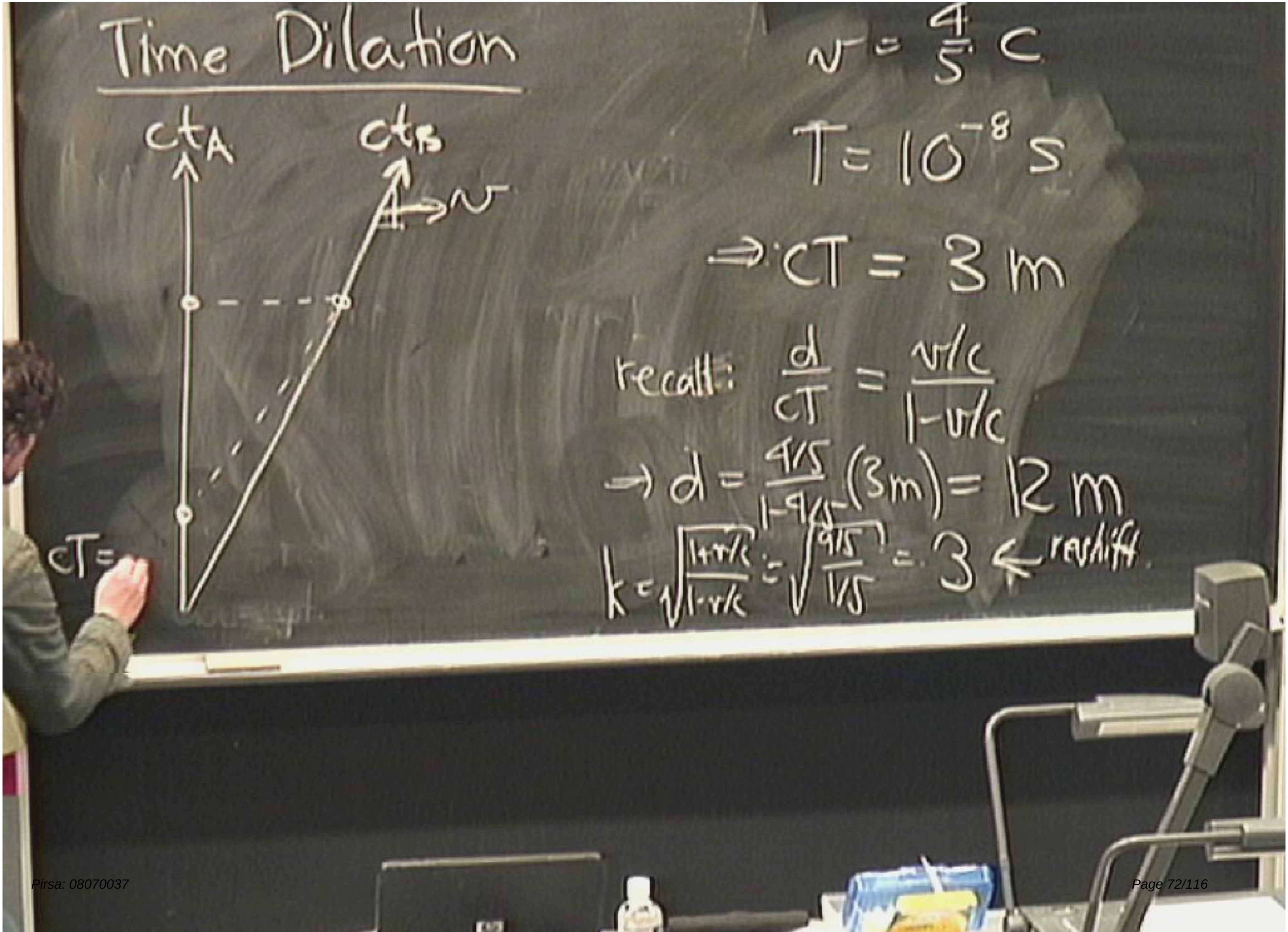
$\Rightarrow cT = 3\,m$

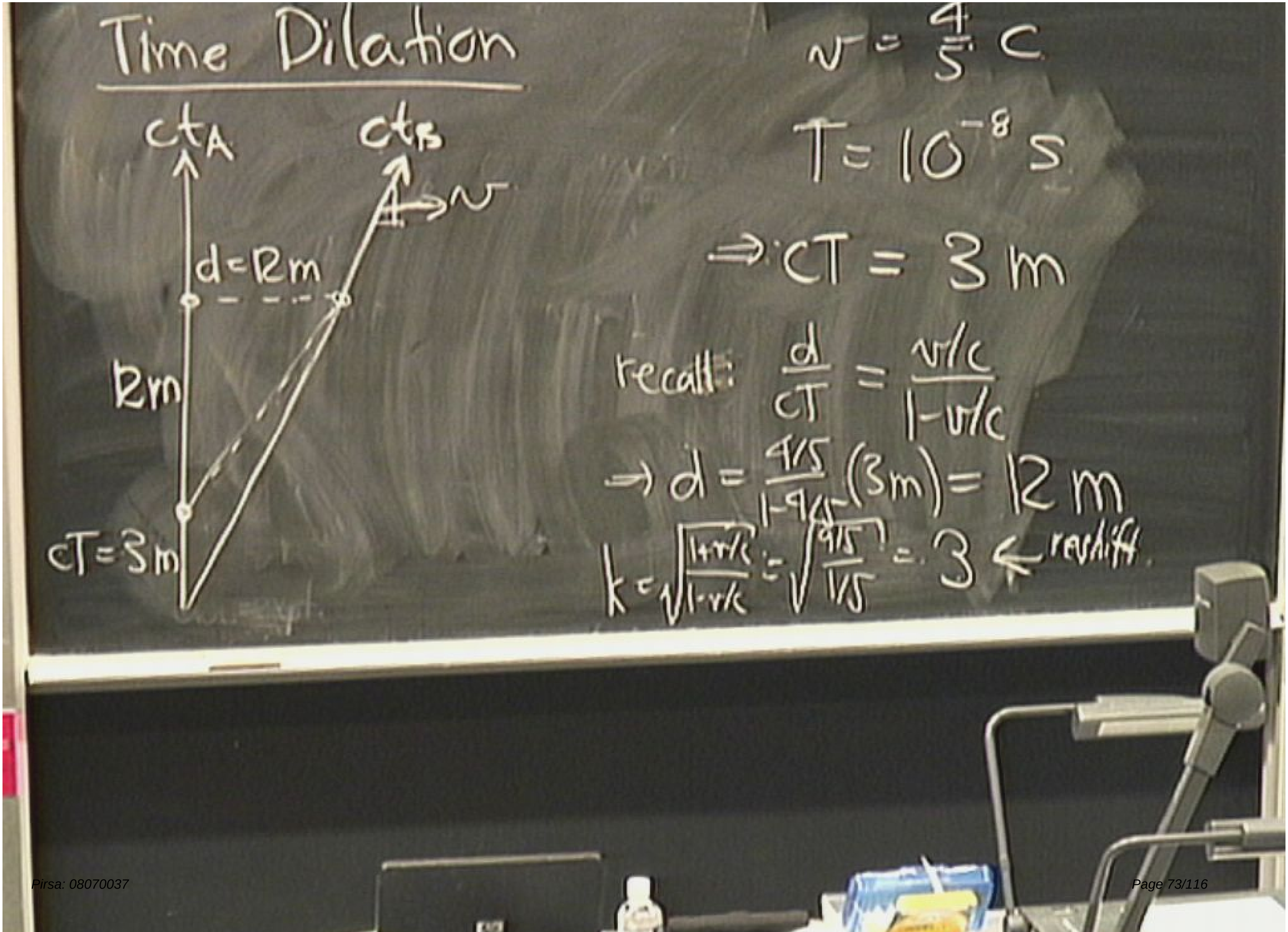
recall: $\frac{d}{cT} = \frac{v/c}{1 - v/c}$

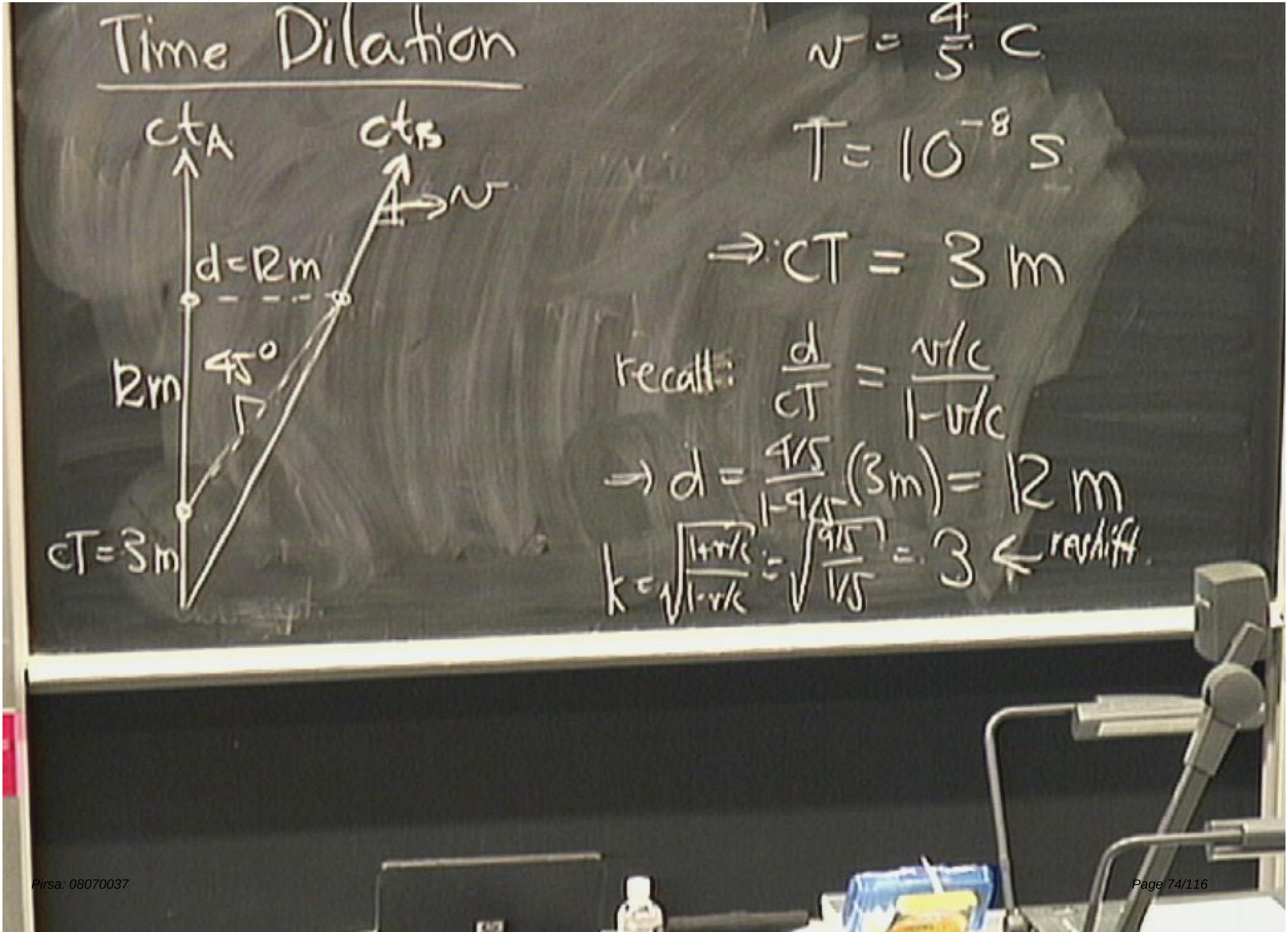
$\rightarrow d = \frac{4/5}{1-4/5}(3m) = 12\,m$

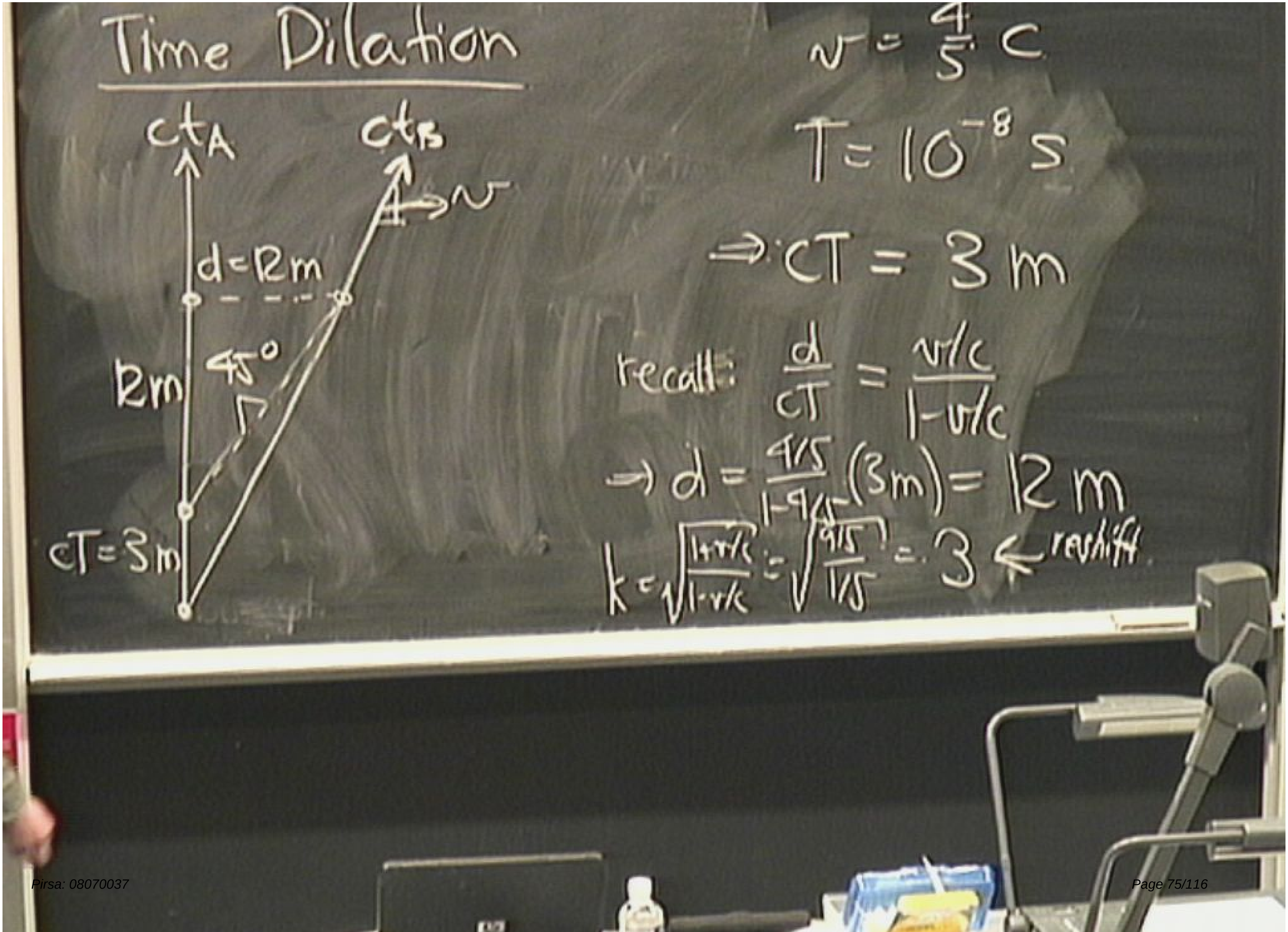
$k = \sqrt{\frac{1+v/c}{1-v/c}} = \sqrt{}$

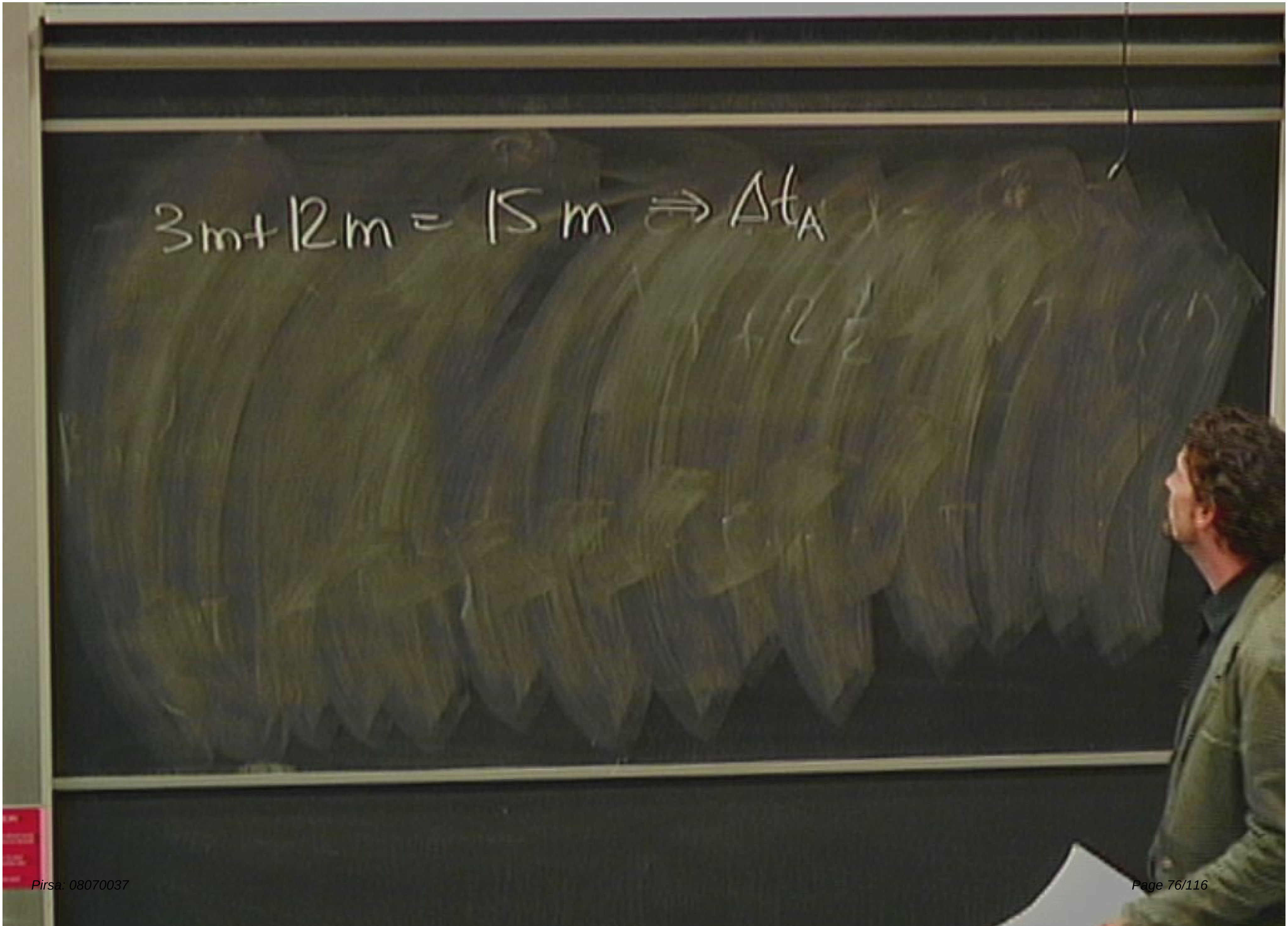

Time Dilation
v = 4/5 c
T = 10^-8 s
⇒ cT = 3 m
recall: d/cT = (v/c)/(1-v/c)
→ d = (4/5)/(1-4/5) (3m) = 12 m
k = √((1+v/c)/(1-v/c)) = √((9/5)/(1/5)) = 3 ← redshift

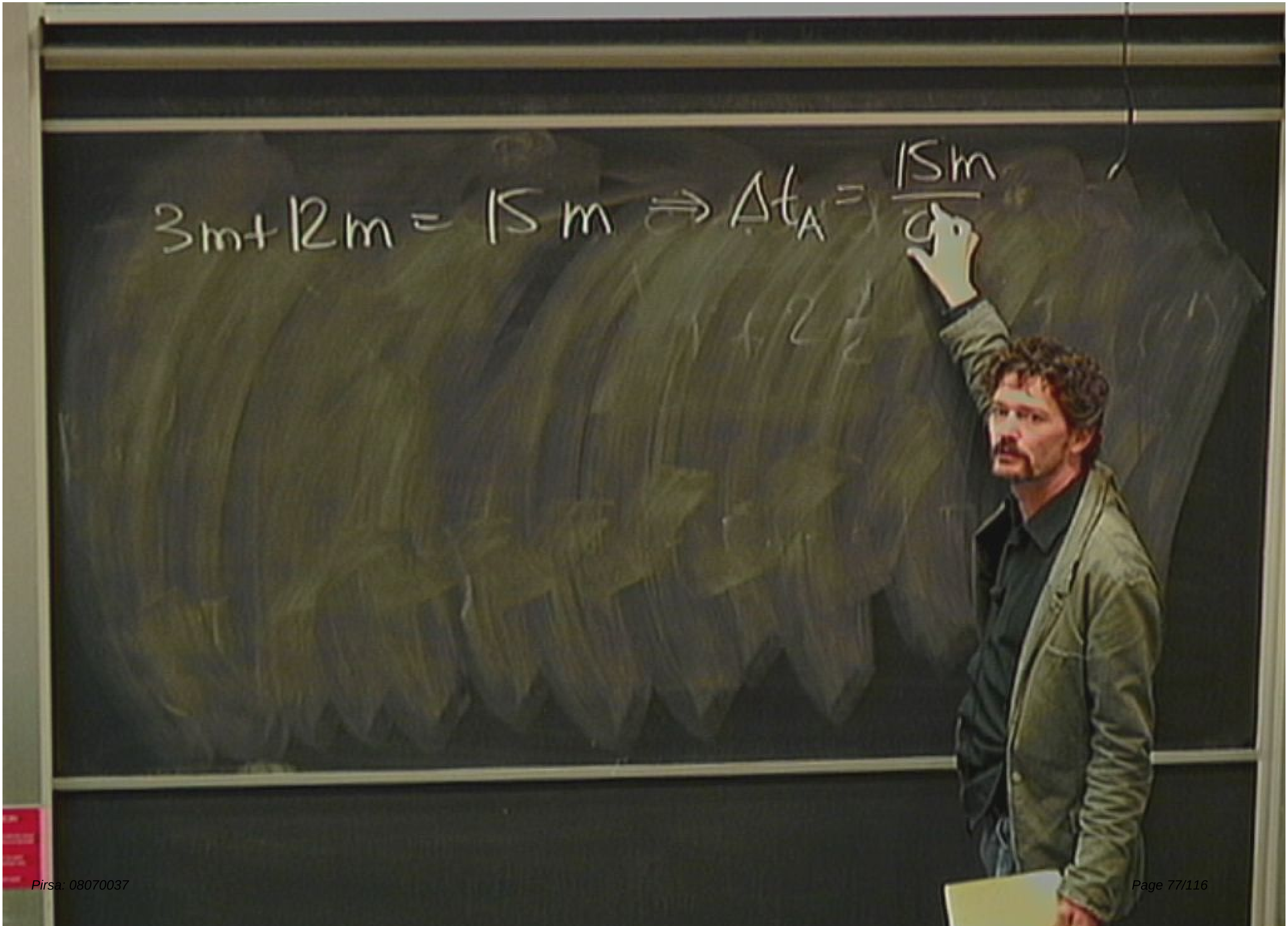

Time Dilation
ct_A
ct_B
v
$cT=$
$v = \frac{4}{5} c$
$T = 10^{-8}\,s$
$\Rightarrow cT = 3\,m$
recall: $\frac{d}{cT} = \frac{v/c}{1-v/c}$
$\rightarrow d = \frac{4/5}{1-4/5}(3m) = 12\,m$
$k = \sqrt{\frac{1+v/c}{1-v/c}} = \sqrt{\frac{9/5}{1/5}} = 3$ ← redshift


Time Dilation
ct_A
ct_B
v
$d=12m$
$12m$
$cT=3m$
$v = \frac{4}{5}c$
$T = 10^{-8}\,s$
$\Rightarrow cT = 3\,m$
recall: $\frac{d}{cT} = \frac{v/c}{1-v/c}$
$\rightarrow d = \frac{4/5}{1-4/5}(3m) = 12\,m$
$k = \sqrt{\frac{1+v/c}{1-v/c}} = \sqrt{\frac{9/5}{1/5}} = 3 \leftarrow$ redshift

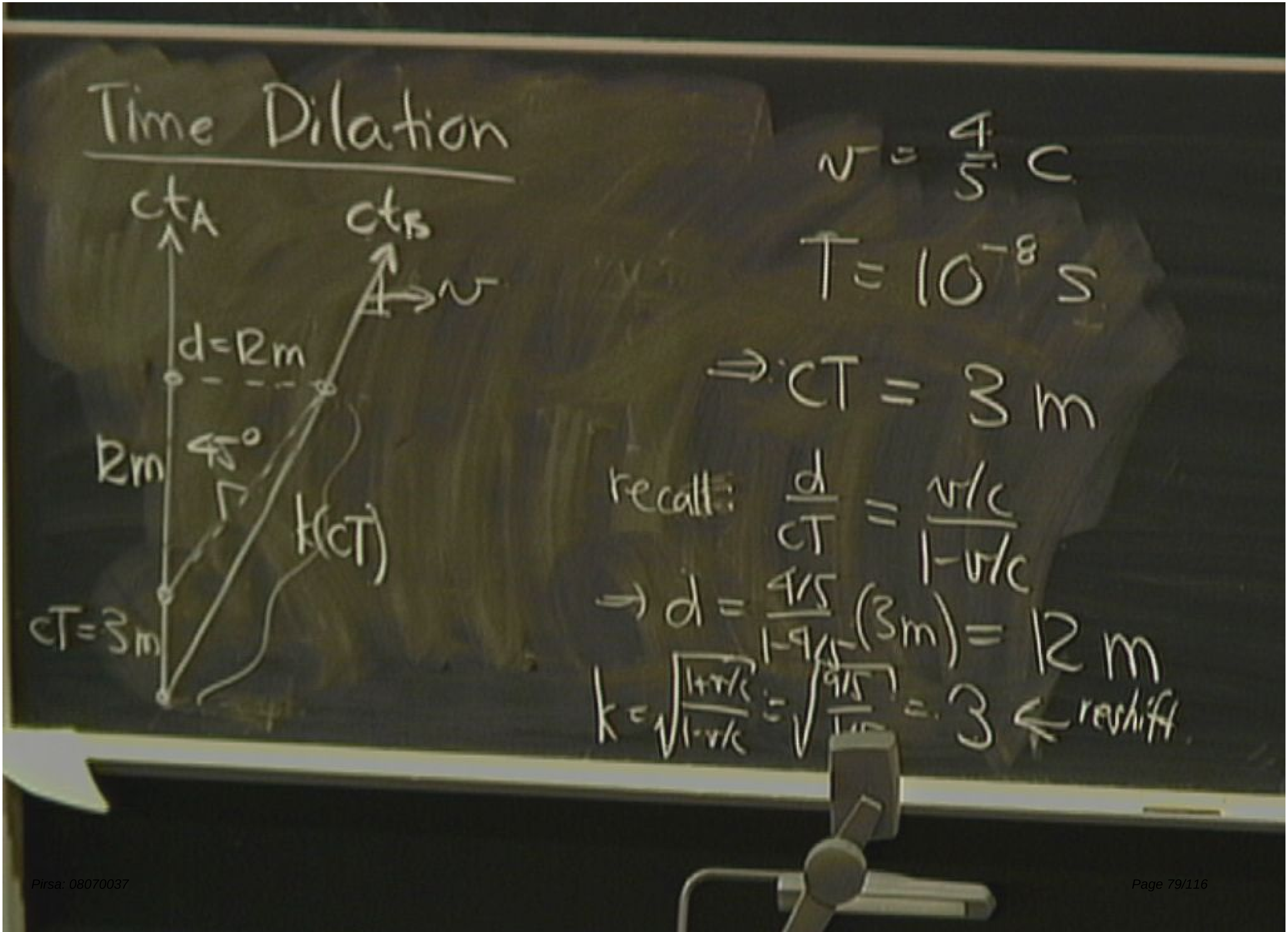

Time Dilation
ctA
ctB
v
d=12m
12m
45°
cT=3m
v = 4/5 c
T = 10^-8 s
⇒ cT = 3 m
recall: d/cT = (v/c)/(1-v/c)
→ d = (4/5)/(1-4/5) (3m) = 12 m
k = √((1+v/c)/(1-v/c)) = √((9/5)/(1/5)) = 3 ← redshift

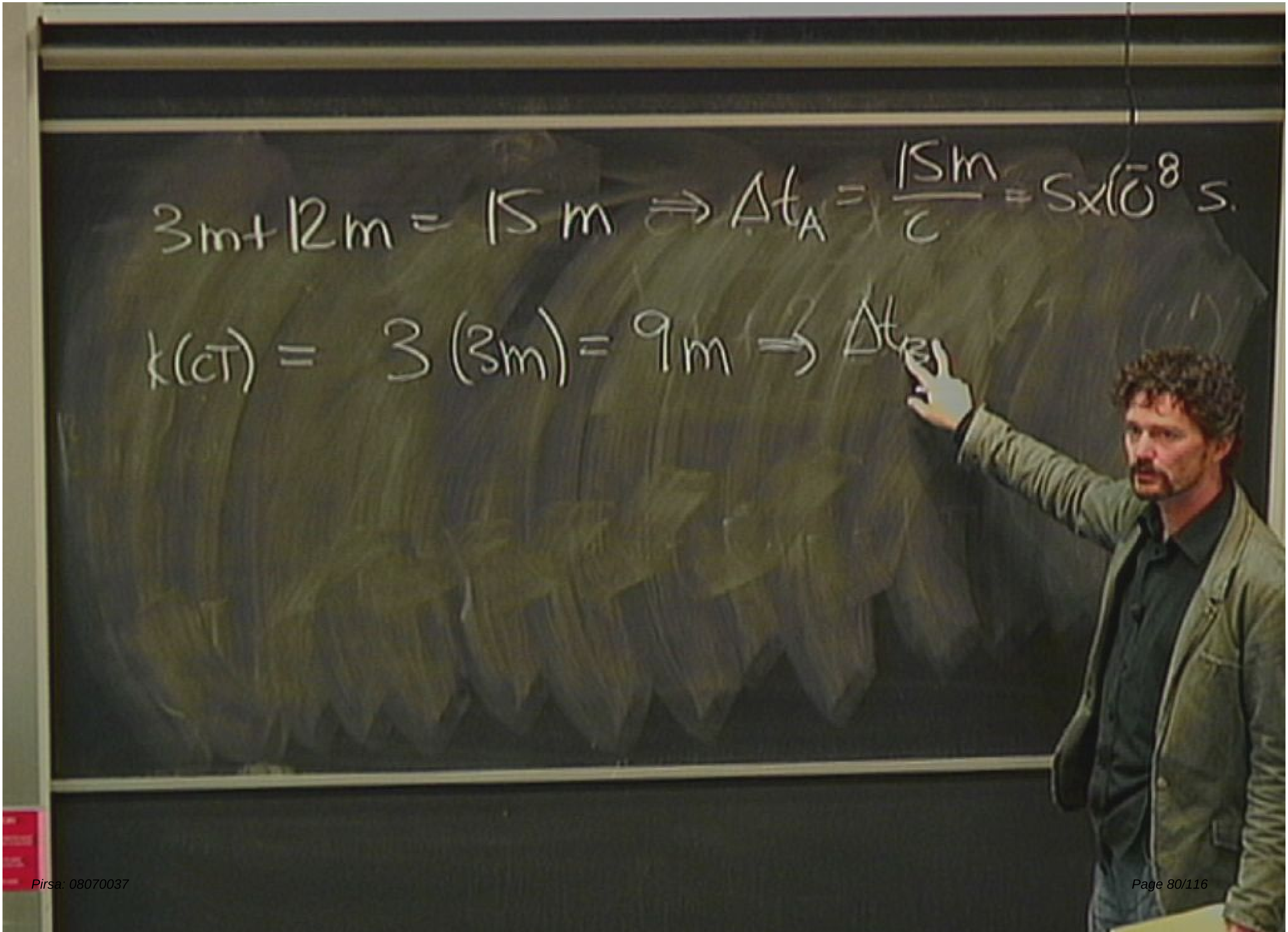

Time Dilation
ct_A
ct_B
v
d=12m
12m
45°
cT=3m
v = 4/5 c
T = 10^-8 s
⇒ cT = 3 m
recall: d/cT = (v/c)/(1-v/c)
→ d = (4/5)/(1-4/5) (3m) = 12 m
k = √((1+v/c)/(1-v/c)) = √((9/5)/(1/5)) = 3 ← redshift


$3m + 12m = 15\,m \Rightarrow \Delta t_A$


$3m + 12m = 15\,m \Rightarrow \Delta t_A = \frac{15m}{c}$

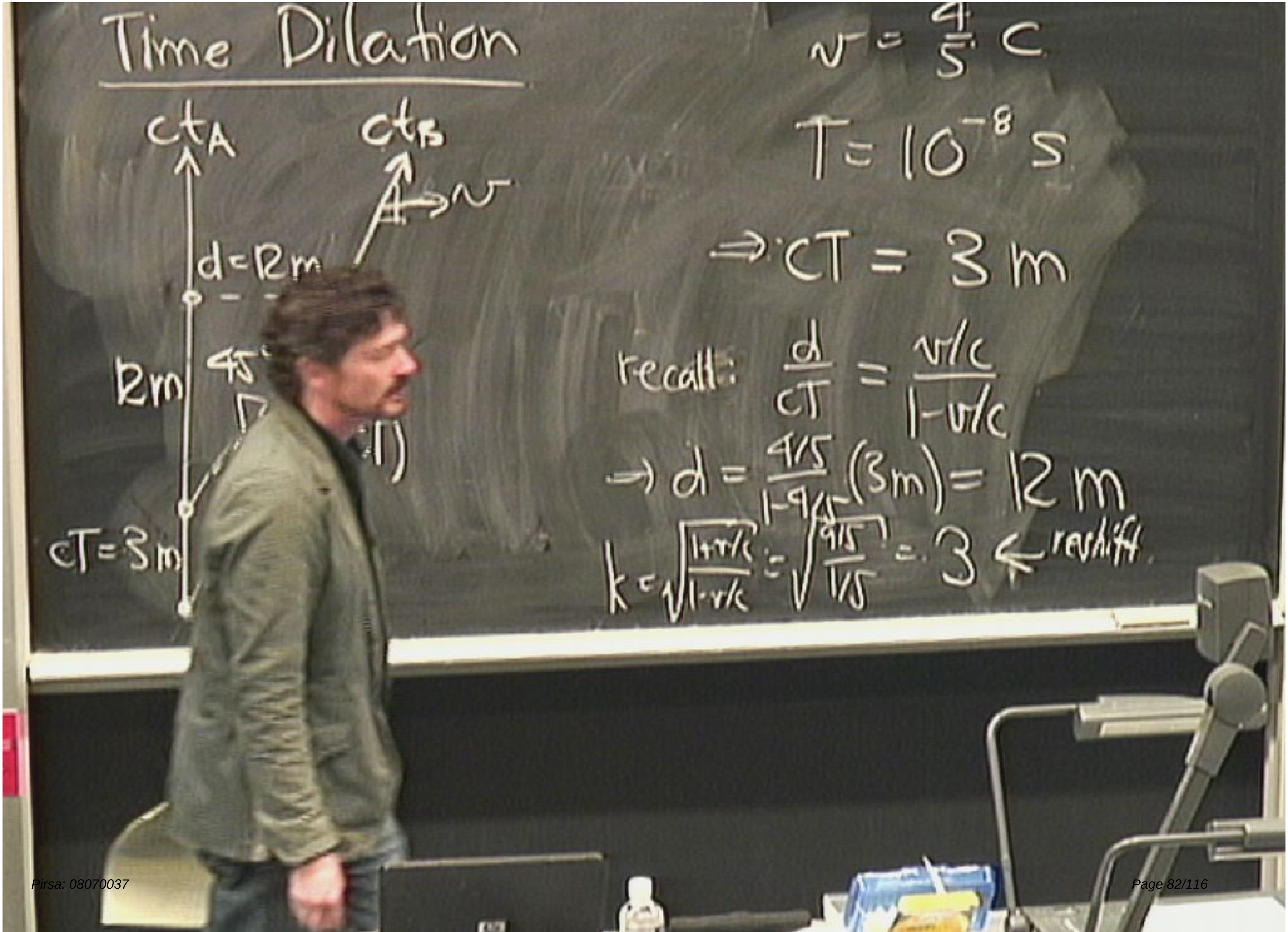
$$3m + 12m = 15\,m \Rightarrow \Delta t_A = \frac{15m}{c} = 5\times10^{-8}\,s.$$

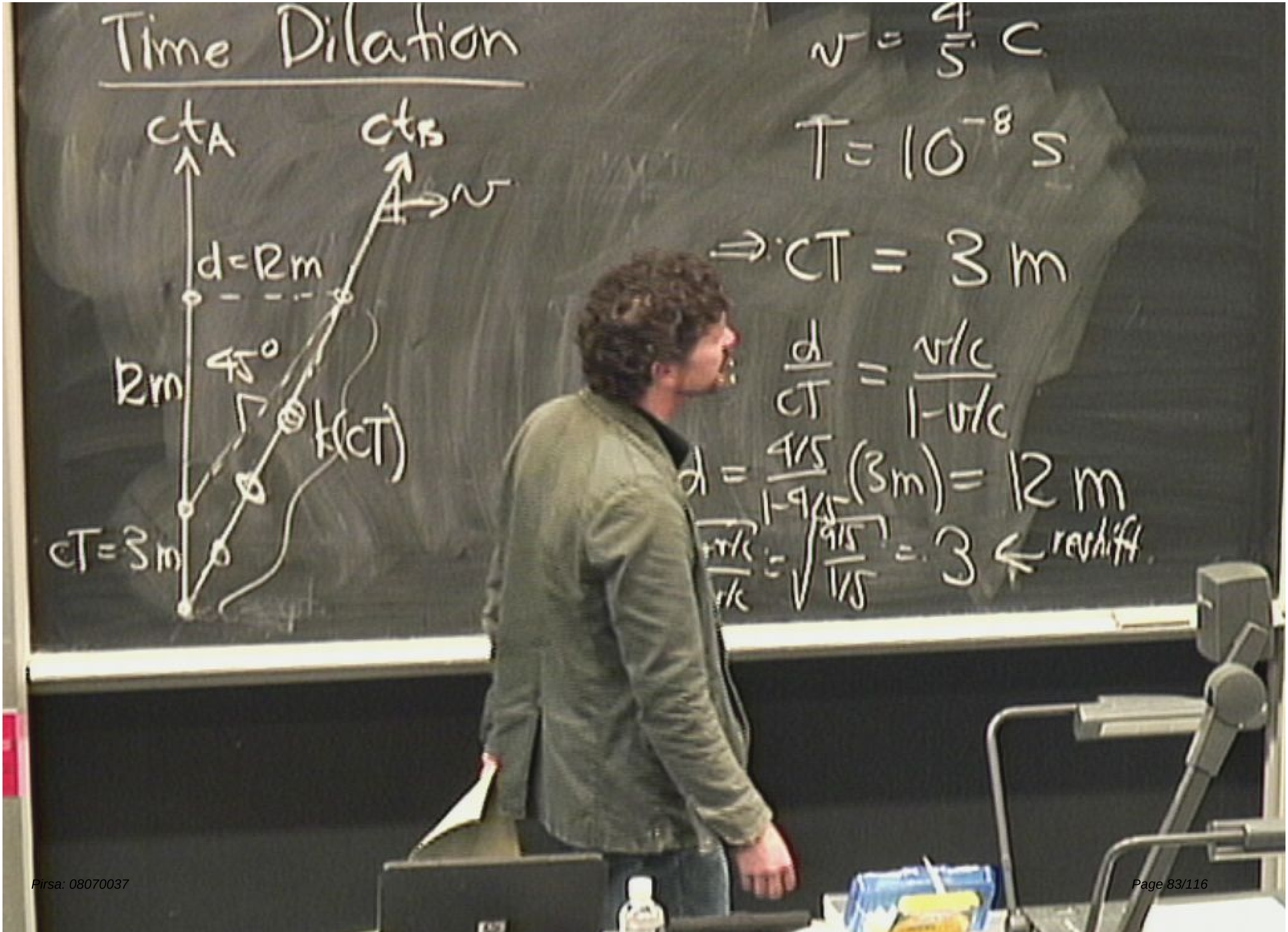

Time Dilation
ctA
ctB
v
d=12m
12m
45°
k(cT)
cT=3m
v = 4/5 c
T = 10^-8 s
⇒ cT = 3 m
recall: d/cT = (v/c)/(1-v/c)
→ d = (4/5)/(1-4/5) (3m) = 12 m
k = √((1+v/c)/(1-v/c)) = √((9/5)/(1/5)) = 3 ← redshift

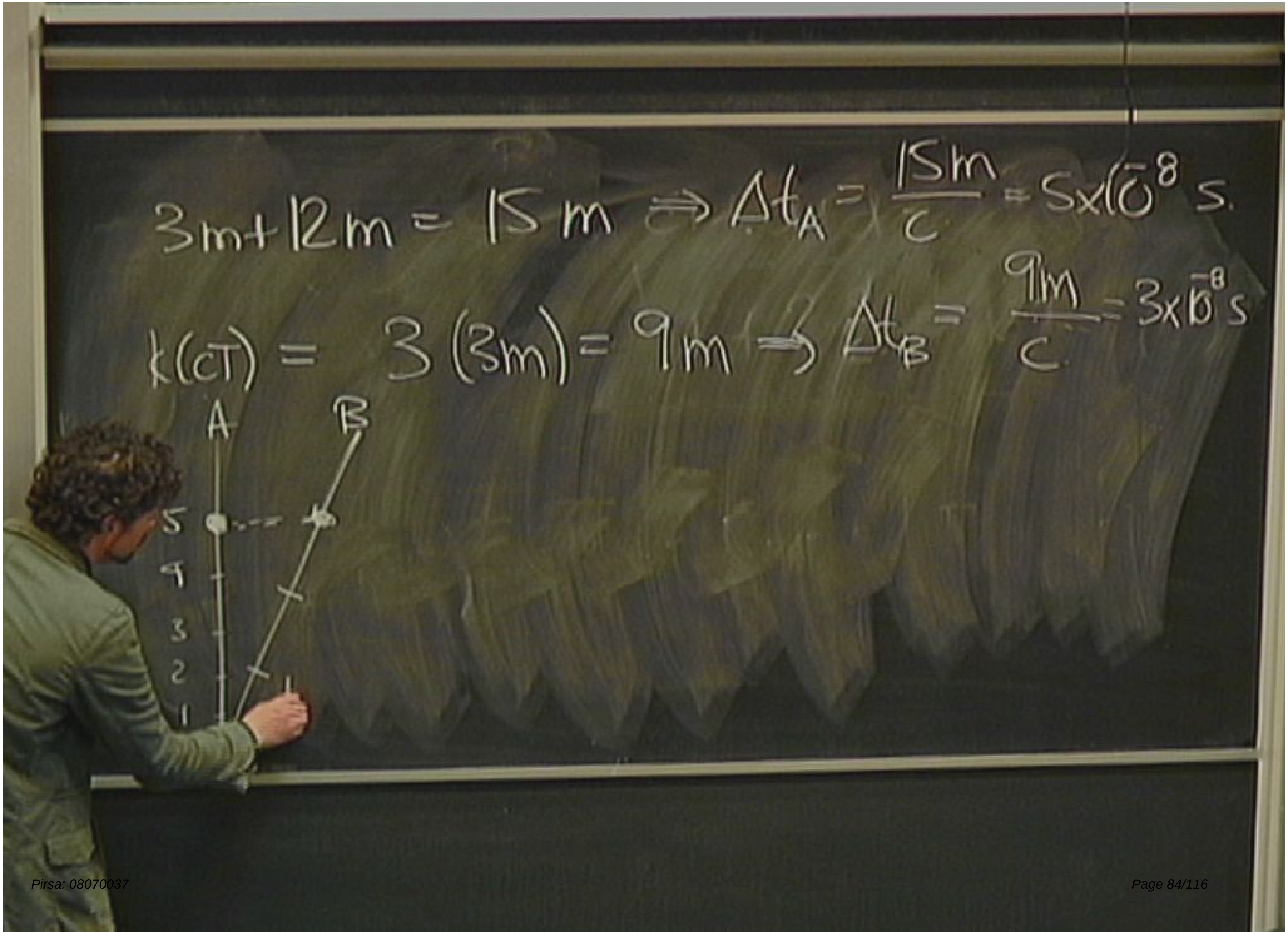

3m+12m = 15 m ⇒ Δt_A = 15m/c = 5×10^-8 s.
k(cT) = 3(3m) = 9m ⇒ Δt_B

$$3m + 12m = 15\,m \Rightarrow \Delta t_A = \frac{15m}{c} = 5\times10^{-8}\,s.$$

$$k(cT) = 3(3m) = 9m \Rightarrow \Delta t_B = \frac{9m}{c} = 3\times10^{-8}\,s$$

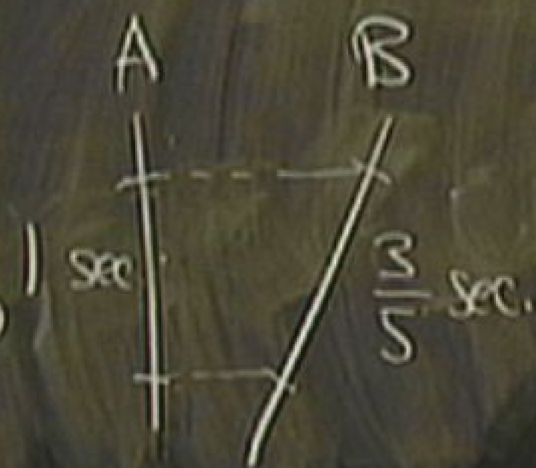

Time Dilation
ctA
ctB
v
d=12m
12m
cT=3m
v = 4/5 c
T = 10^-8 s
⇒ cT = 3 m
recall: d/cT = (v/c)/(1-v/c)
→ d = (4/5)/(1-4/5) (3m) = 12 m
k = √((1+v/c)/(1-v/c)) = √((9/5)/(1/5)) = 3 ← redshift


Time Dilation
ctA
ctB
v
d=12m
12m
45°
k(cT)
cT=3m
v = 4/5 c
T=10^-8 s
⇒ cT = 3 m
d/cT = v/c / 1-v/c
d = 4/5 / 1-4/5 (3m) = 12 m
= √(9/5 / 1/5) = 3 ← redshift


3m+12m = 15 m ⇒ Δt_A = 15m/c = 5×10^-8 s.
k(cT) = 3(3m) = 9m ⇒ Δt_B = 9m/c = 3×10^-8 s
A
B
5
4
3
2
1

$$3m + 12m = 15m \Rightarrow \Delta t_A = \frac{15m}{c} = 5\times 10^{-8}\ s.$$

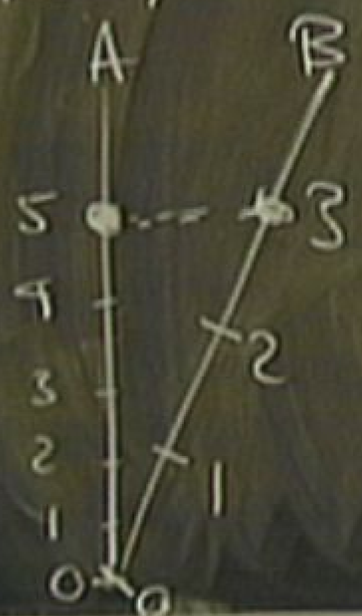
$$k(cT) = 3(3m) = 9m \rightarrow \Delta t_B = \frac{9m}{c} = 3\times 10^{-8}\ s$$

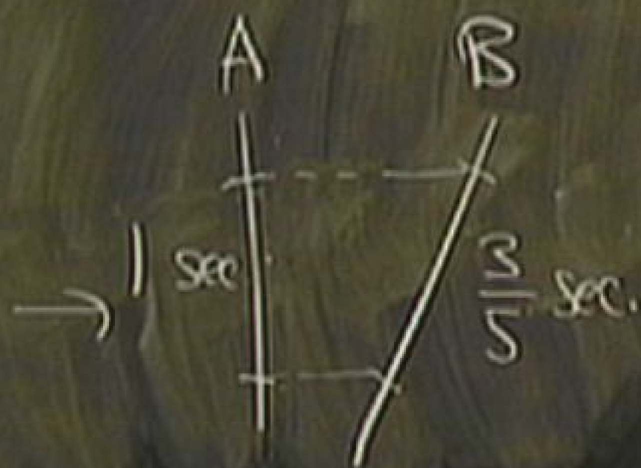


time dilation

$$3m + 12m = 15m \Rightarrow \Delta t_A = \frac{15m}{c} = 5\times10^{-8}\ s.$$

$$k(cT) = 3(3m) = 9m \Rightarrow \Delta t_B = \frac{9m}{c} = 3\times10^{-8}\ s$$

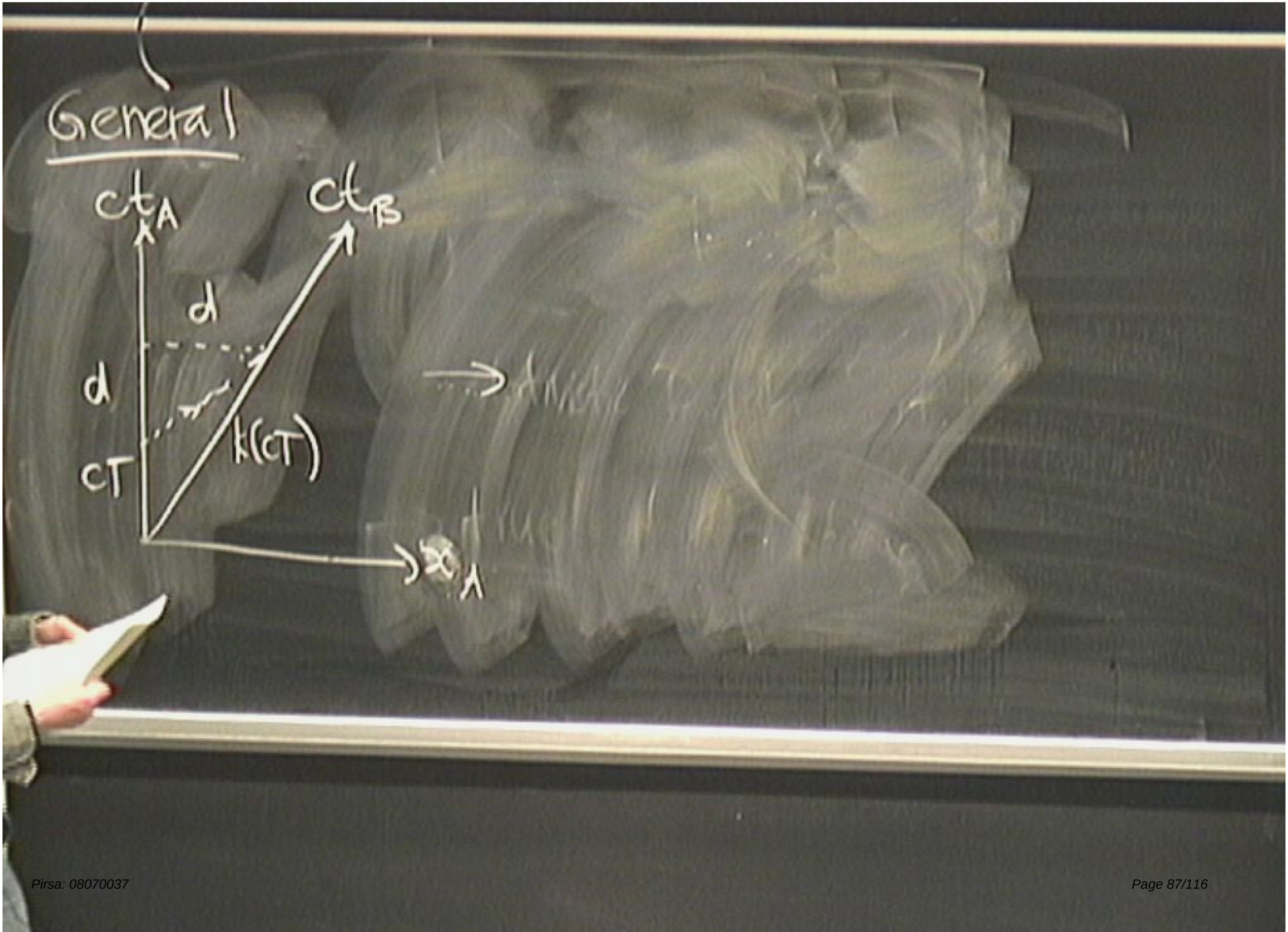


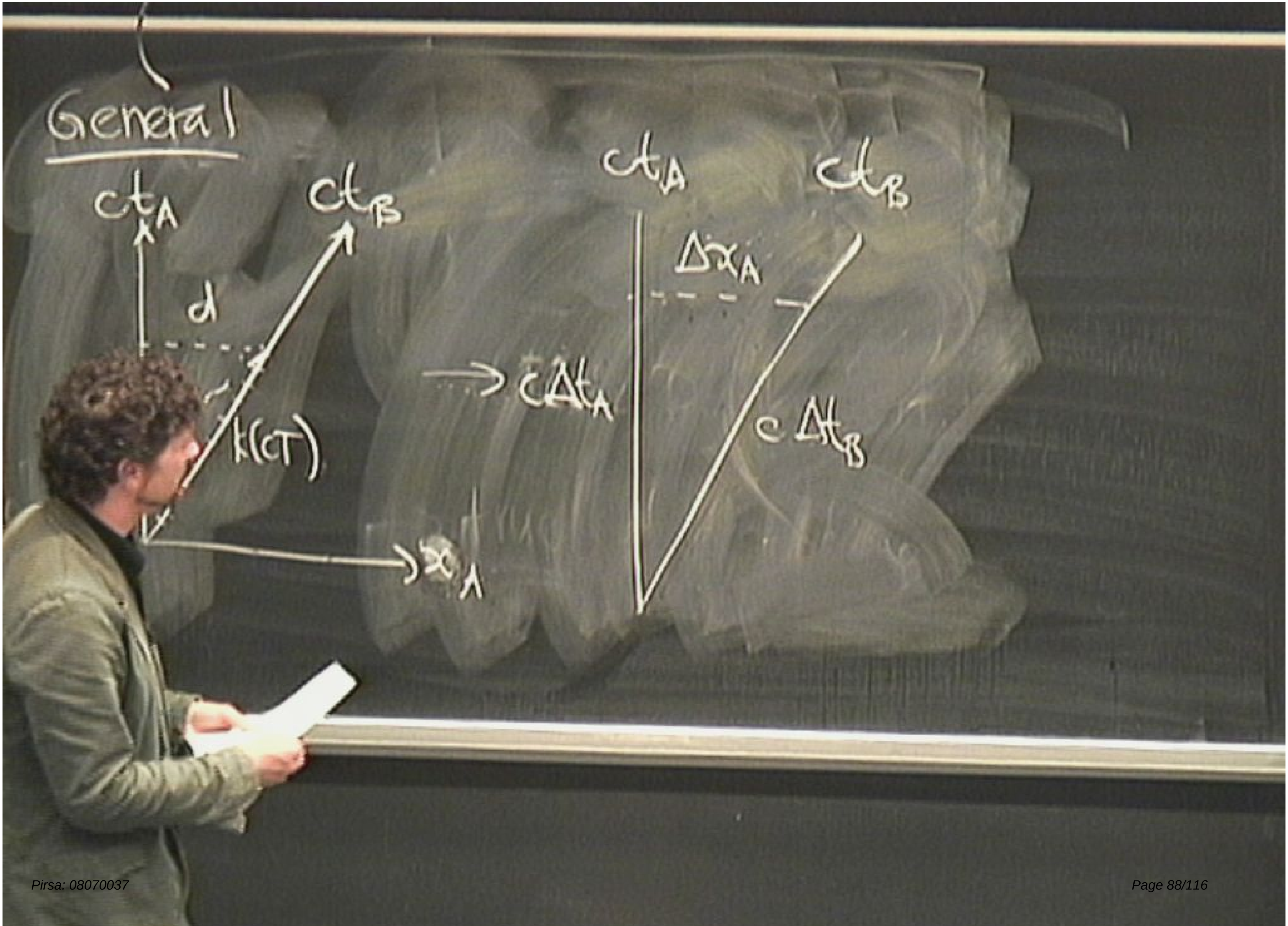


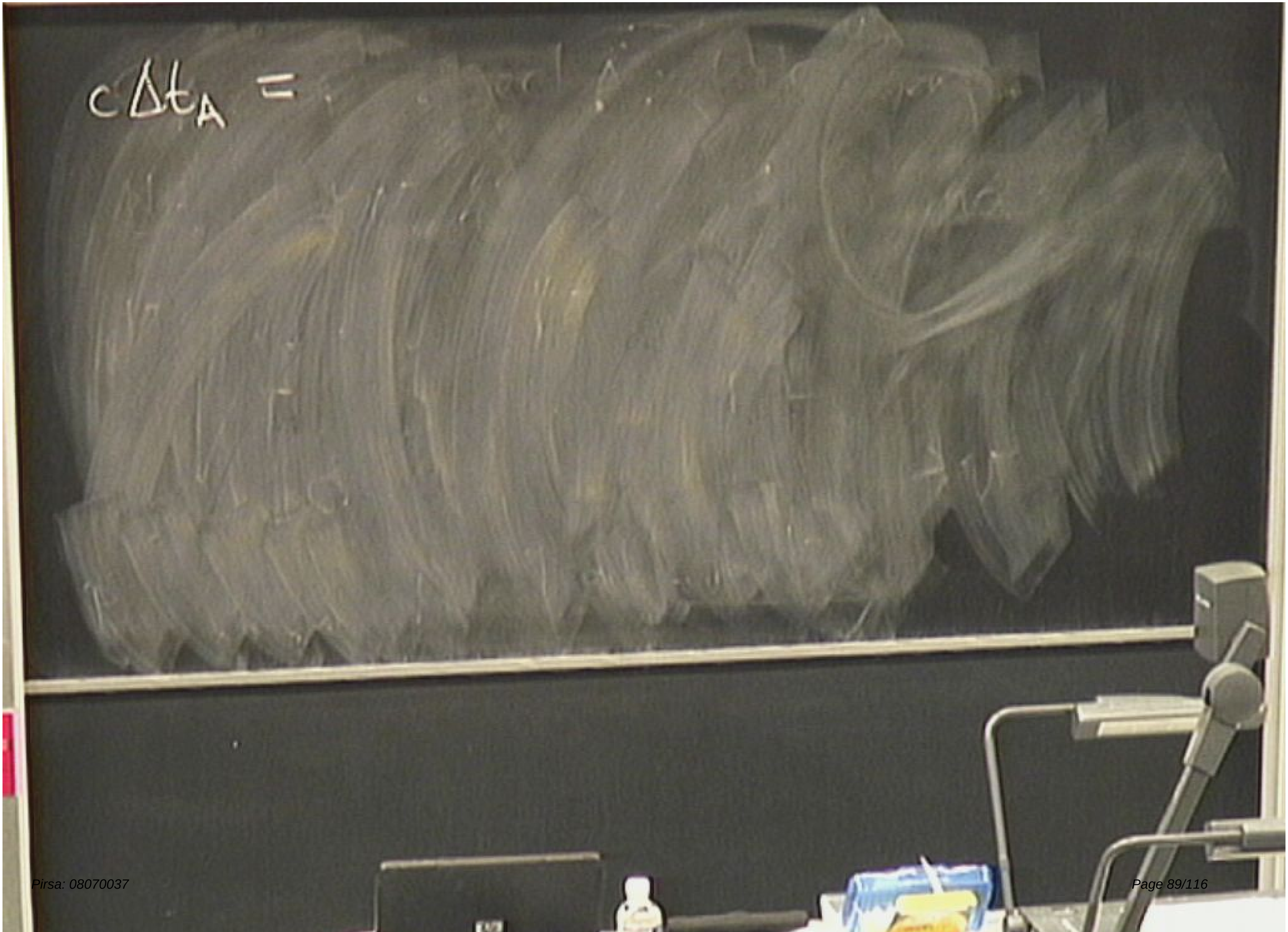
time dilation

light = physical entity satisfying relativity

⇒ time is not (universal)


General
ct A
ct B
d
d
cT
k(cT)
x A


General
ct_A
ct_B
d
k(cT)
x_A
cΔt_A
Δx_A
cΔt_B


$c\Delta t_A =$

$$c\Delta t_A = cT + d \Rightarrow \Delta t_A = T + \frac{d}{c}$$

$$c\Delta t_B = kcT \Rightarrow \Delta t_B = kT$$

$$\Delta x_A = d$$

$$\begin{cases} c\Delta t_A = cT + d \Rightarrow \Delta t_A = T + \dfrac{d}{c} \\ c\Delta t_B = kcT \Rightarrow \Delta t_B = kT \\ \Delta x_A = d \end{cases}$$

$$(1): \quad \frac{d}{cT} = \frac{v/c}{1 - v/c} \longrightarrow$$

$$
\begin{cases}
c\Delta t_A = cT + d \Rightarrow \Delta t_A = T + \frac{d}{c} \\
c\Delta t_B = kcT \Rightarrow \Delta t_B = kT \\
\Delta x_A = d
\end{cases}
$$

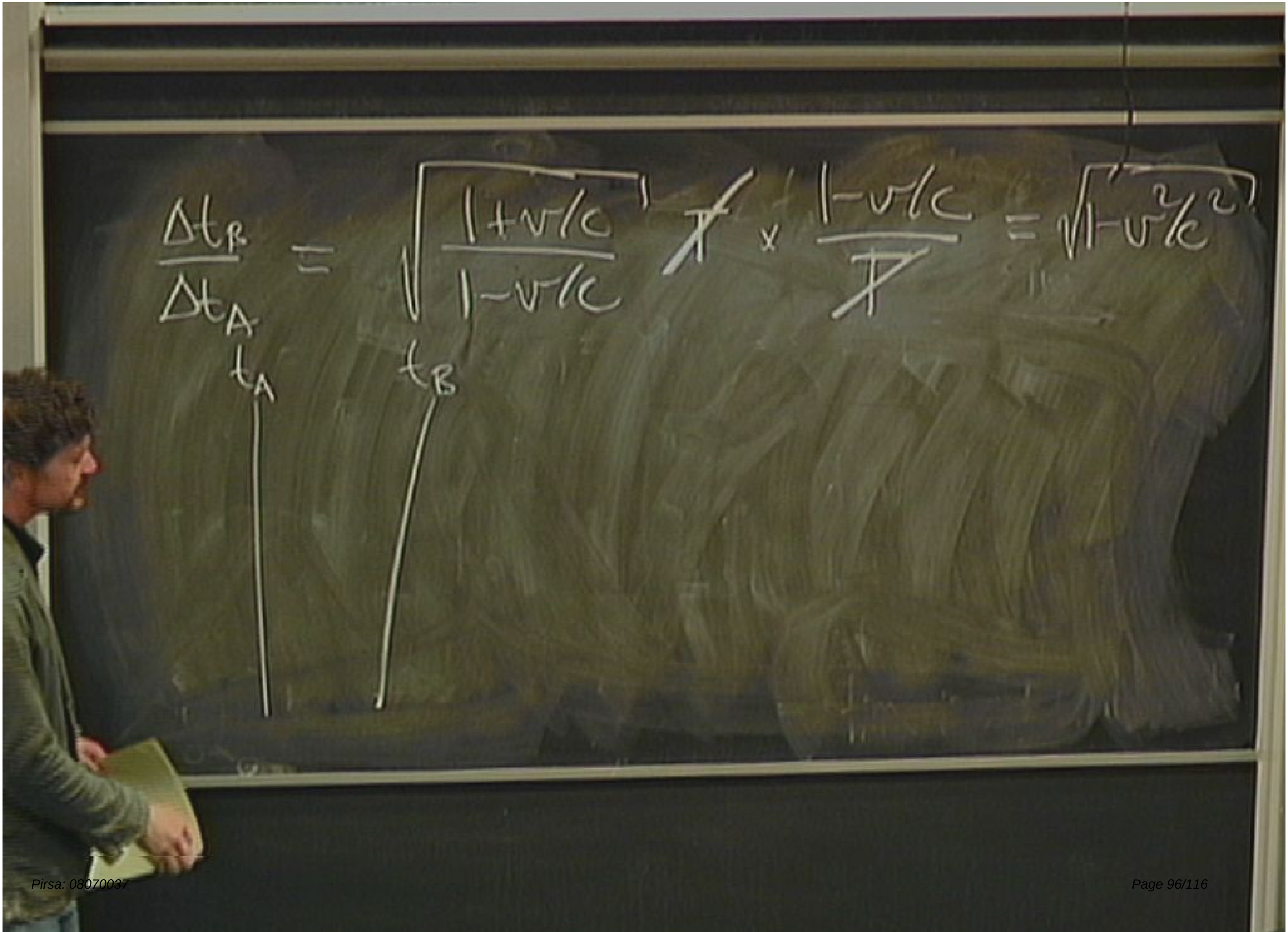
$$
(1):\ \frac{d}{cT} = \frac{v/c}{1-v/c} \rightarrow \Delta t_A = T + \frac{v/c}{1-v/c}T =
$$

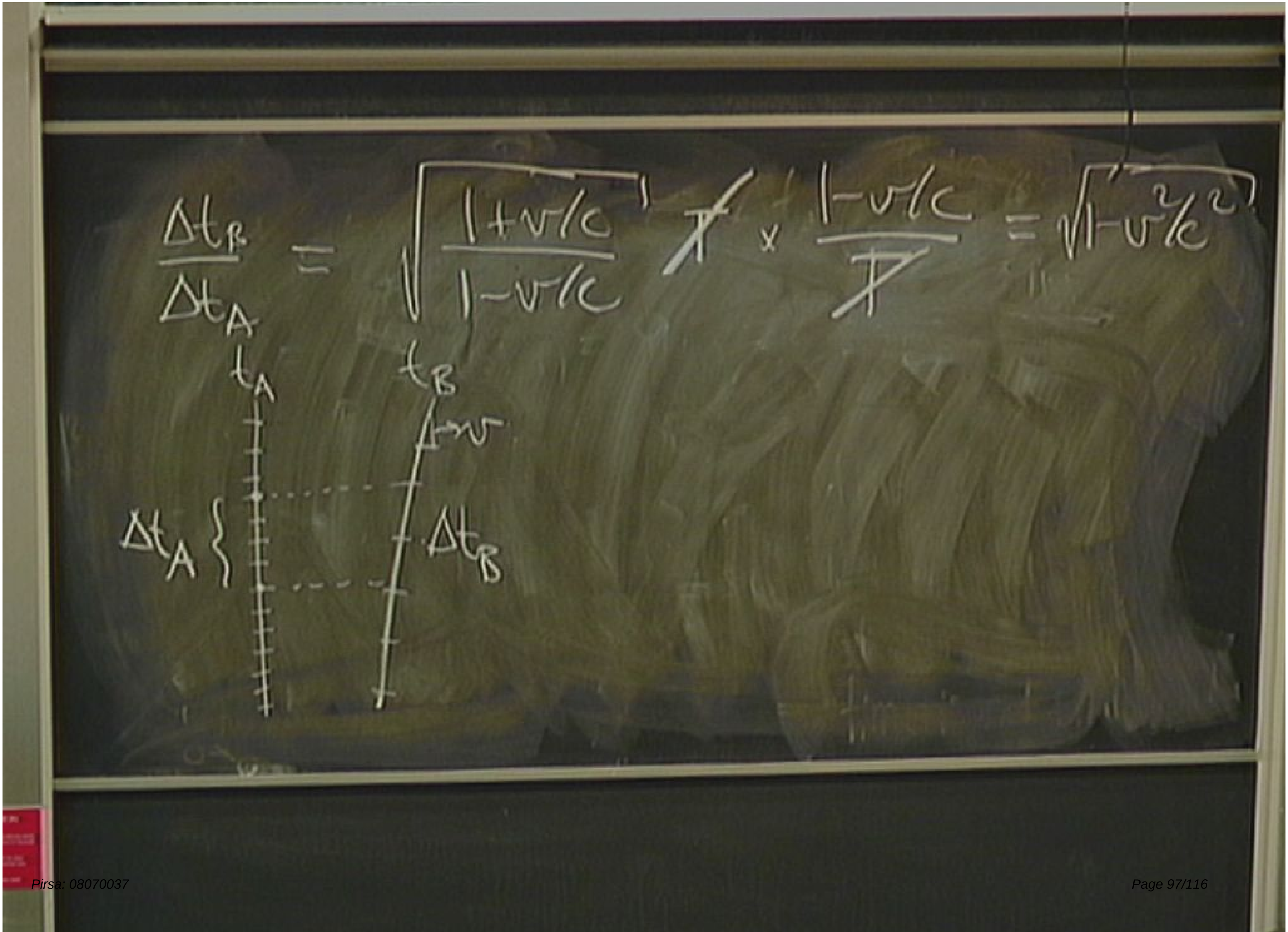
$$\begin{cases} c\Delta t_A = cT + d \Rightarrow \Delta t_A = T + \frac{d}{c} \\ c\Delta t_B = kcT \Rightarrow \Delta t_B = kT \\ \Delta x_A = d \end{cases}$$

$$(1): \frac{d}{cT} = \frac{v/c}{1-v/c} \rightarrow \Delta t_A = T + \frac{v/c}{1-v/c} T = \frac{1}{1-v/c} T$$

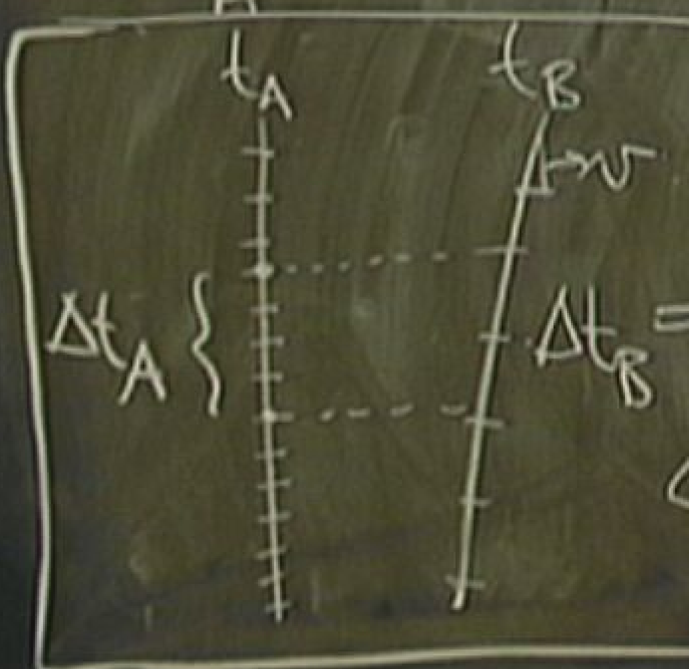
$$\frac{\Delta t_B}{\Delta t_A} = \frac{1}{1+v/c} \; T$$

$$\frac{\Delta t_R}{\Delta t_A} = \sqrt{\frac{1+v/c}{1-v/c}}\,\cancel{\gamma} \times \frac{1-v/c}{\cancel{\gamma}} =$$


Δt_B / Δt_A = √((1+v/c) / (1−v/c)) × (1−v/c) = √(1−v²/c²)
t_A
t_B


$\frac{\Delta t_B}{\Delta t_A} = \sqrt{\frac{1+v/c}{1-v/c}}\ \cancel{T} \times \frac{1-v/c}{\cancel{T}} = \sqrt{1-v^2/c^2}$
t_A
t_B
v
Δt_A
Δt_B

$$\frac{\Delta t_B}{\Delta t_A} = \sqrt{\frac{1+v/c}{1-v/c}}\,\cancel{T} \times \frac{1-v/c}{\cancel{T}} = \sqrt{1-v^2/c^2}$$



$$\Delta t_B = \sqrt{1-v^2/c^2}\,\Delta t_A < \Delta t_A$$

$$\frac{\Delta t_B}{\Delta t_A} = \sqrt{\frac{1+v/c}{1-v/c}}\,\cancel{T} \times \frac{1-v/c}{\cancel{T}} = \sqrt{1-v^2/c^2}$$

$$v = \tfrac{4}{5}c$$

$$\sqrt{1-v^2/c^2} = \frac{3}{5}$$

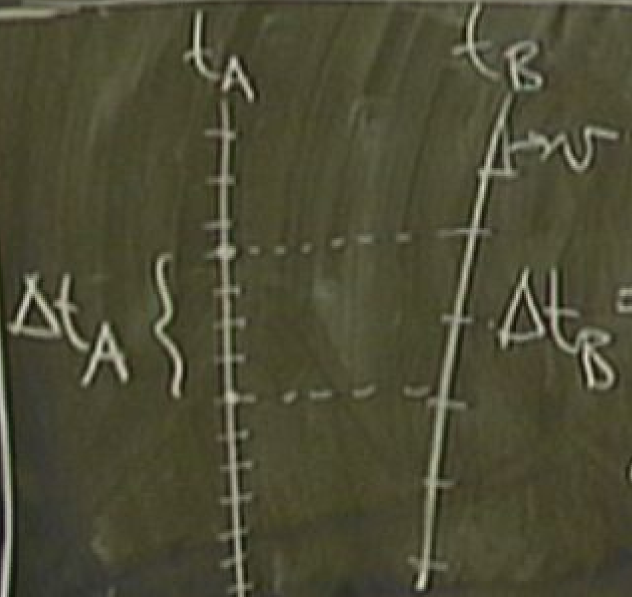
t_A $\quad$ t_B

$\rightarrow v$

Δt_A

$$\Delta t_B = \sqrt{1-v^2/c^2}\,\Delta t_A$$
$$< \Delta t_A$$

$$\frac{\Delta t_B}{\Delta t_A} = \sqrt{\frac{1+v/c}{1-v/c}}\ \cancel{T} \times \frac{1-v/c}{\cancel{T}} = \sqrt{1-v^2/c^2}$$

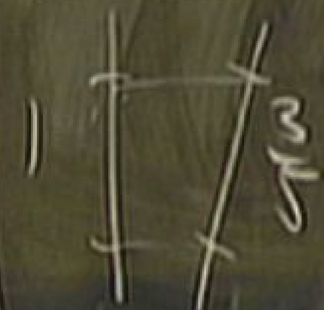


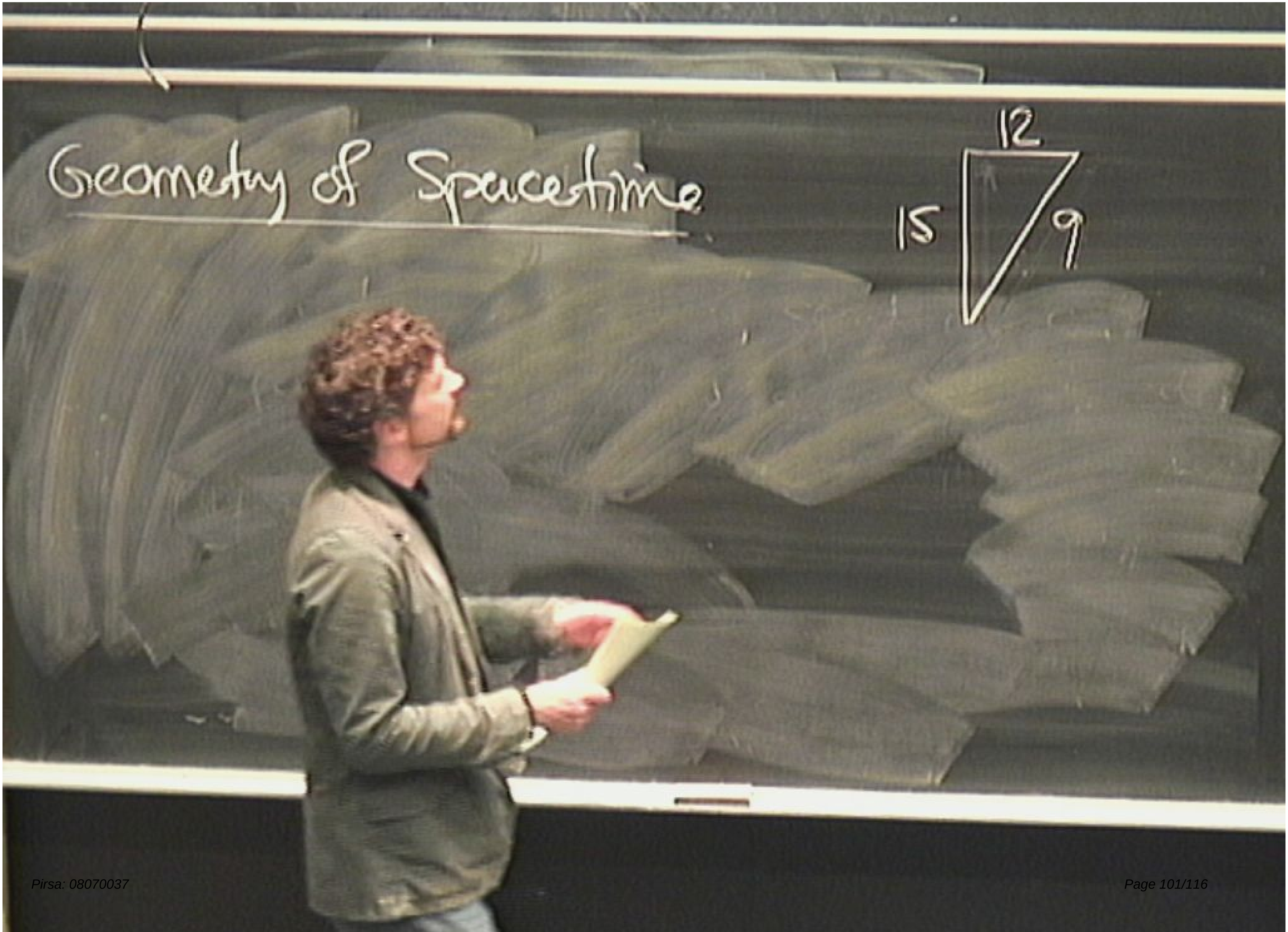
$$\Delta t_B = \sqrt{1-v^2/c^2}\,\Delta t_A$$

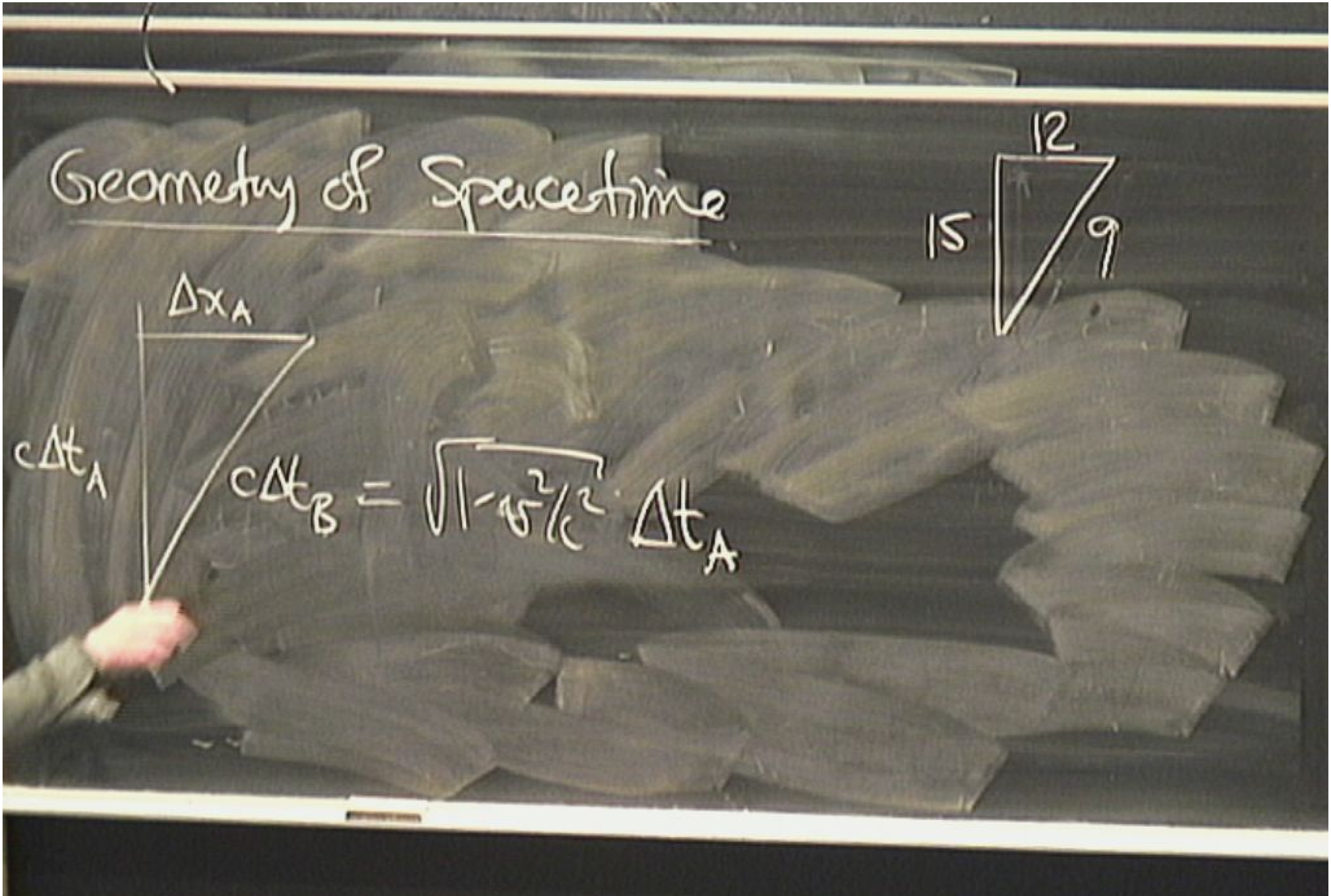
$$< \Delta t_A$$

$$v = \frac{4}{5}c$$

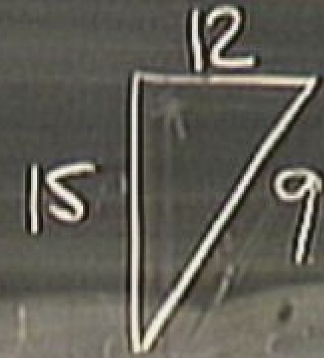
$$\sqrt{1-v^2/c^2} = \frac{3}{5}$$

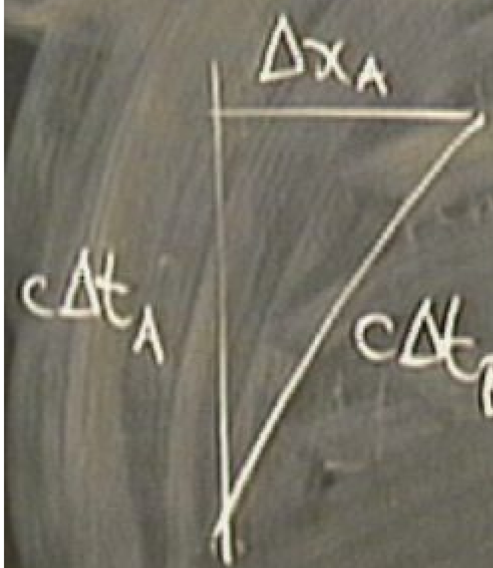



Geometry of Spacetime
12
15
9

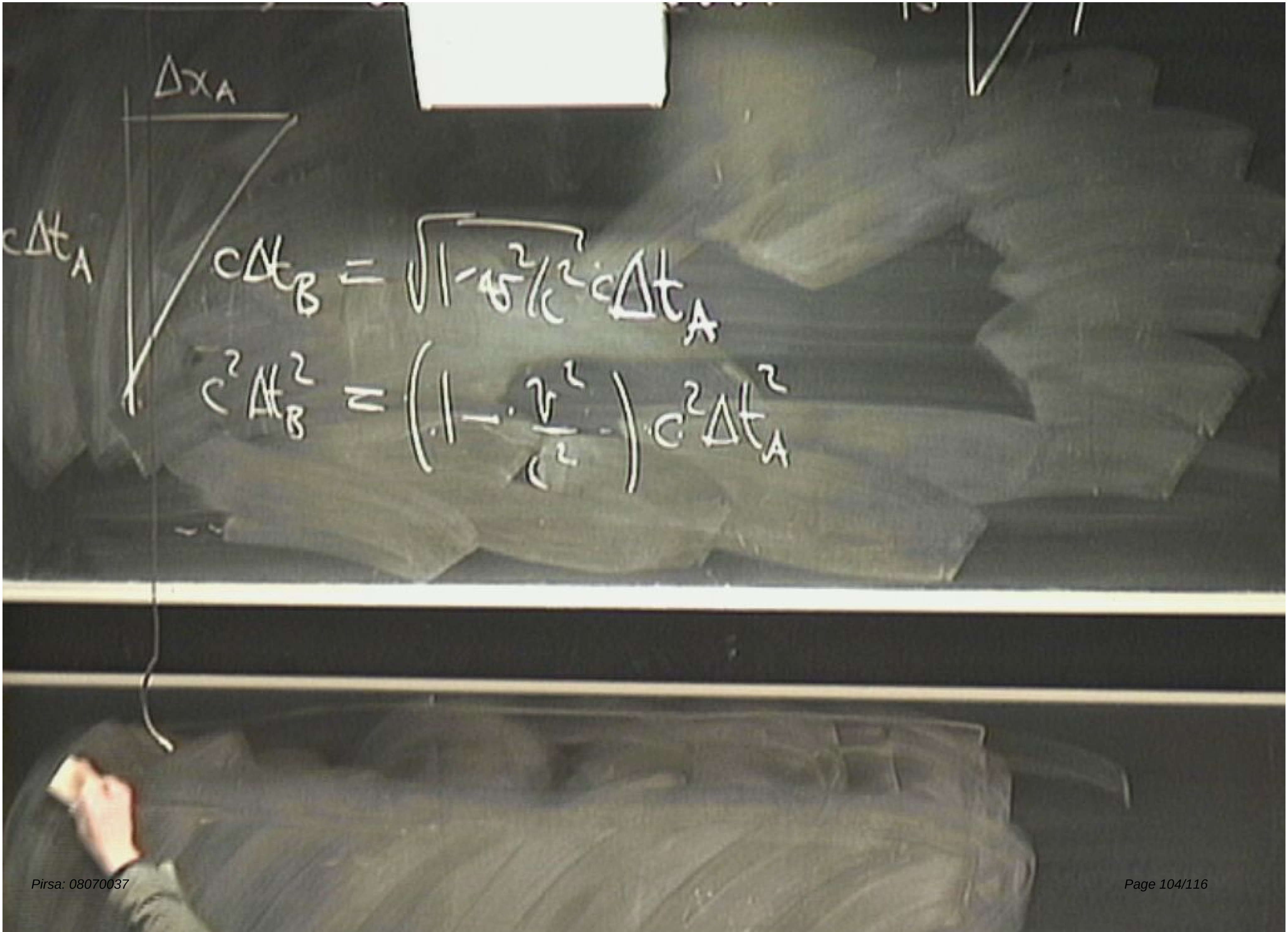

Geometry of Spacetime
12
15
9
Δx_A
$c\Delta t_A$
$c\Delta t_B = \sqrt{1 - v^2/c^2}\,\Delta t_A$

Geometry of Spacetime



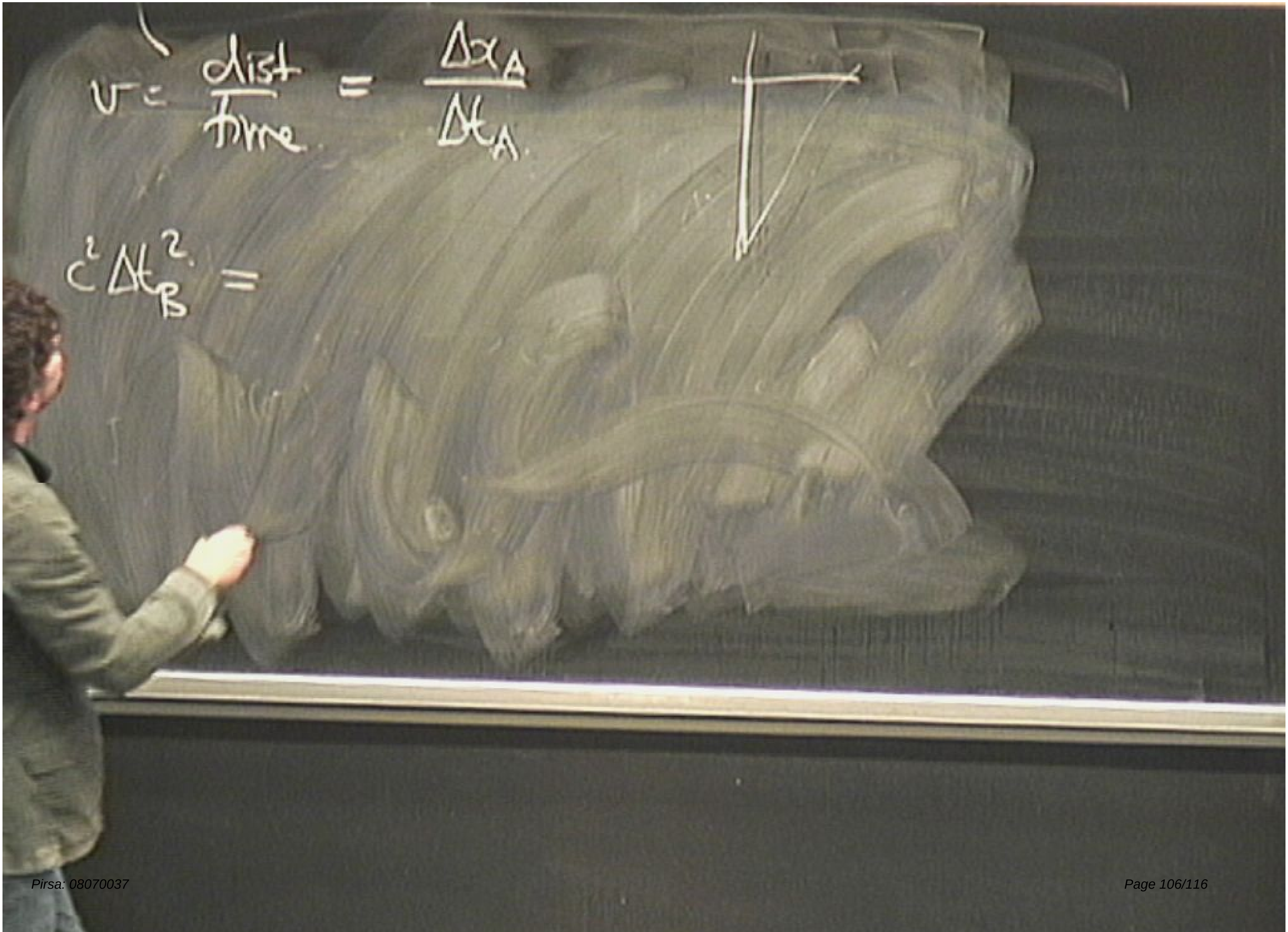


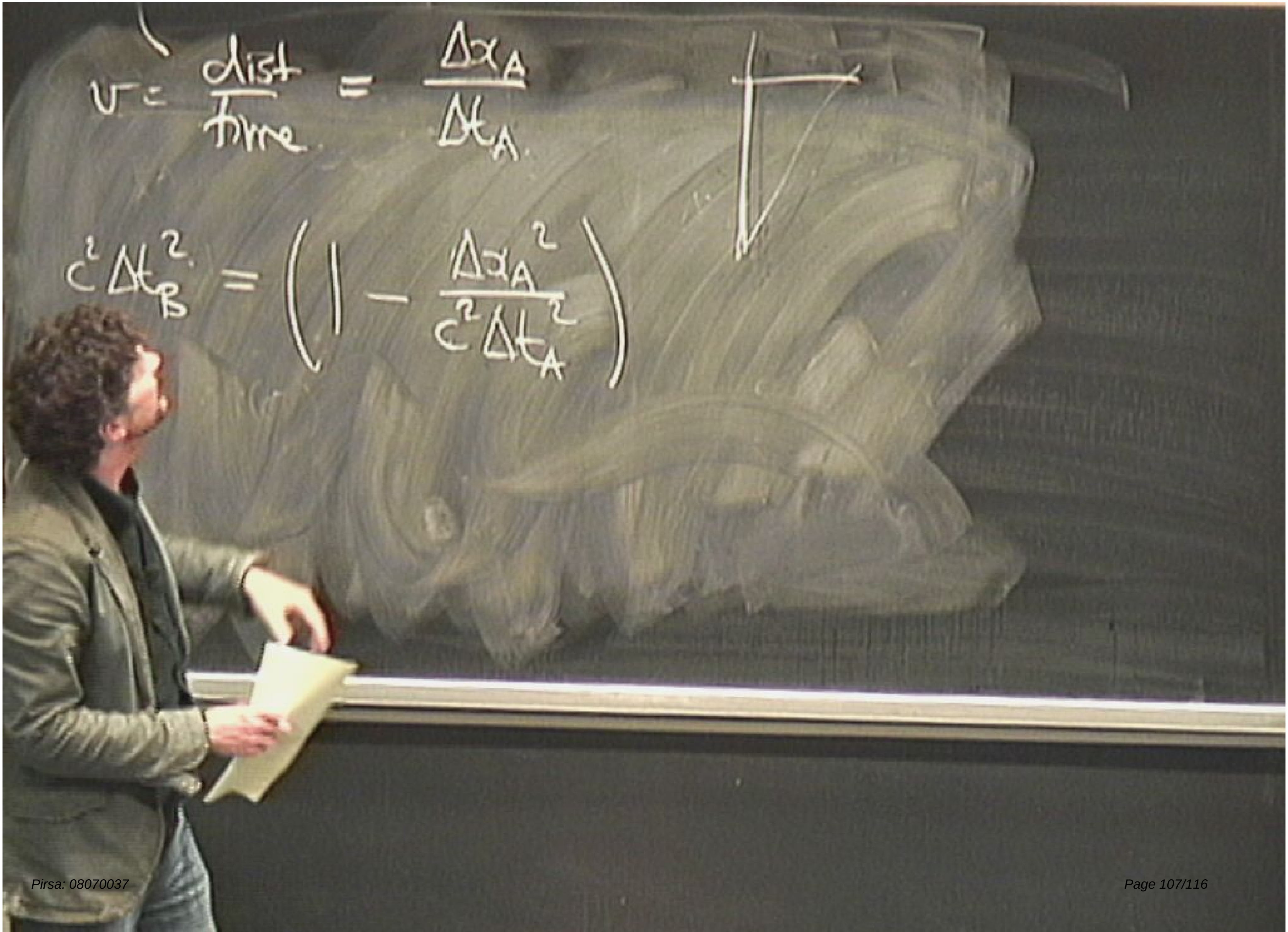
$$c\Delta t_B = \sqrt{1 - v^2/c^2}\ \Delta t_A$$



Δx_A
$c\Delta t_A$
$c\Delta t_B = \sqrt{1 - v^2/c^2}\, c\Delta t_A$
$c^2\Delta t_B^2 = \left(1 - \frac{v^2}{c^2}\right) c^2 \Delta t_A^2$

$$v = \frac{\text{dist}}{\text{time}} =$$

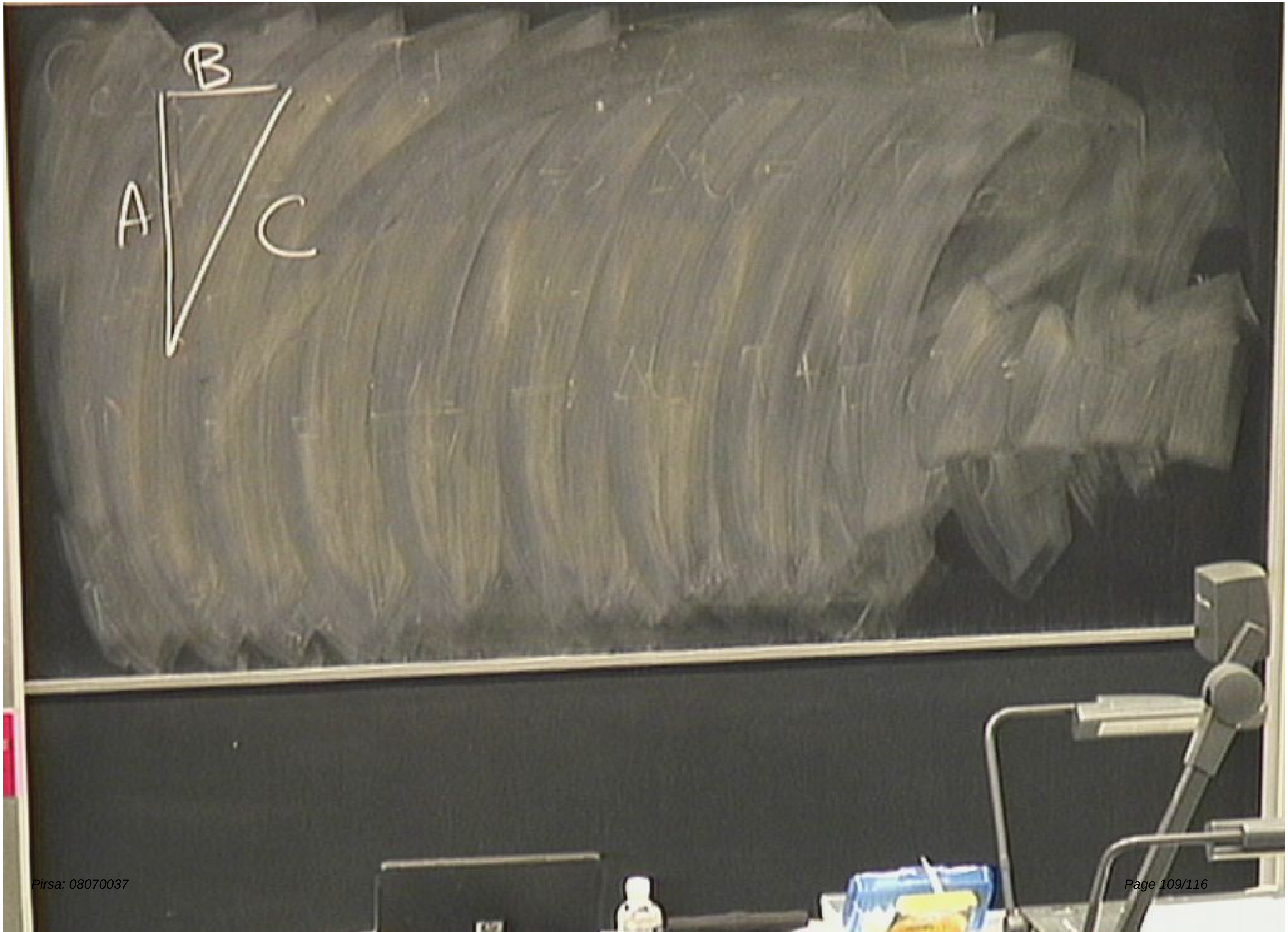

$v = \frac{\text{dist}}{\text{time}} = \frac{\Delta x_A}{\Delta t_A}$
$c^2 \Delta t_B^2 =$

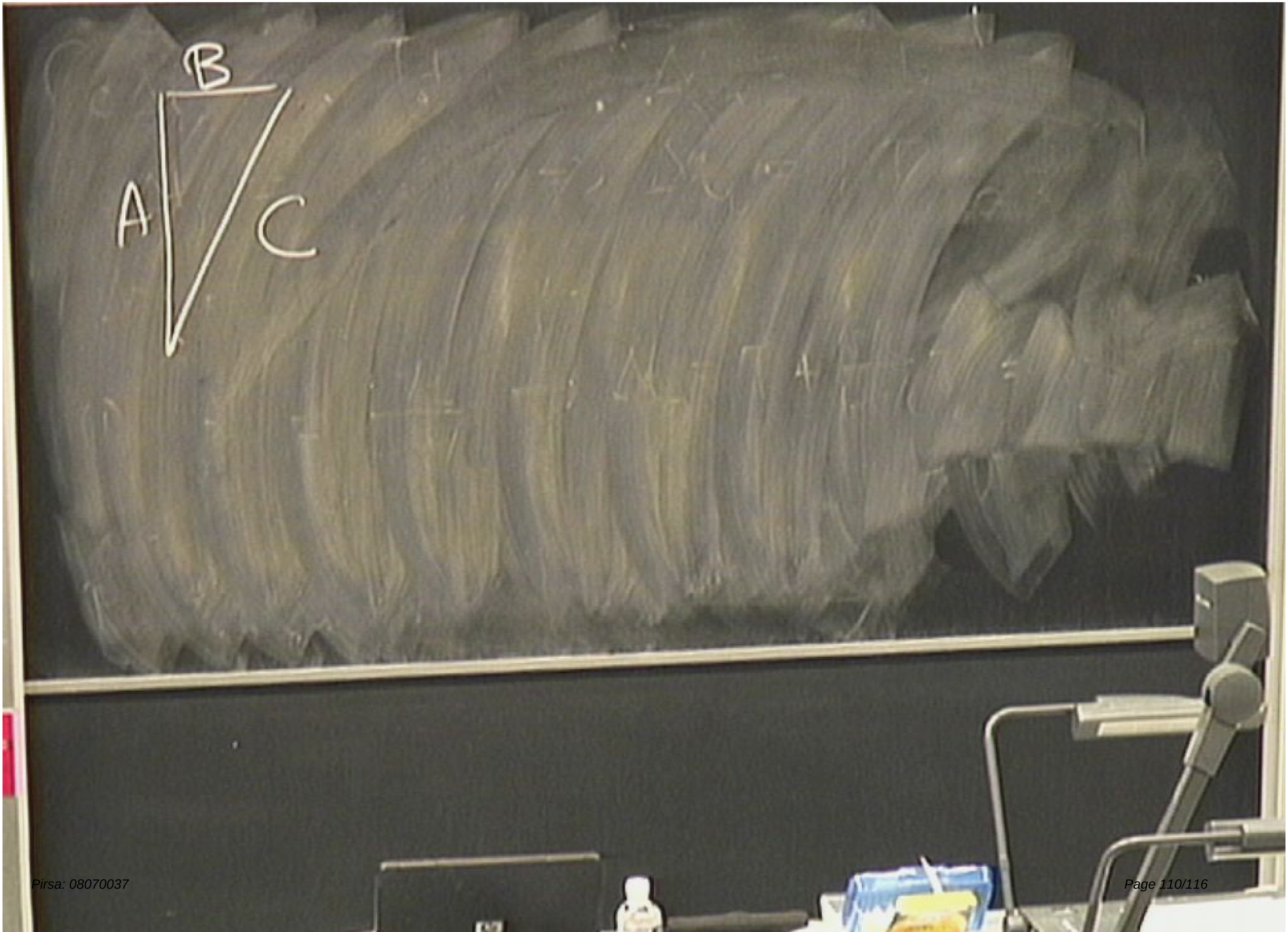

$v = \frac{\text{dist}}{\text{time}} = \frac{\Delta x_A}{\Delta t_A}$
$c^2 \Delta t_B^2 = \left(1 - \frac{\Delta x_A^2}{c^2 \Delta t_A^2}\right)$

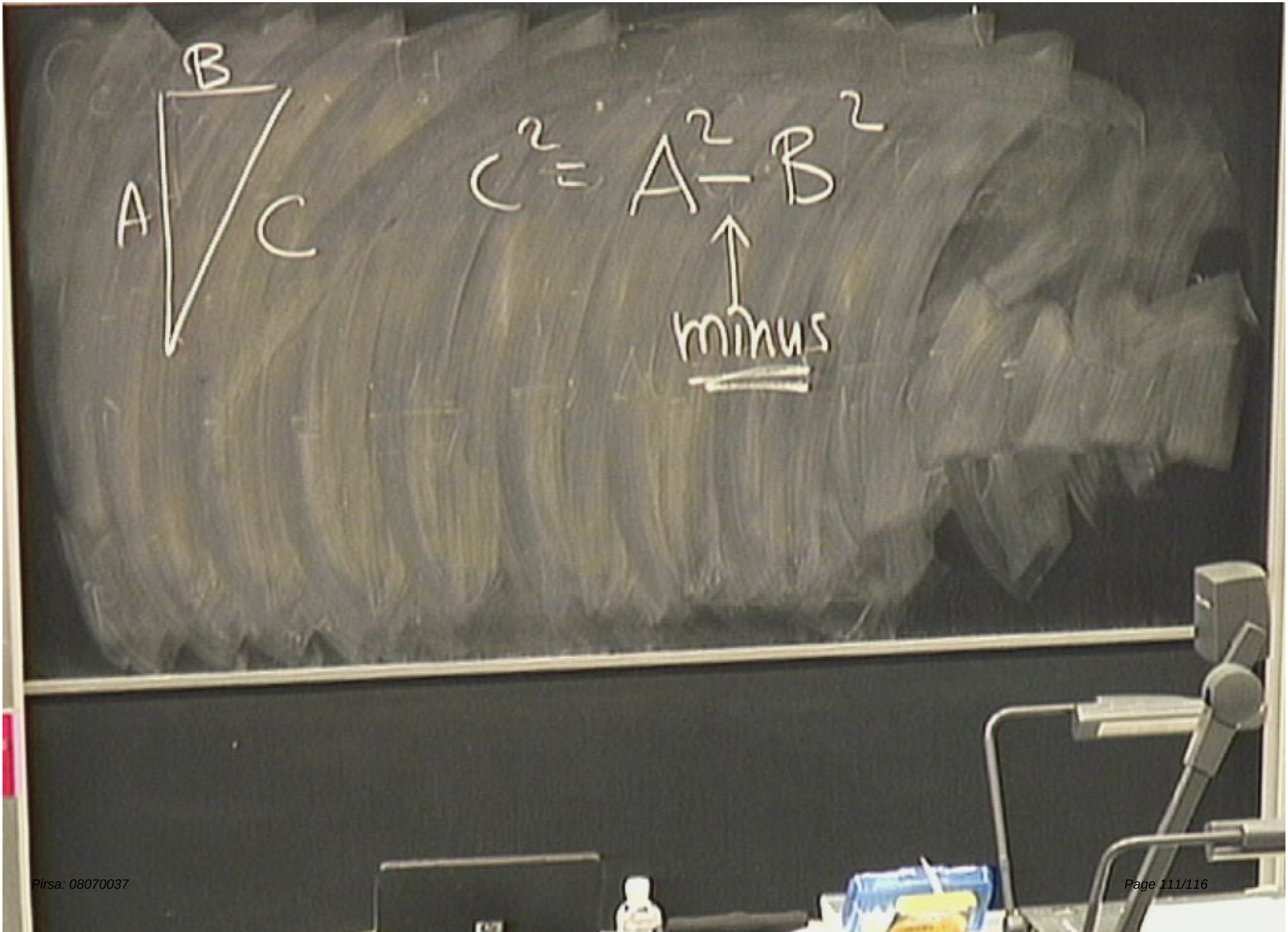
$$v = \frac{\text{dist}}{\text{time}} = \frac{\Delta x_A}{\Delta t_A}$$

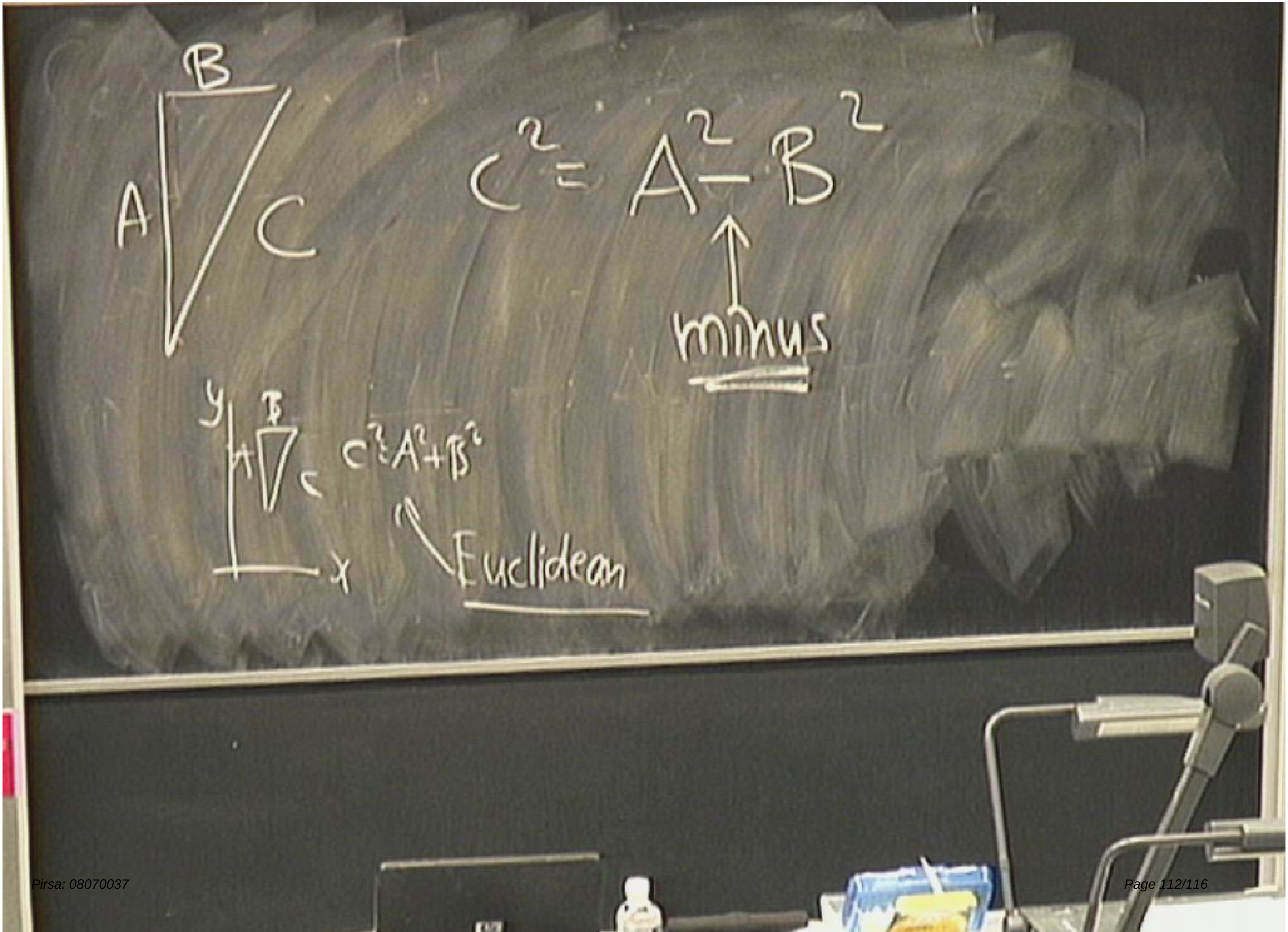
$$c^2 \Delta t_B^2 = \left(1 - \frac{\Delta x_A^2}{c^2 \Delta t_A^2}\right) c^2 \Delta t_A^2$$

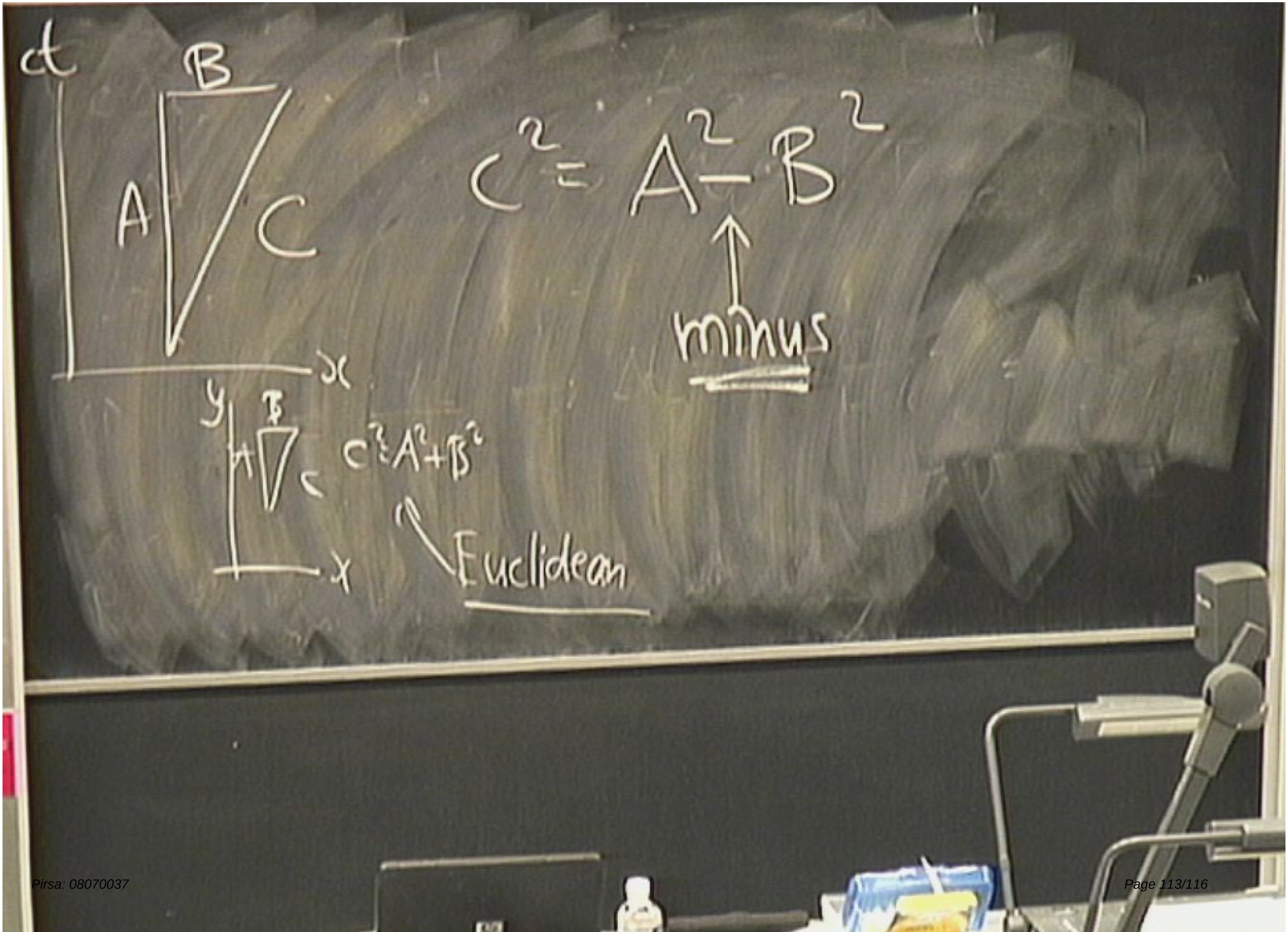
$$\boxed{c^2 \Delta t_B^2 = c^2 \Delta t_A^2 - \Delta x_A^2}$$

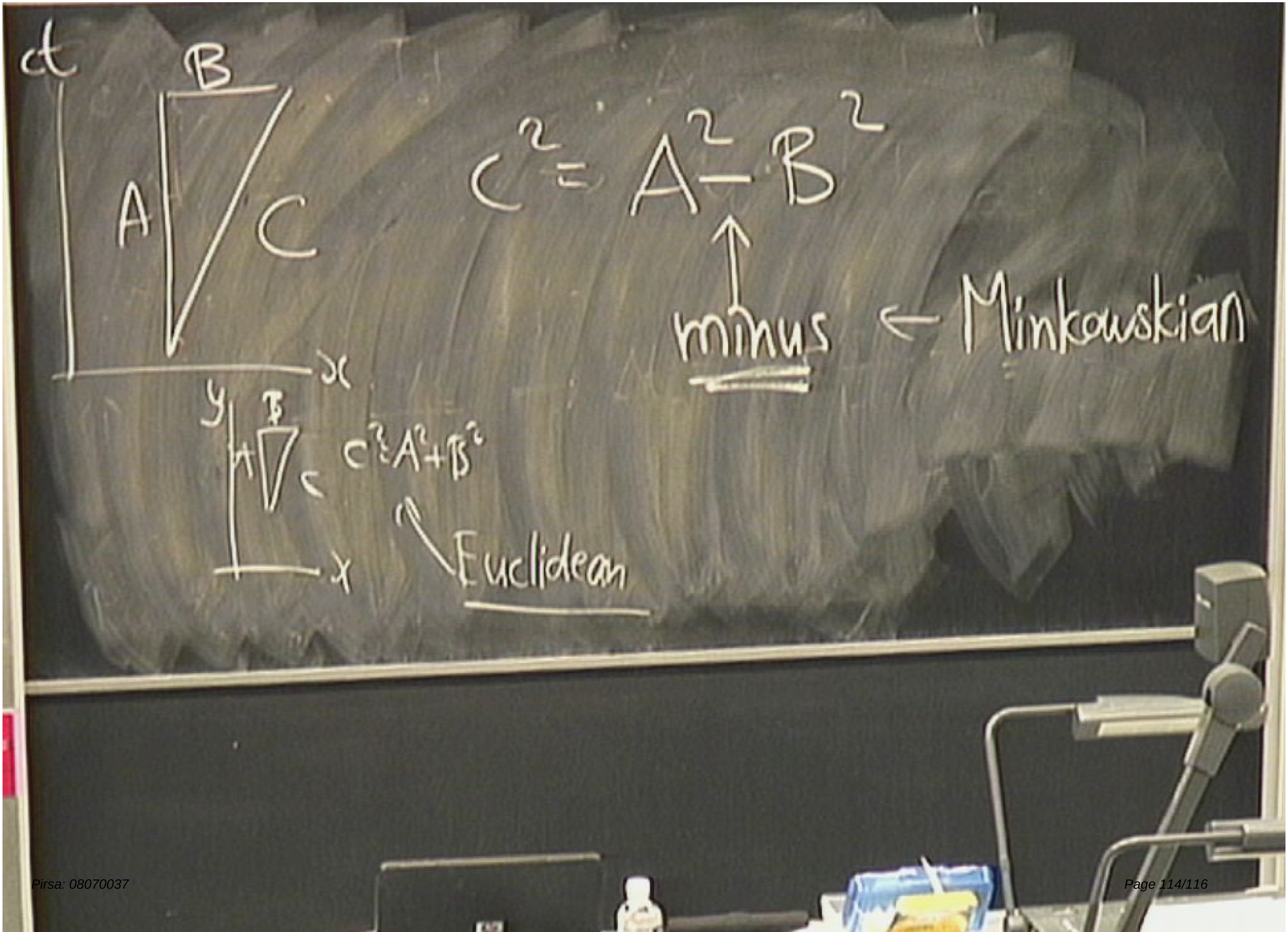

B
A
C

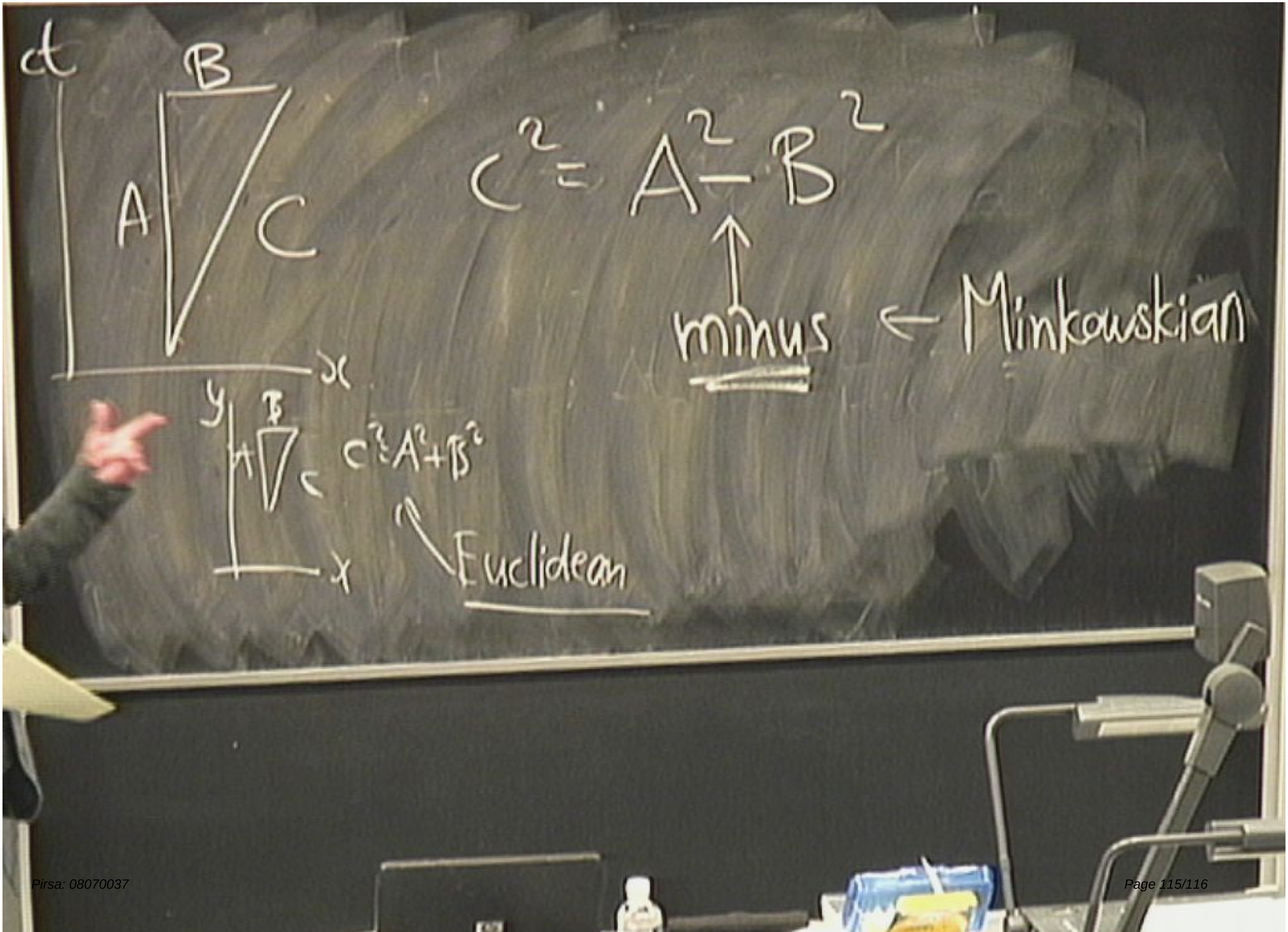

B
A
C

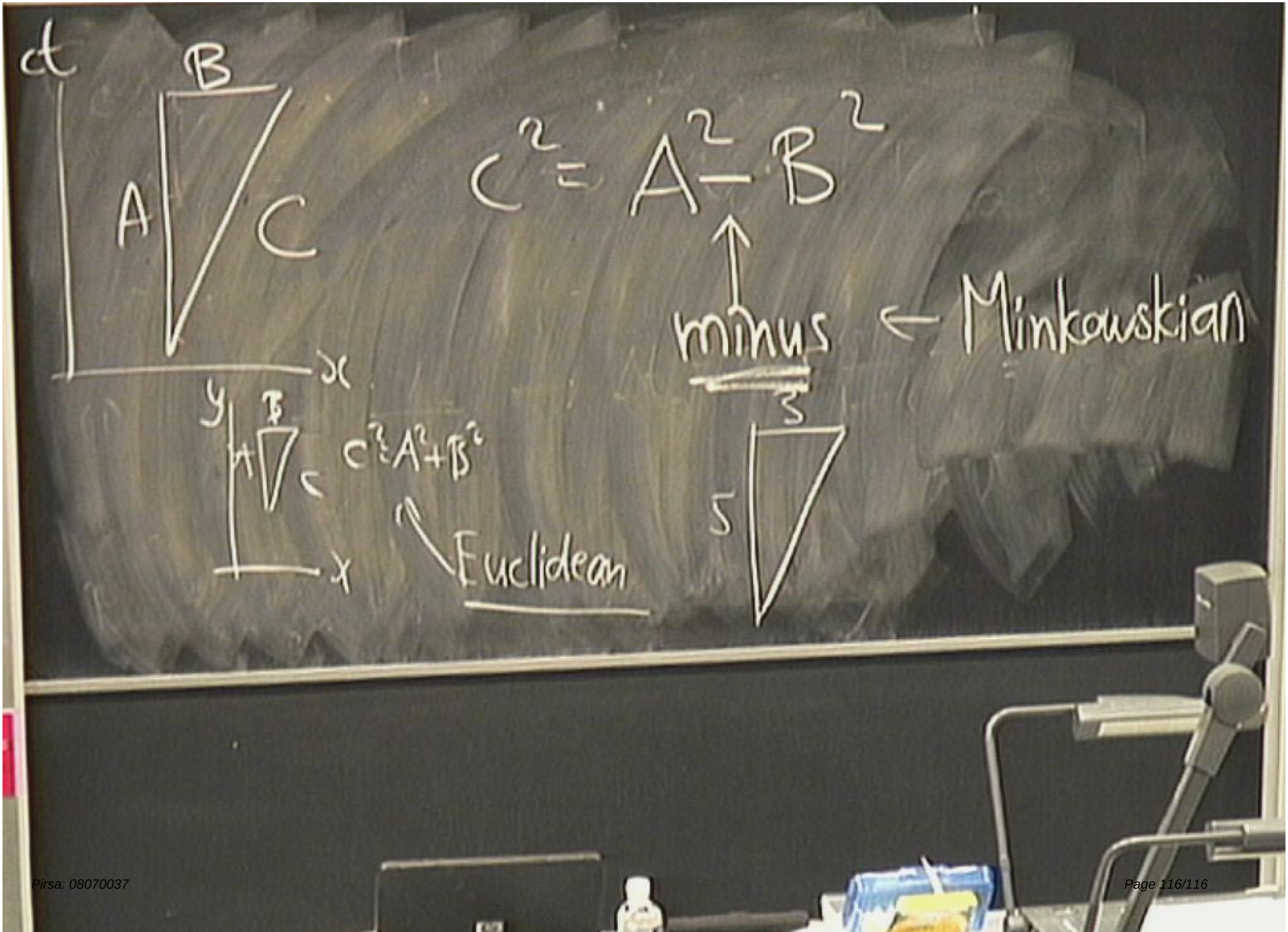

B
A
C
C² = A² − B²
minus


B
A
C
C² = A² − B²
minus
y
B
A
C
C² = A² + B²
x
Euclidean


ct
B
A
C
x
C² = A² − B²
minus
y
B
A
C
C² = A² + B²
Euclidean
x


ct
B
A
C
x
C² = A² − B²
minus
← Minkowskian
y
B
A
C
x
C² = A² + B²
Euclidean


ct
B
A
C
c² = A² – B²
minus
Minkowskian
x
y
B
A
c
c² = A² + B²
Euclidean
x


ct
B
A
C
x
C² = A² − B²
minus
← Minkowskian
y
B
A
c
c² = A² + B²
Euclidean
x
3
5