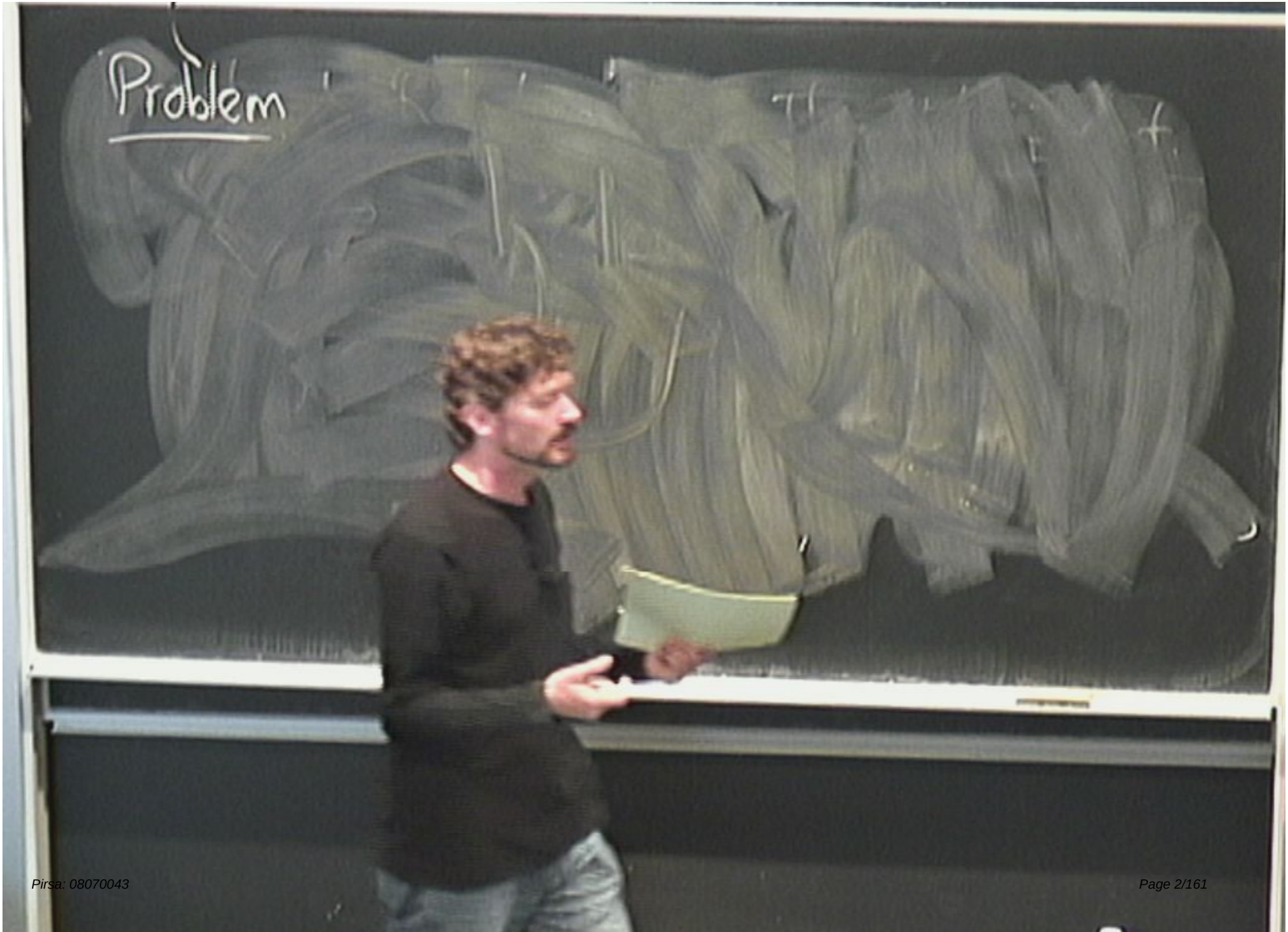
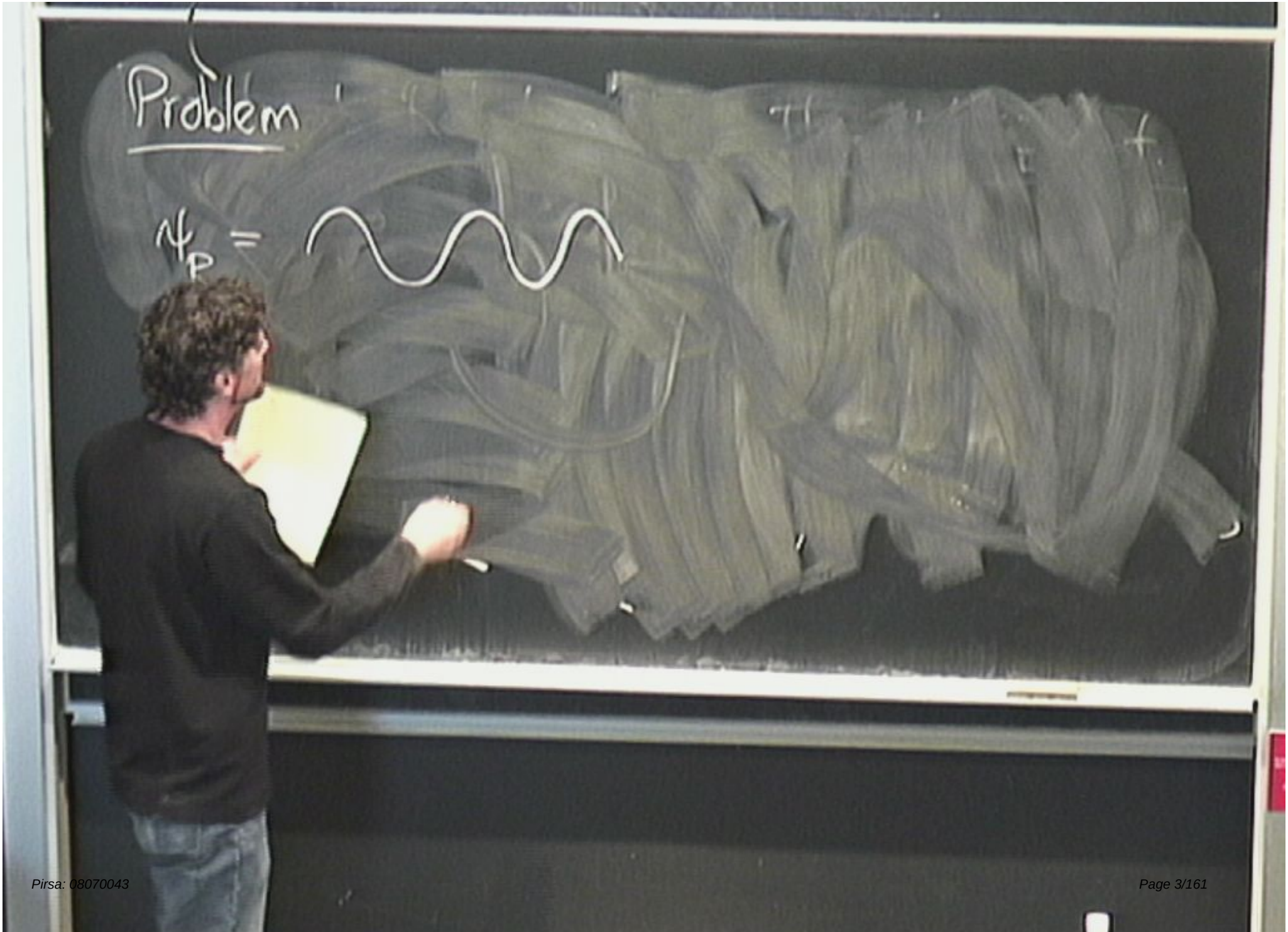
Title: Quantum 4

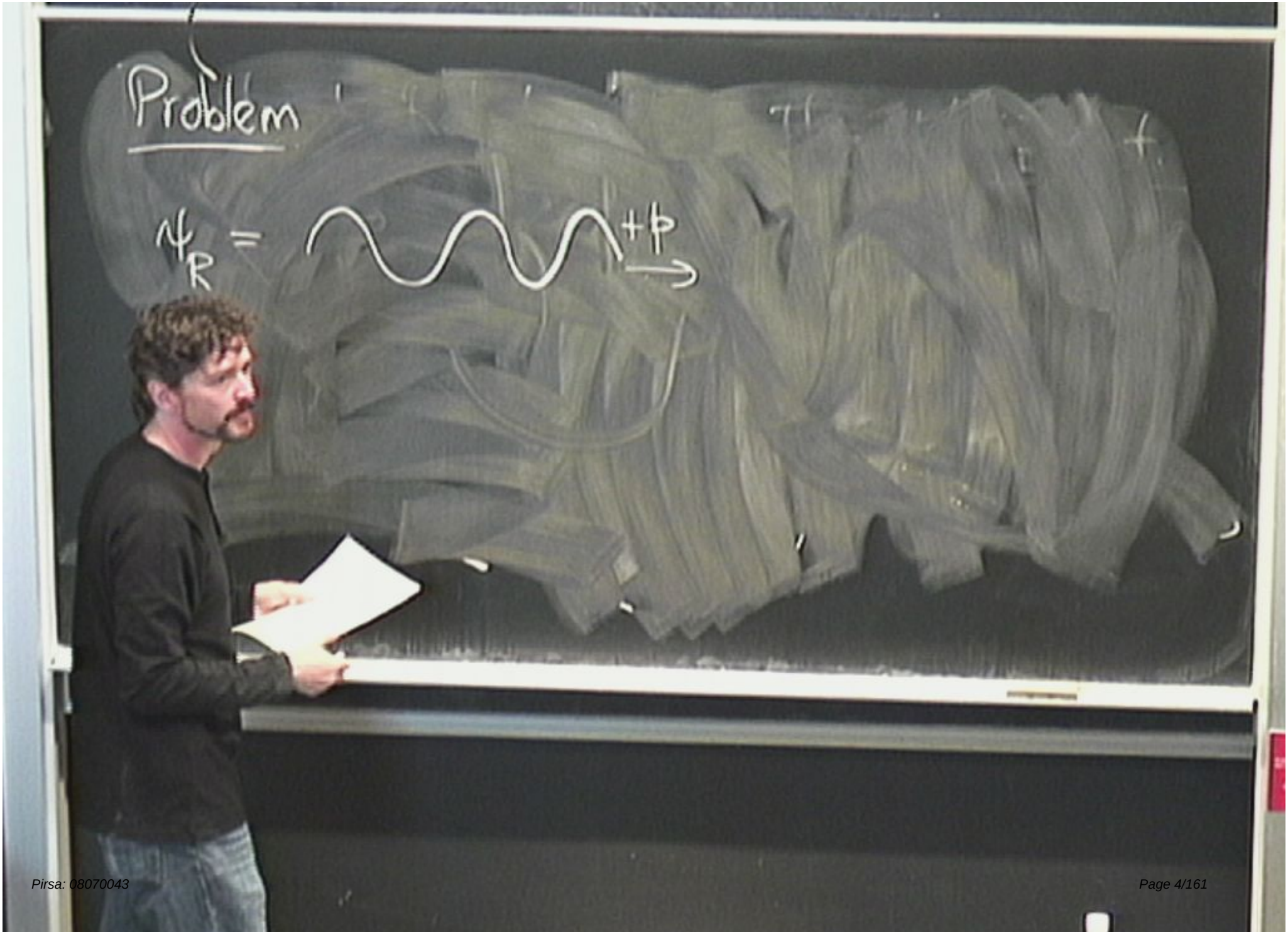
Date: Jul 27, 2008 10:30 AM

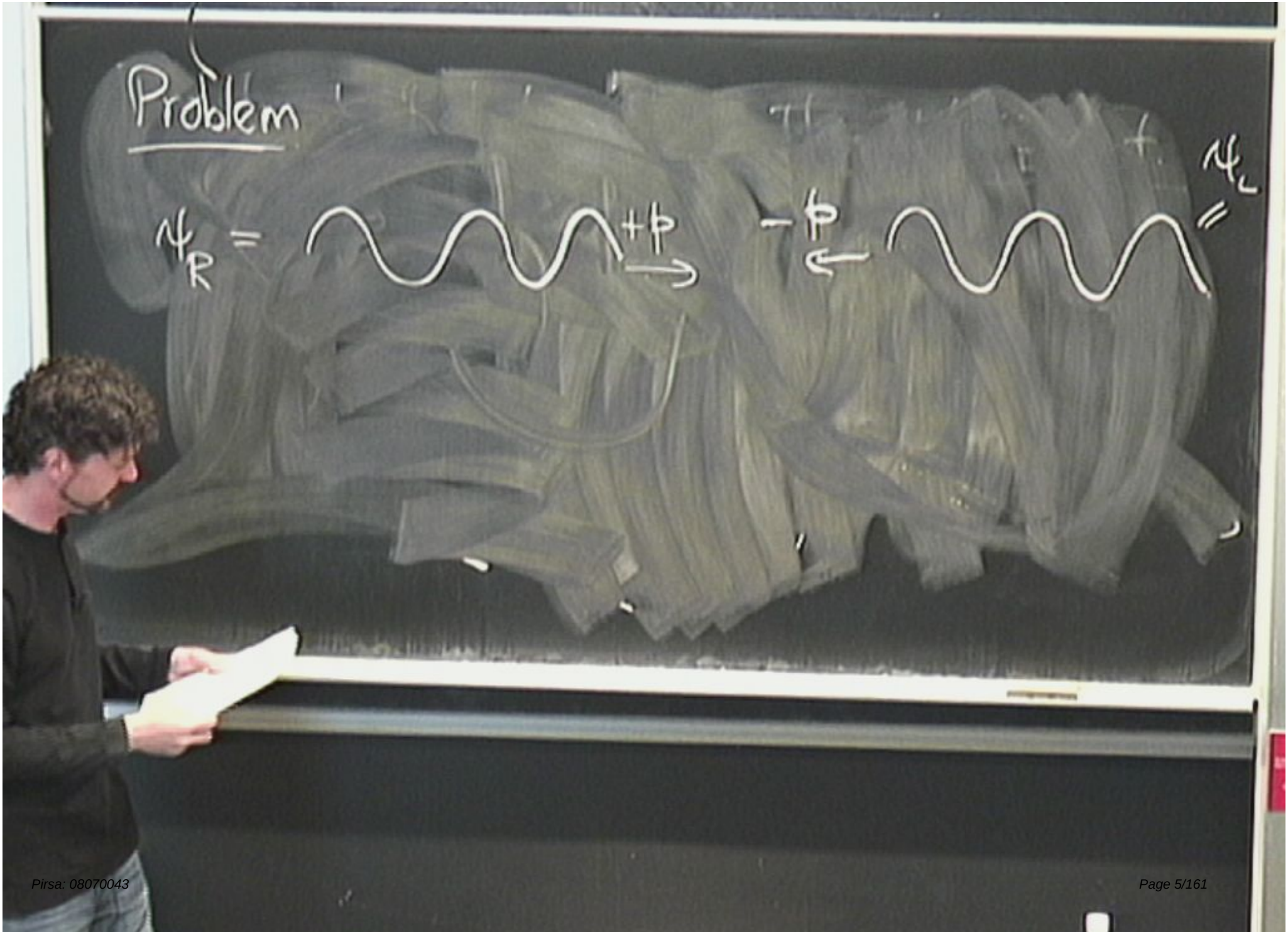
URL: http://pirsa.org/08070043

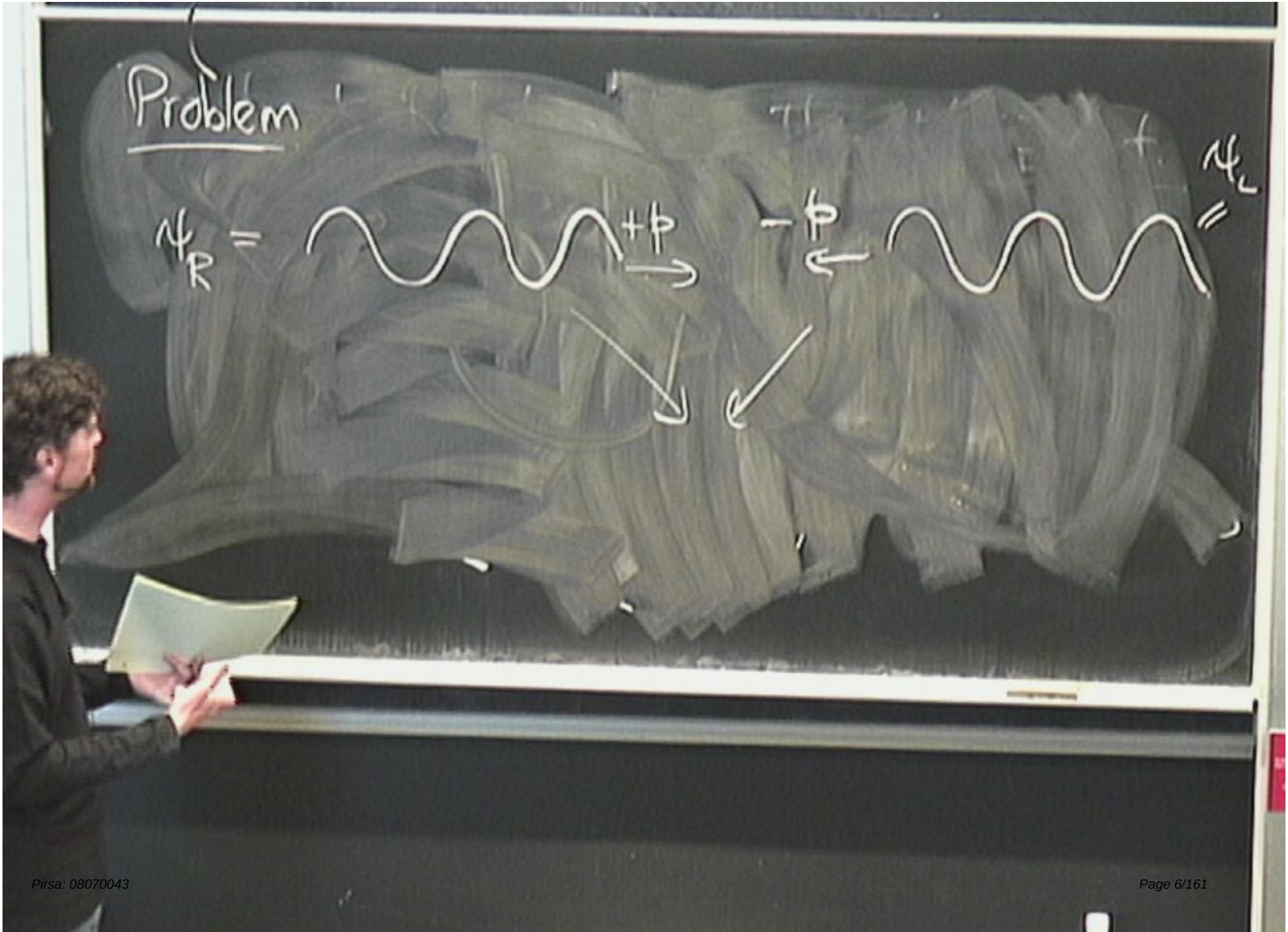
Abstract:

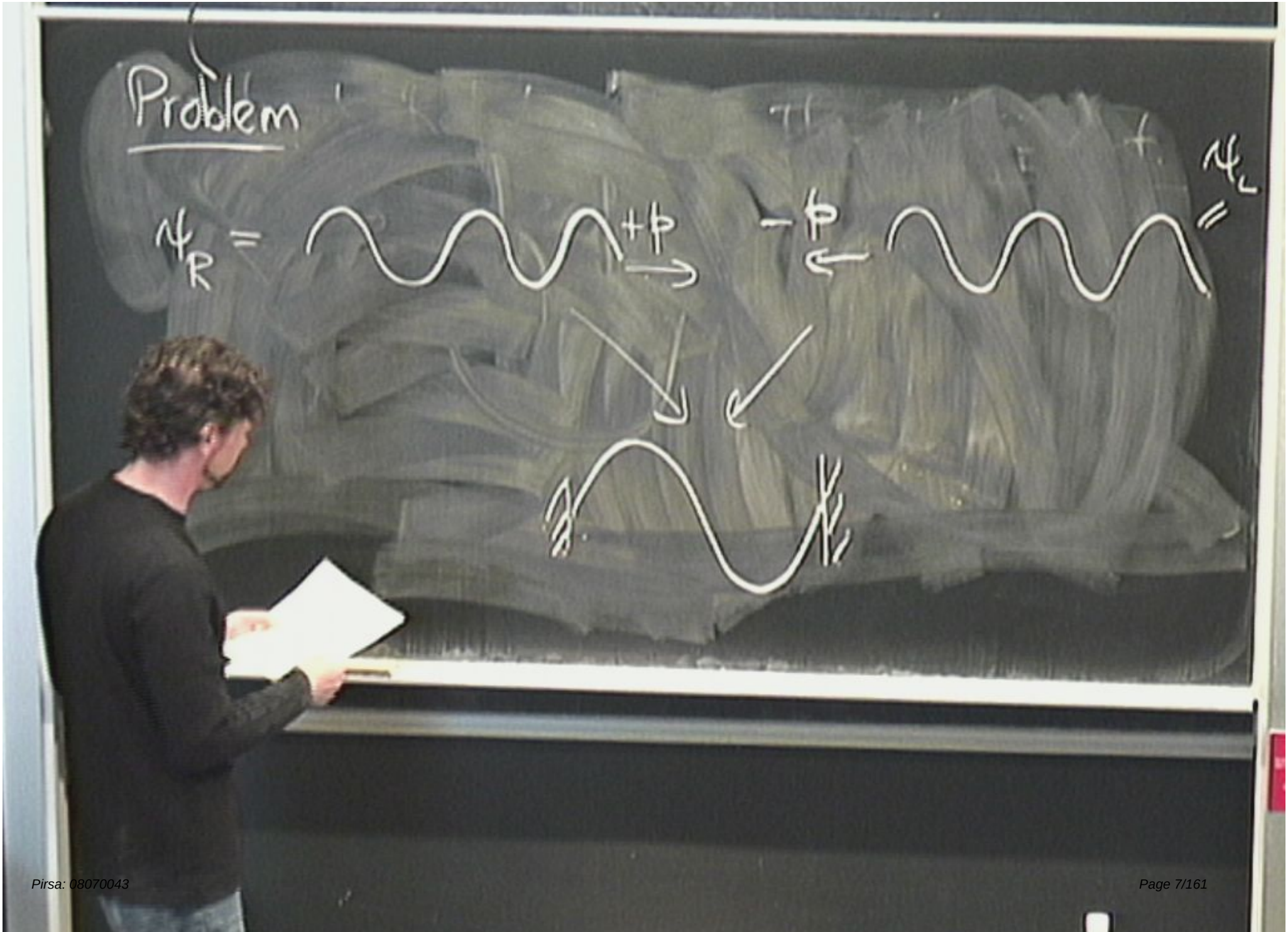

Problem

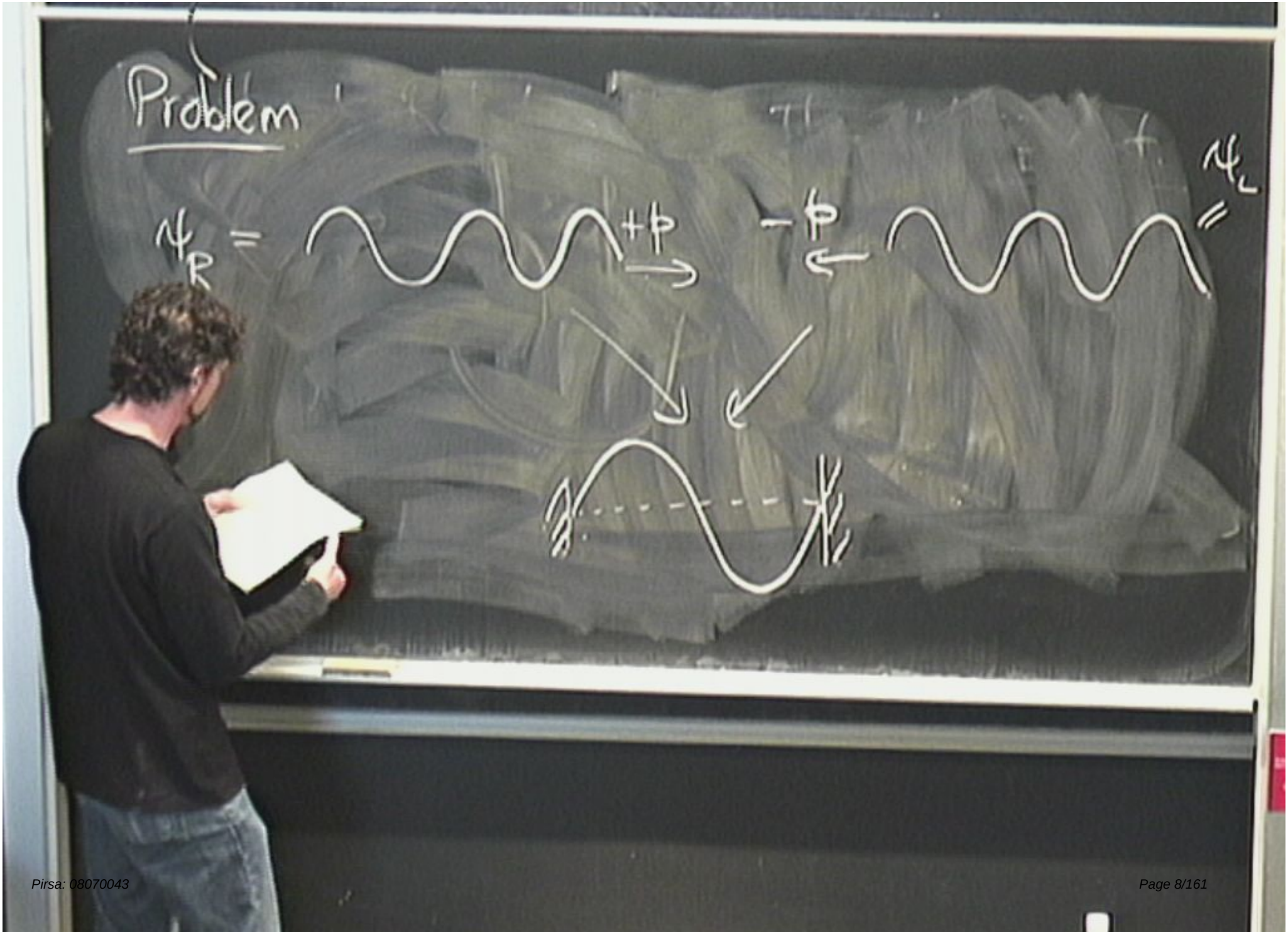

Problem
$\psi_p =$

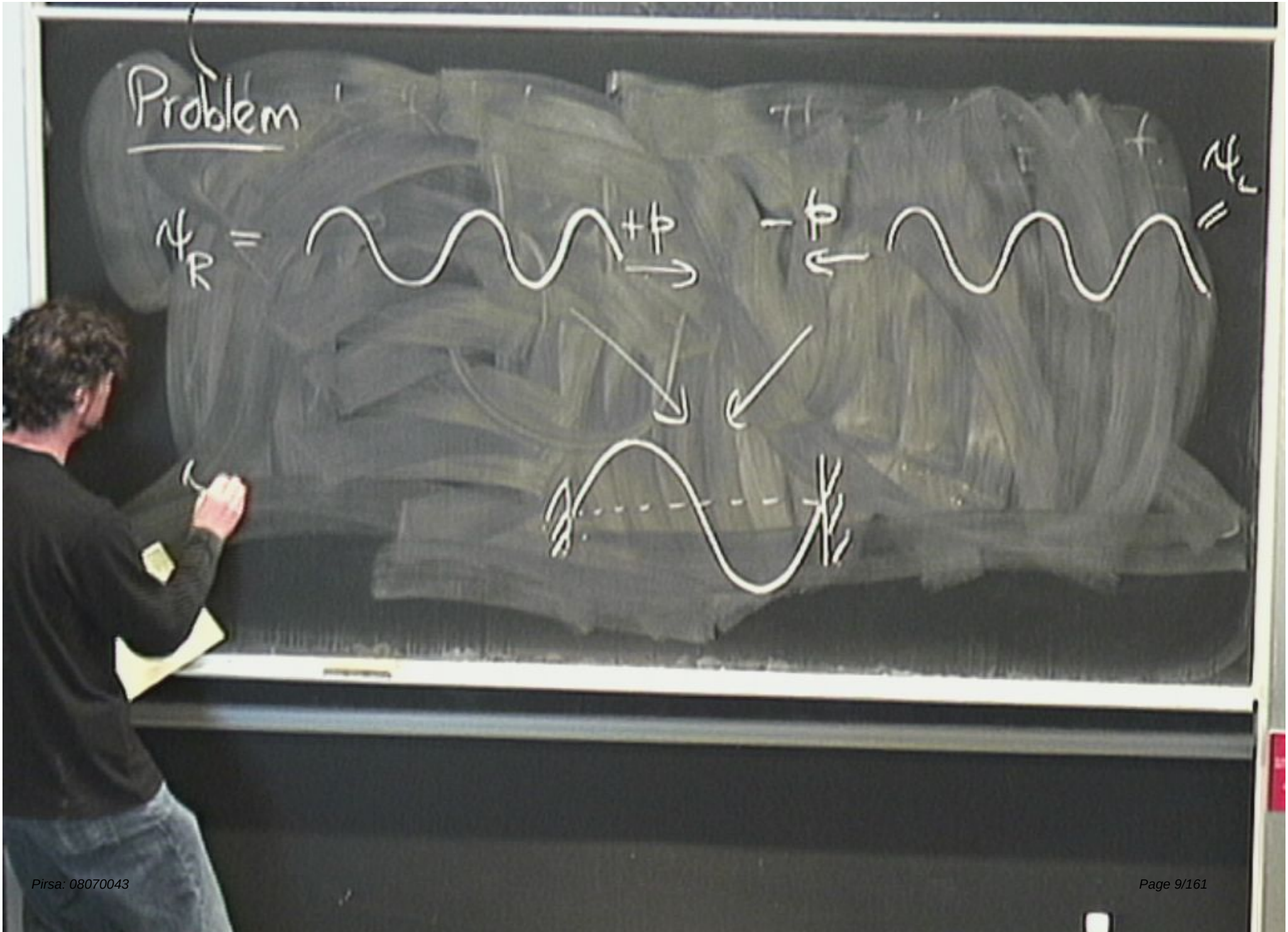

Problem
ψ_R =
+p

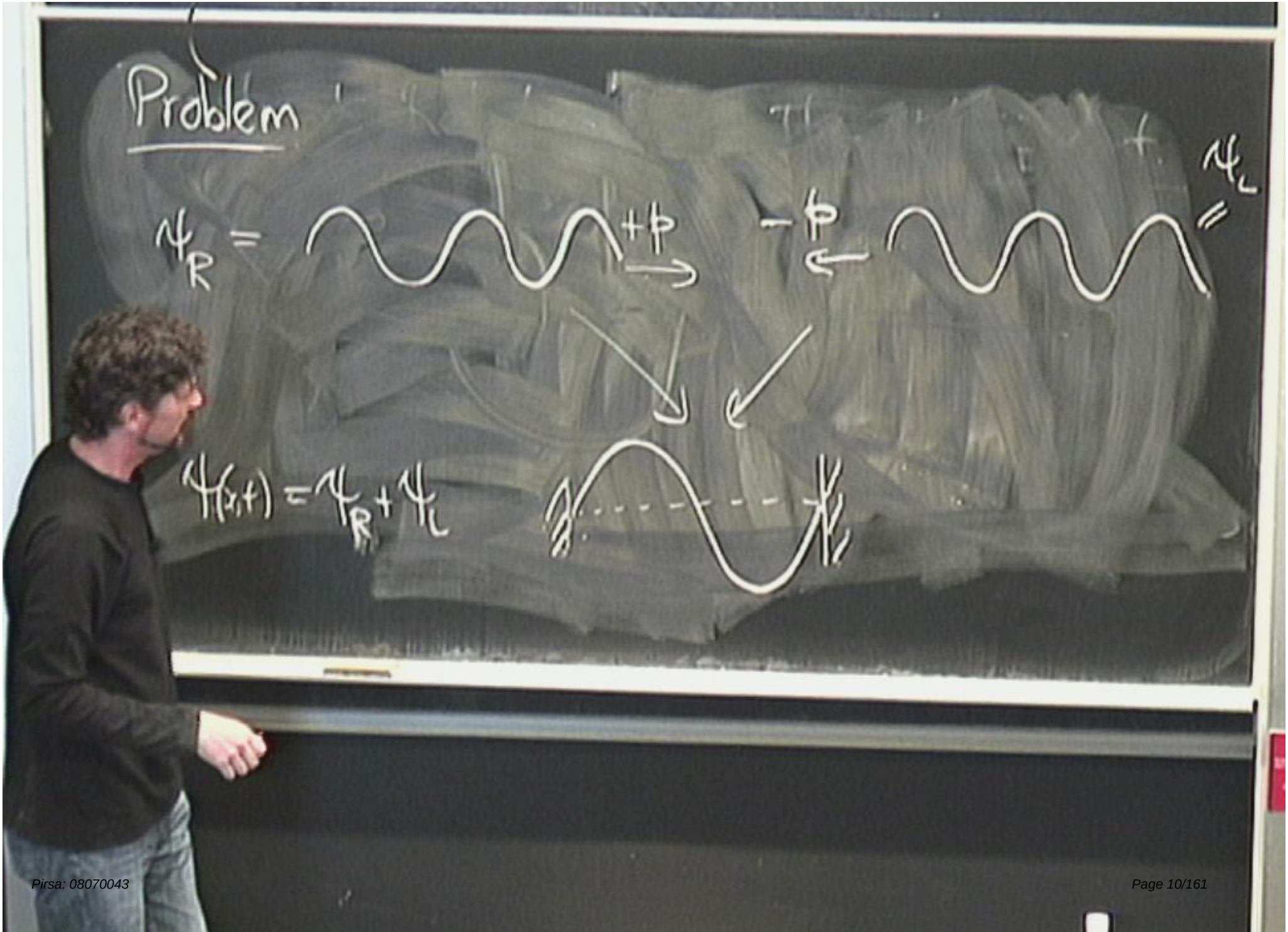

Problem
ψ_R =
+p
−p
ψ_L

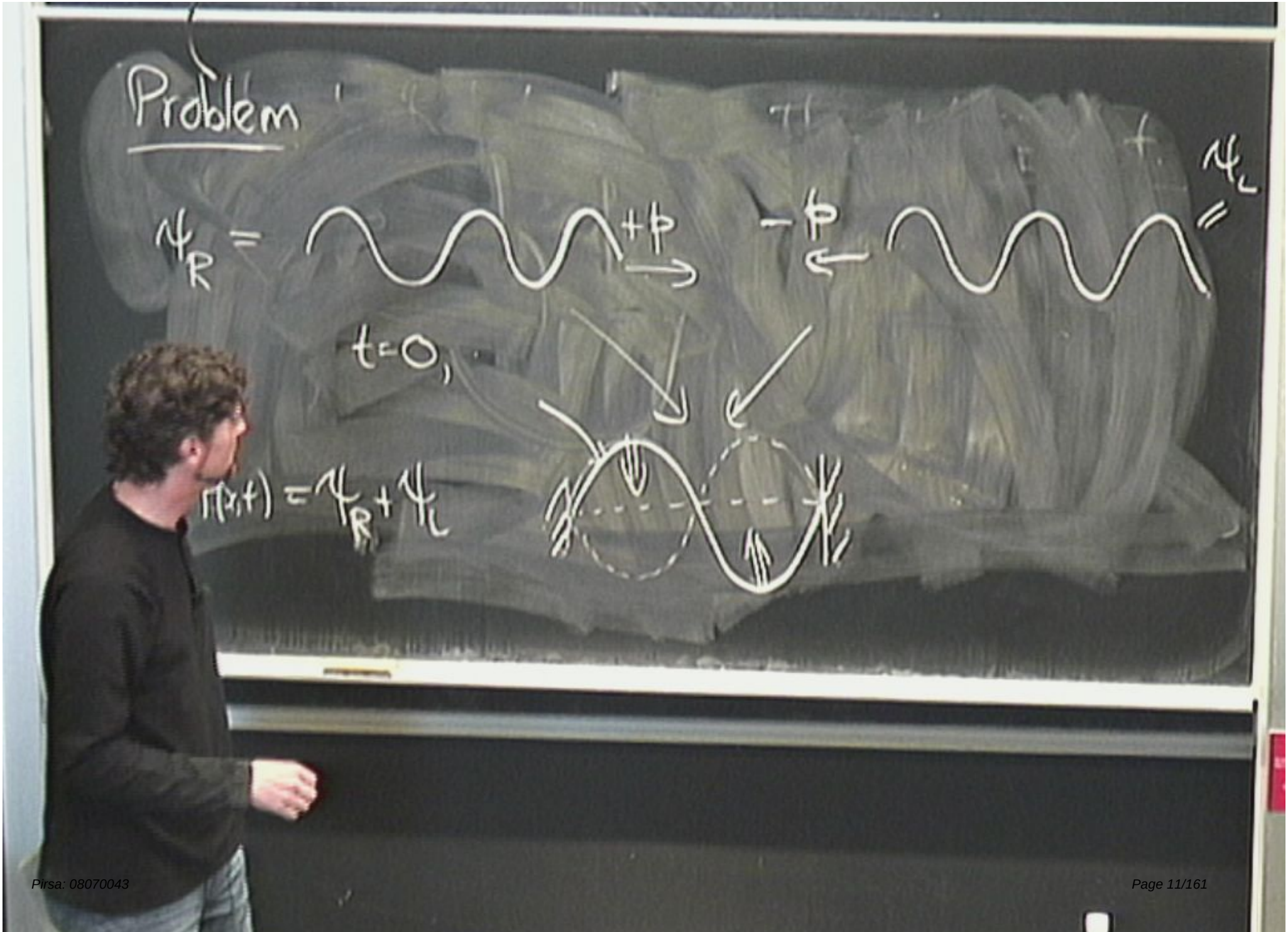

Problem
ψ_R =
+p
−p
ψ_L

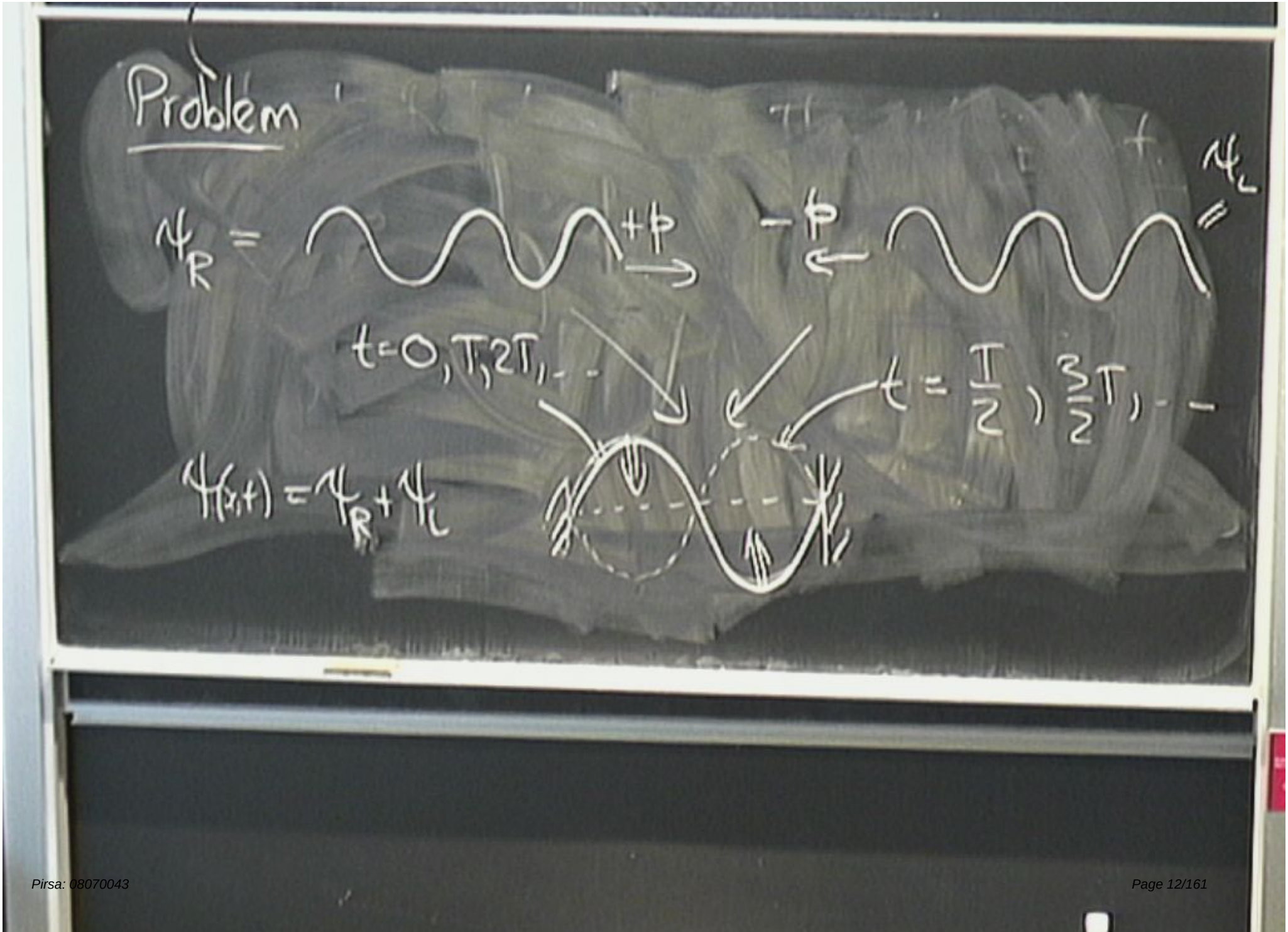

Problem
ψ_R =
+p
−p
ψ_L

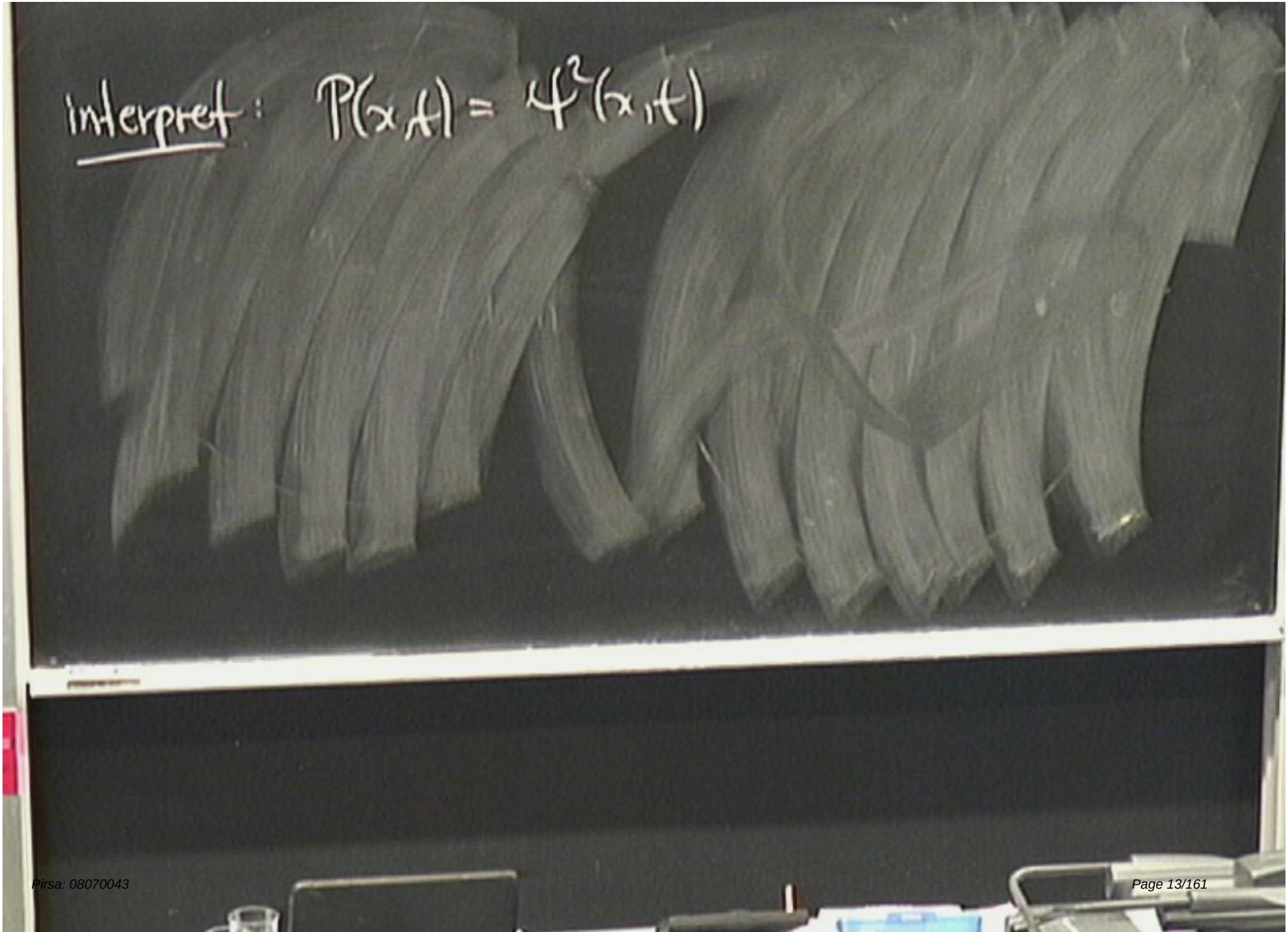

Problem
ψ_R =
+p
−p
ψ_L

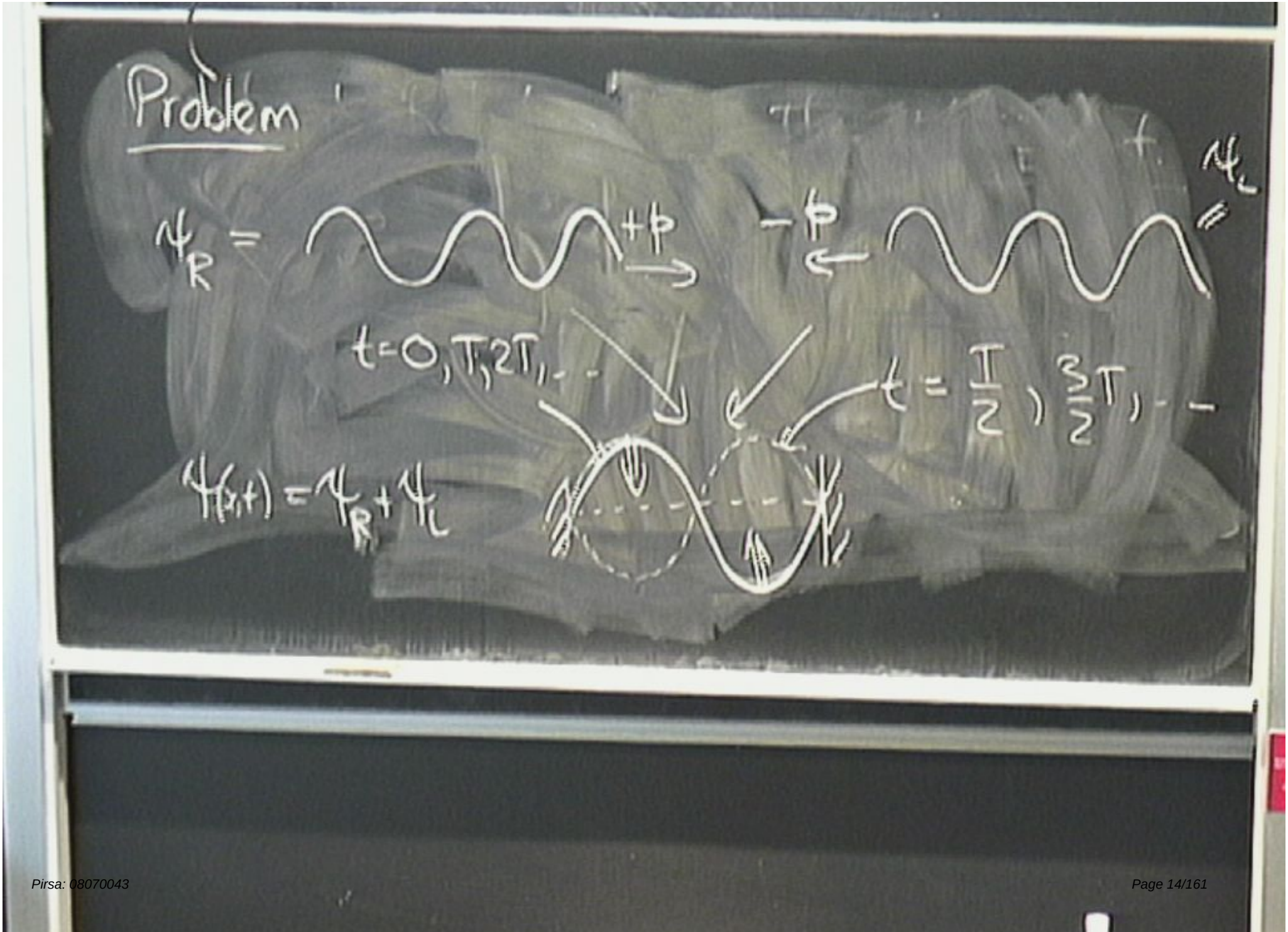

Problem
ψ_R =
+p
−p
ψ_L


Problem
ψ_R =
+p
−p
ψ_L
$\psi(x,t) = \psi_R + \psi_L$


Problem
ψ_R =
+p
−p
ψ_L
t=0,
$\Psi(x,t) = \psi_R + \psi_L$


Problem
ψ_R =
+p
−p
ψ_L
t=0, T, 2T, - -
t = T/2, 3/2 T, - -
$\psi(x,t) = \psi_R + \psi_L$


Interpret: $P(x,t) = \Psi^2(x,t)$


Problem
ψ_R =
+p
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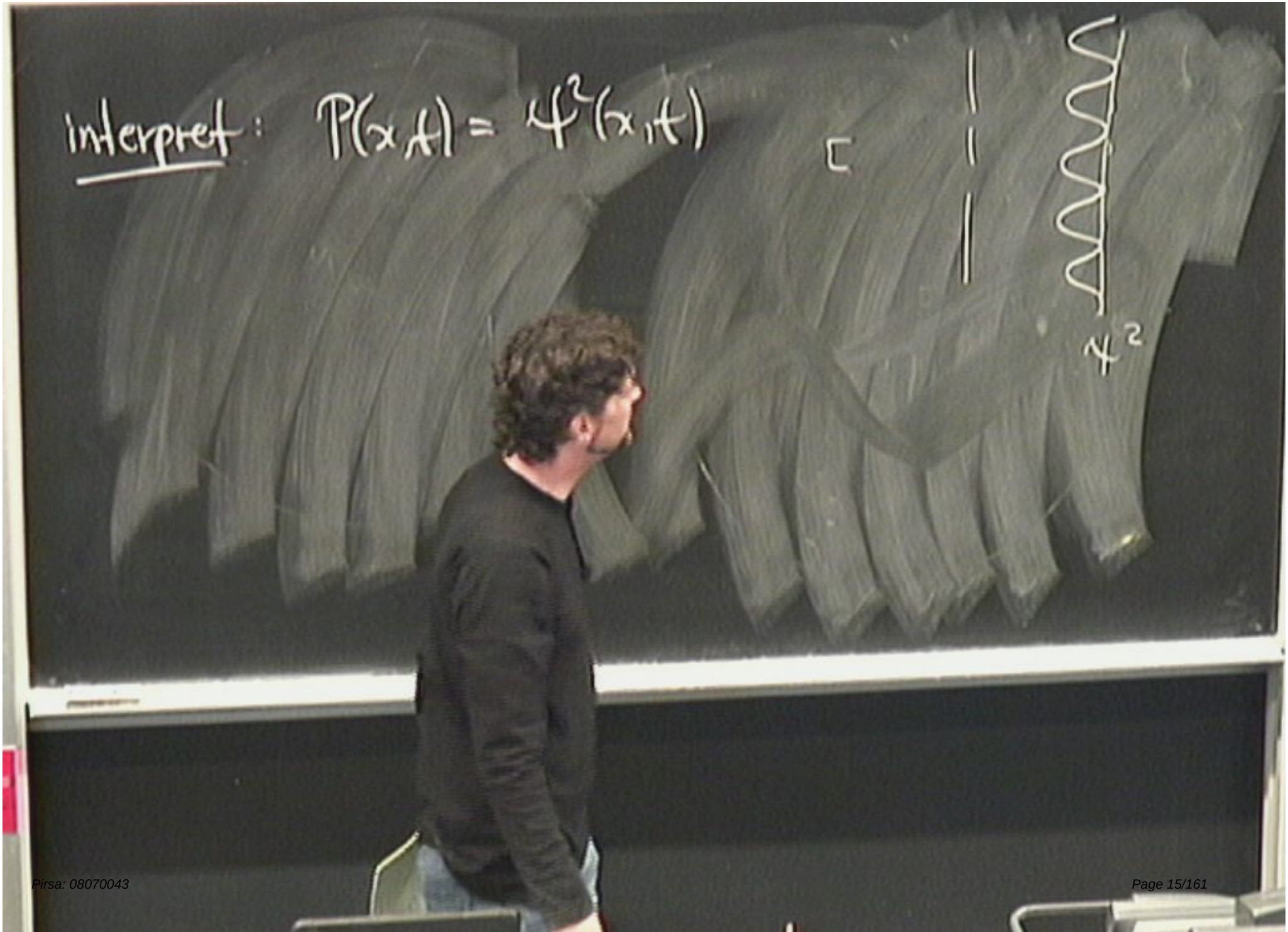
t=0, T, 2T, . . .
t = T/2, 3/2 T, . . .
$\psi(x,t) = \psi_R + \psi_L$


Interpret: $P(x,t) = \Psi^2(x,t)$
Ψ^2

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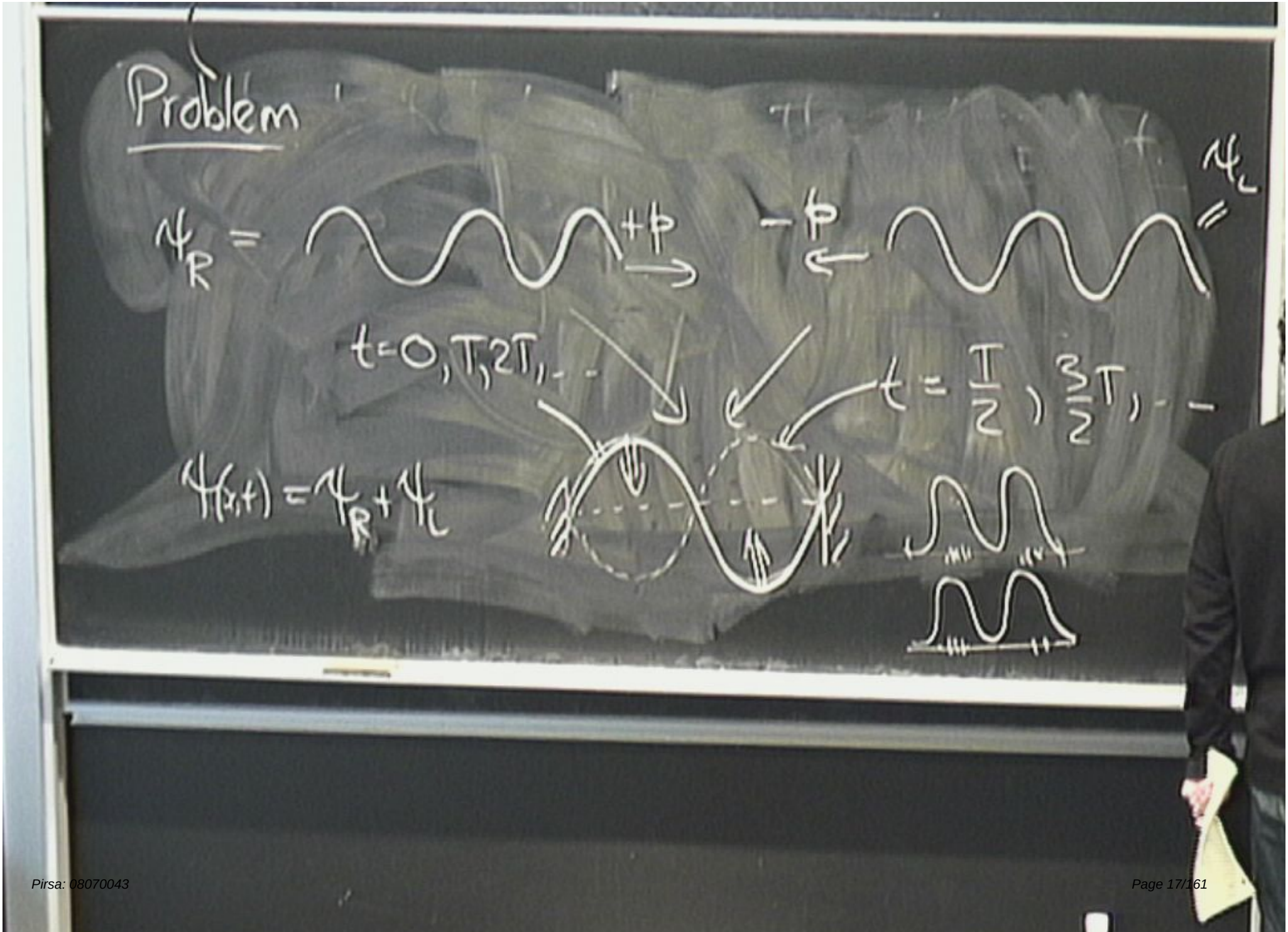
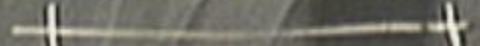
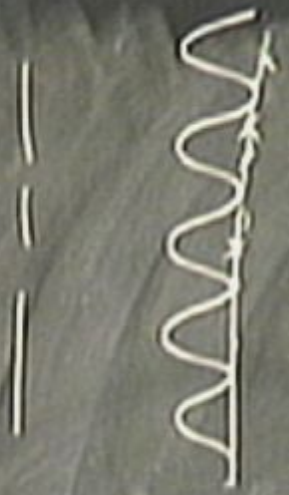
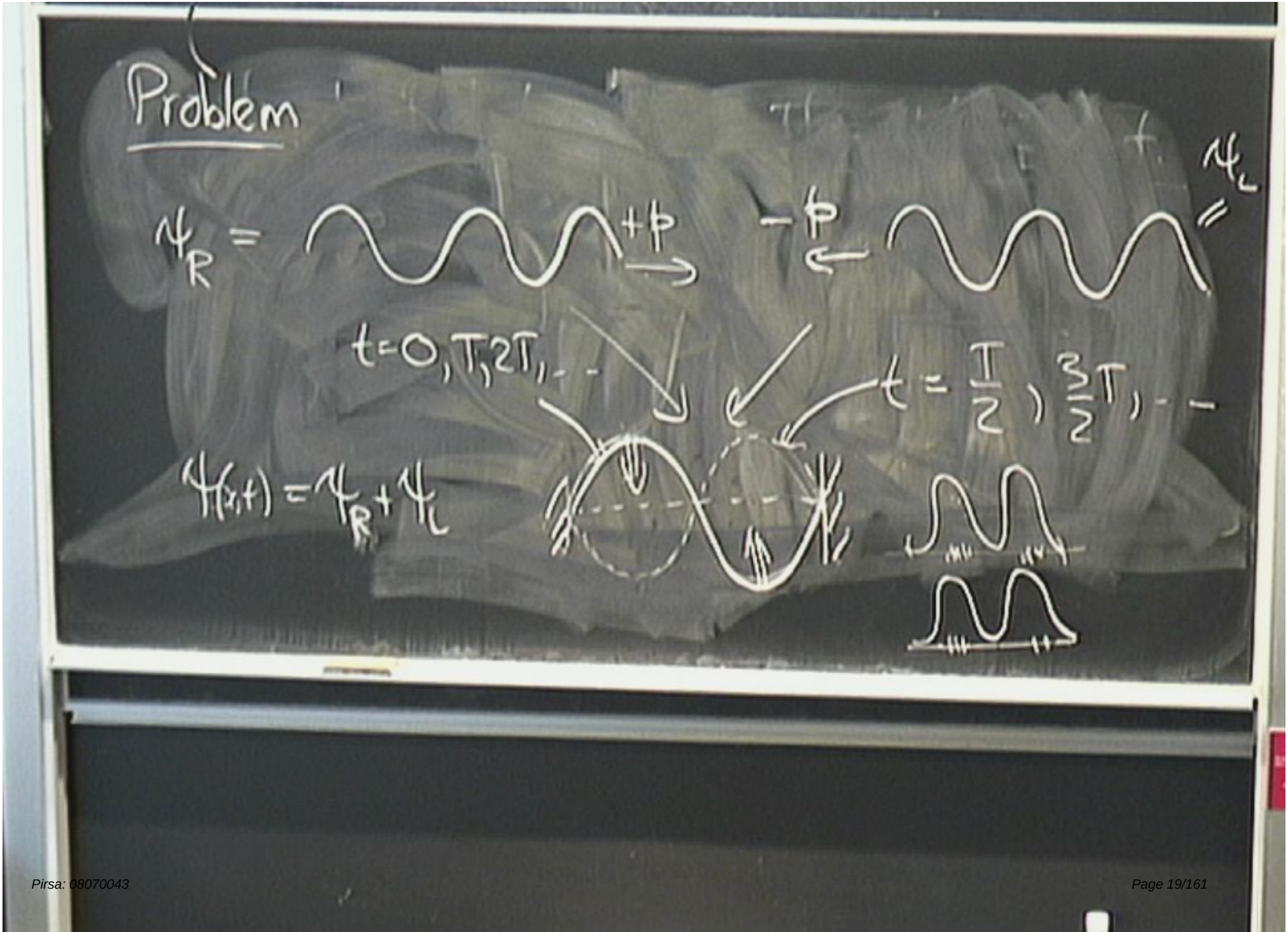

Problem
ψ_R =
+p
−p
ψ_L
t=0, T, 2T, - -
t = T/2, 3/2 T, - -
$\psi(x,t) = \psi_R + \psi_L$

Interpret: $P(x,t) = \psi^2(x,t)$

$t = \frac{T}{4}$ $\psi =$ 




Problem
ψ_R =
+p
−p
ψ_L
t=0, T, 2T, - -
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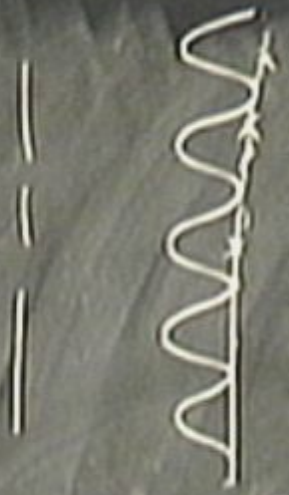
$\psi(x,t) = \psi_R + \psi_L$

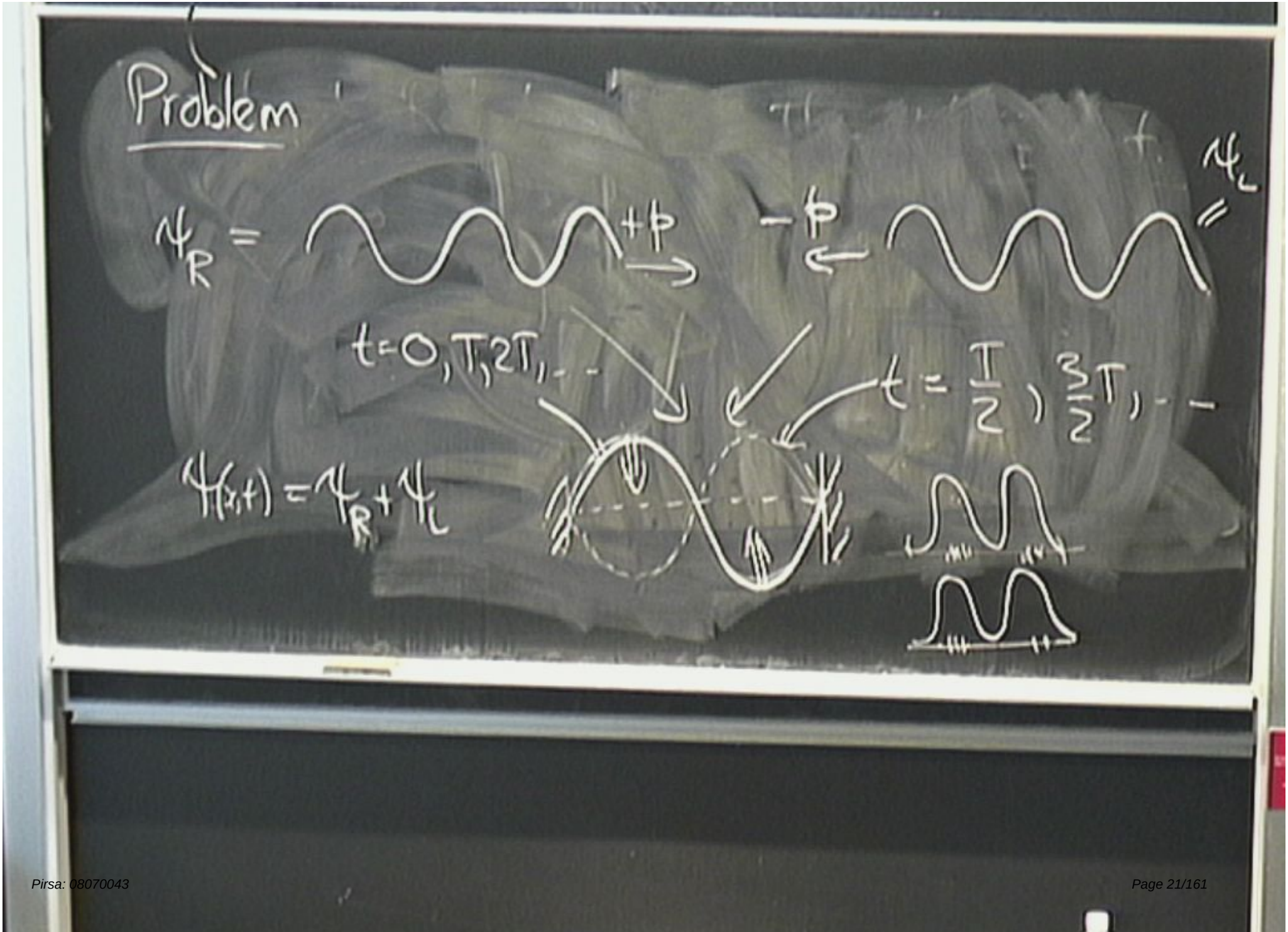
Interpret: $P(x,t) = \psi^2(x,t)$

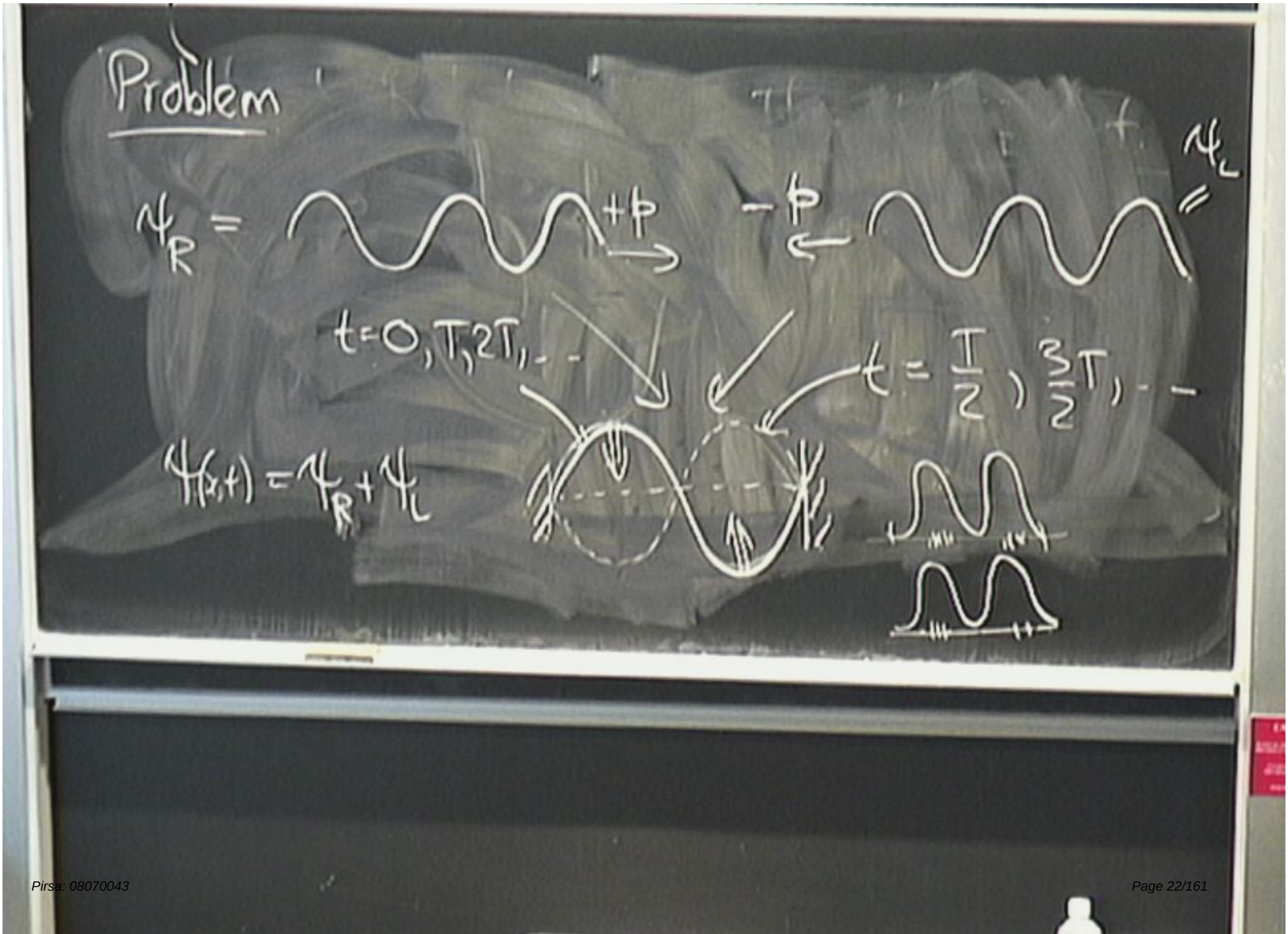
$t = \frac{T}{4}$ $\psi =$ 

$P =$  zero



$\psi^2 = P$


Problem
ψ_R =
+p
−p
ψ_L
t=0, T, 2T, - -
t = T/2, 3/2 T, - -
$\psi(x,t) = \psi_R + \psi_L$


Problem
ψ_R =
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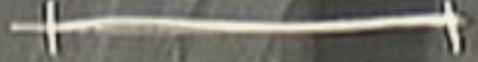
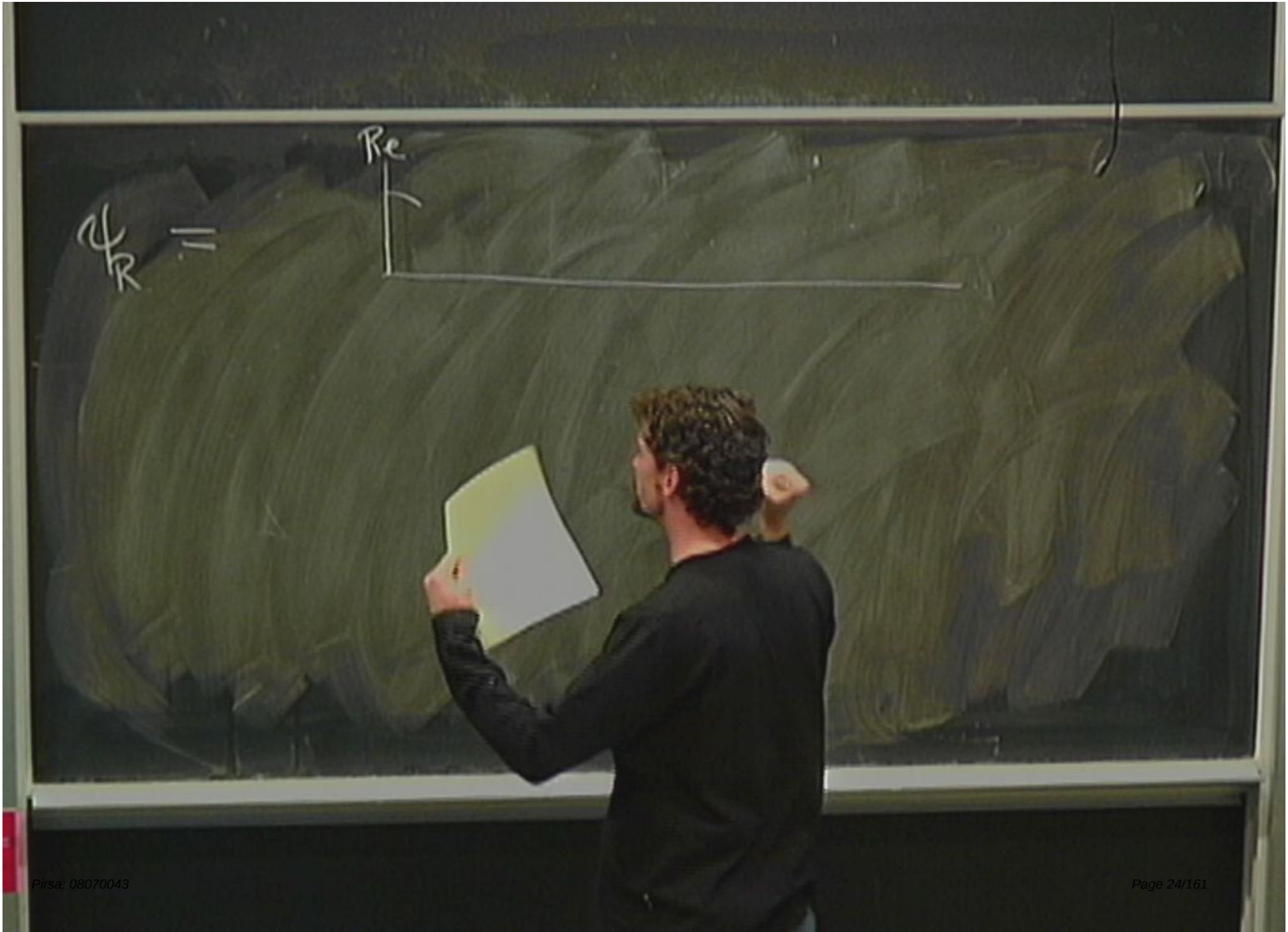
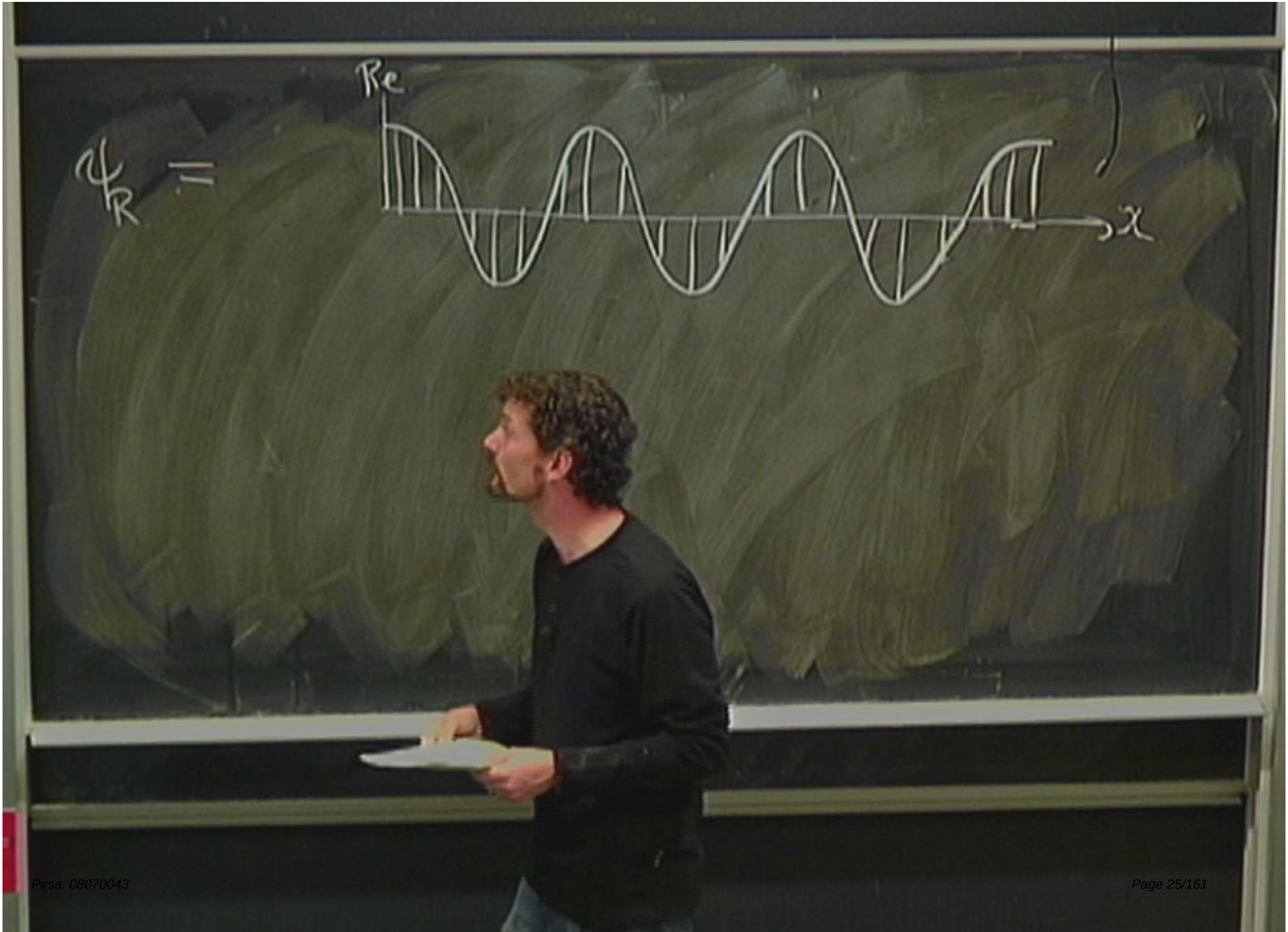
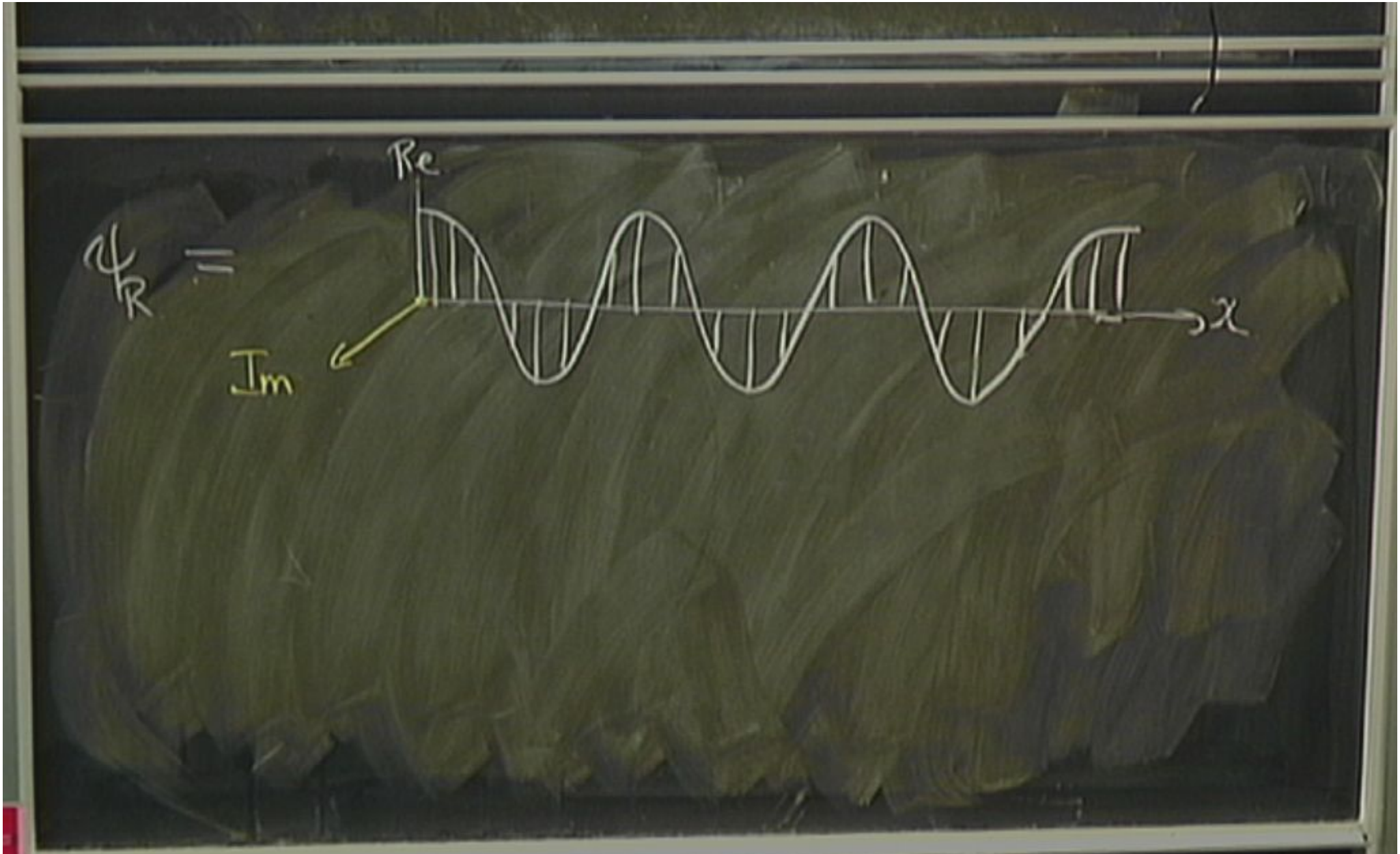
$t = \frac{T}{4}$ $\psi =$ 

$P =$  zero

ψ_R, ψ_L ... are complex travelling waves.


Re
ψ_R =

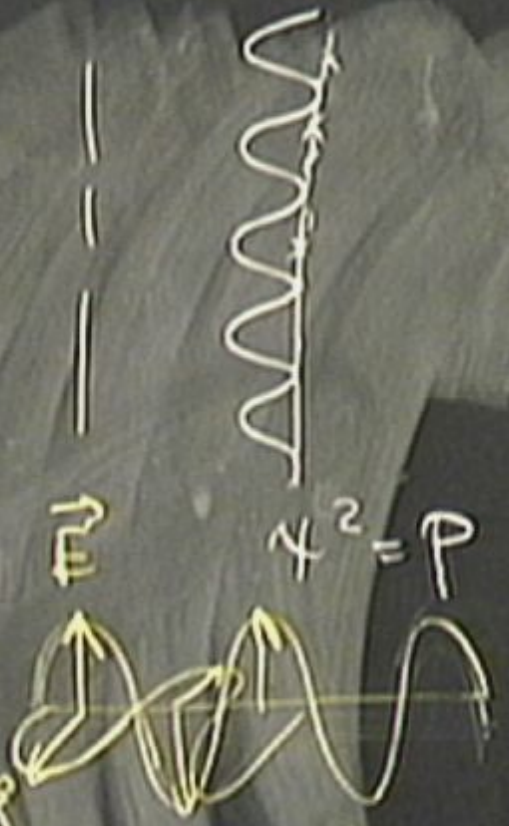

Re
$\psi_R =$
x


$\psi_R =$
Re
Im
x

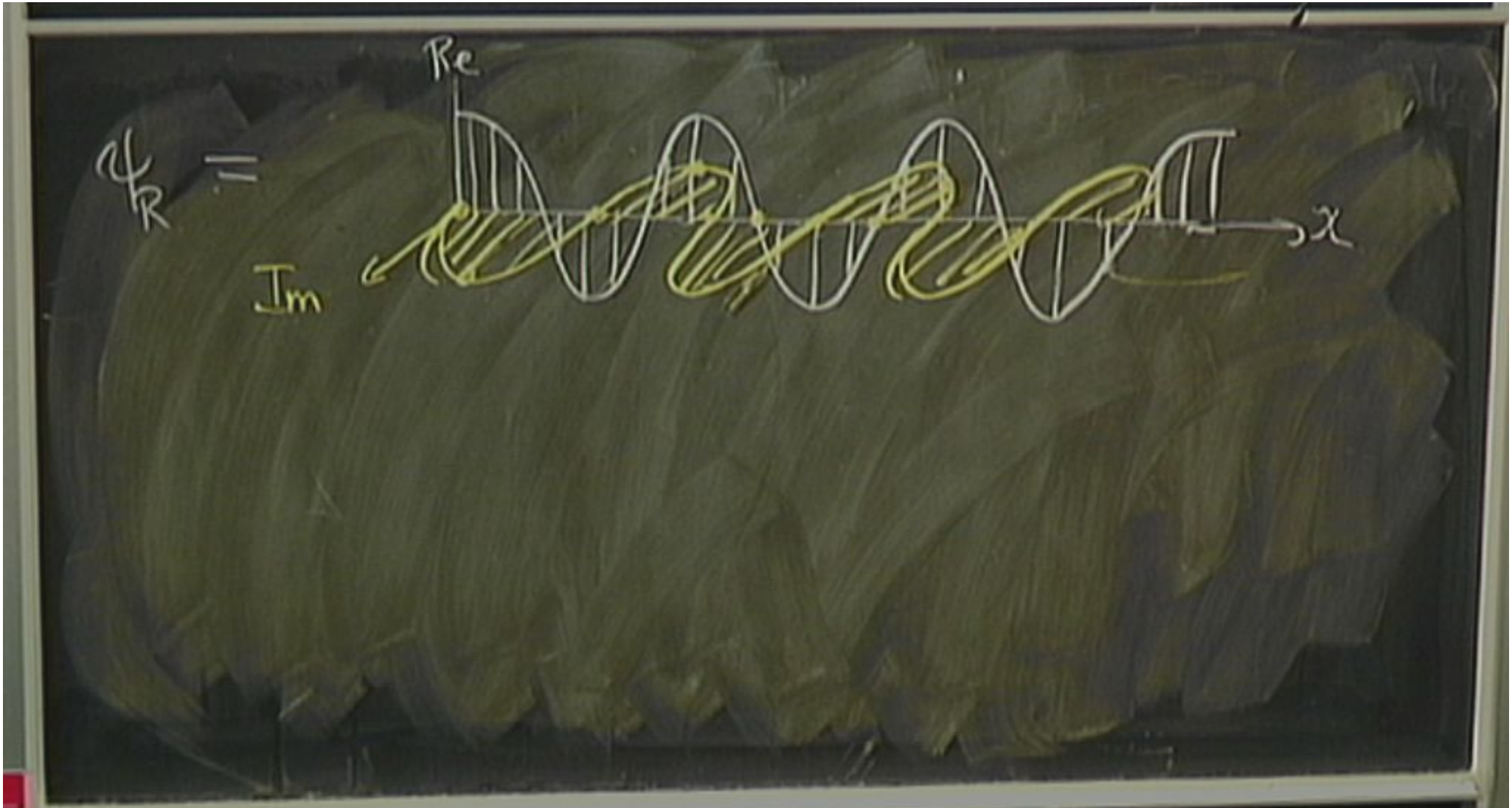
interpret: $P(x,t) = \psi^2(x,t)$

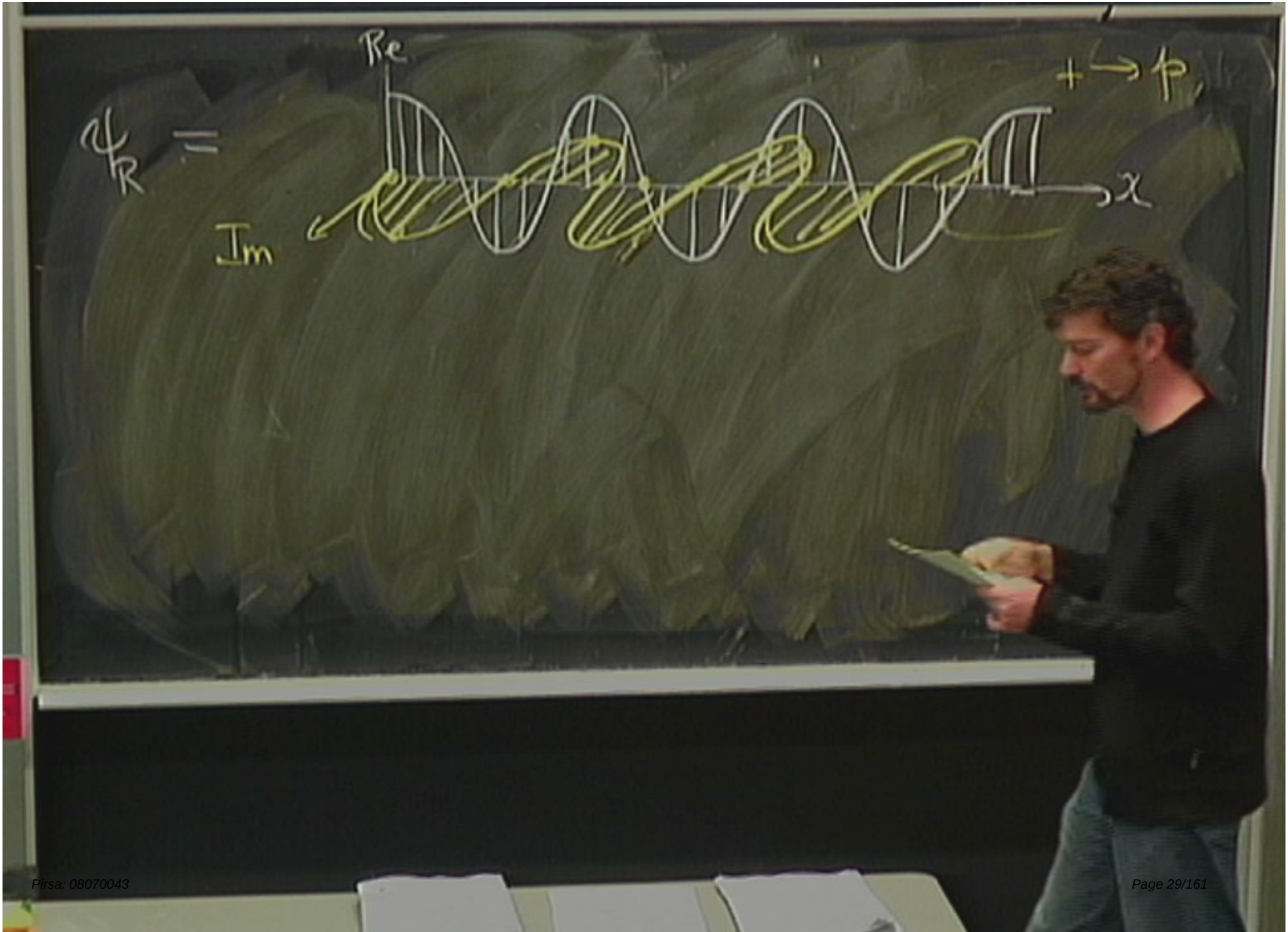
$t = \frac{T}{4}$ $\psi =$ 

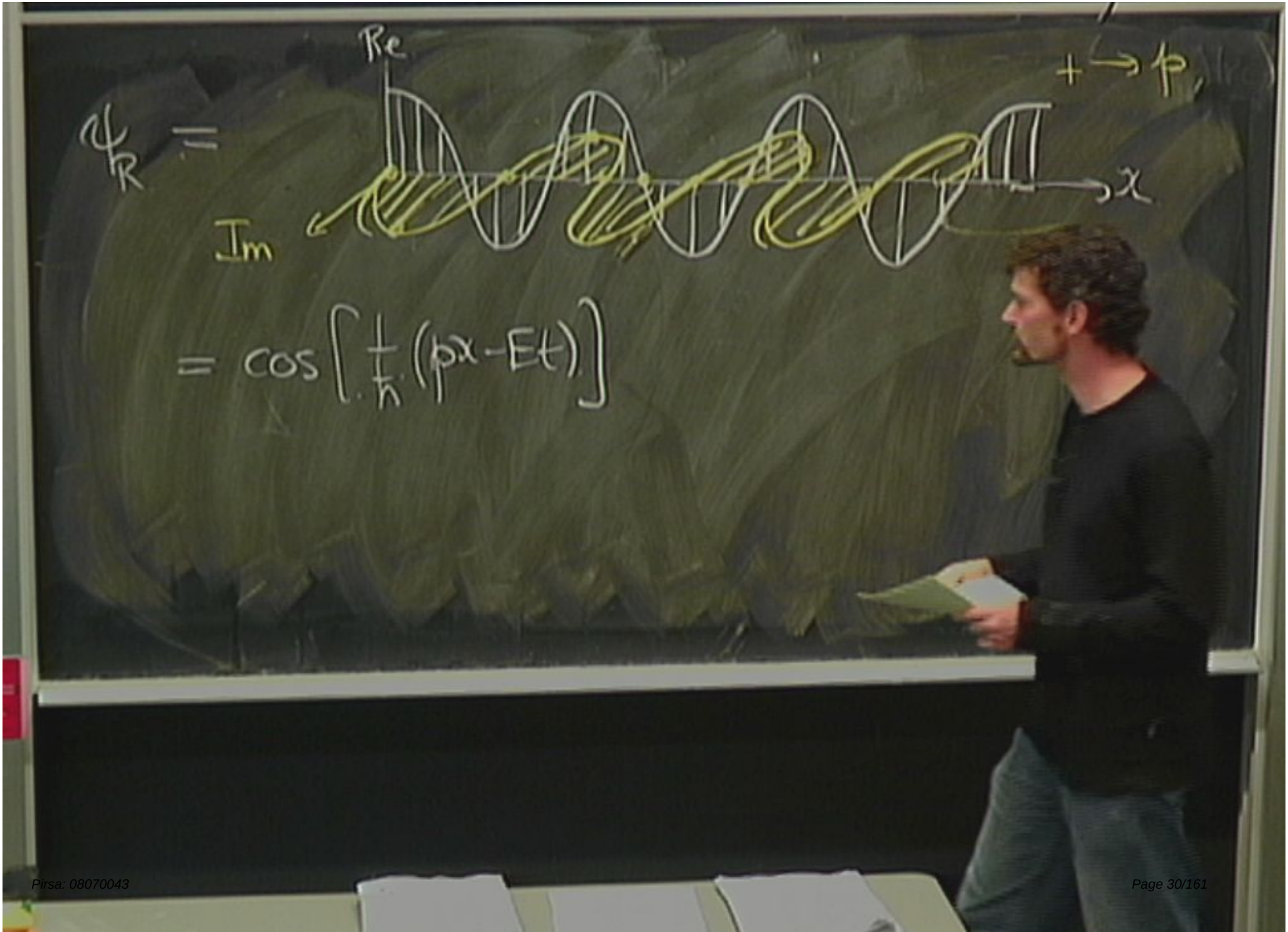
$P =$  zero



ψ_R, ψ_L ... are complex travelling waves.


Re
ψ_R =
Im
x


Re
ψ_R =
Im
x


Re
+ → p
$\psi_R =$
x
Im
$= \cos\left[\frac{1}{\hbar}(px - Et)\right]$

$\Psi_R =$

$+ \rightarrow p$

$\hbar = \frac{h}{2\pi}$

$= \cos\left[\frac{1}{\hbar}(px - Et)\right] + i \sin\left[\frac{1}{\hbar}(px - Et)\right]$

$= e^{\frac{i}{\hbar}(px - Et)}$

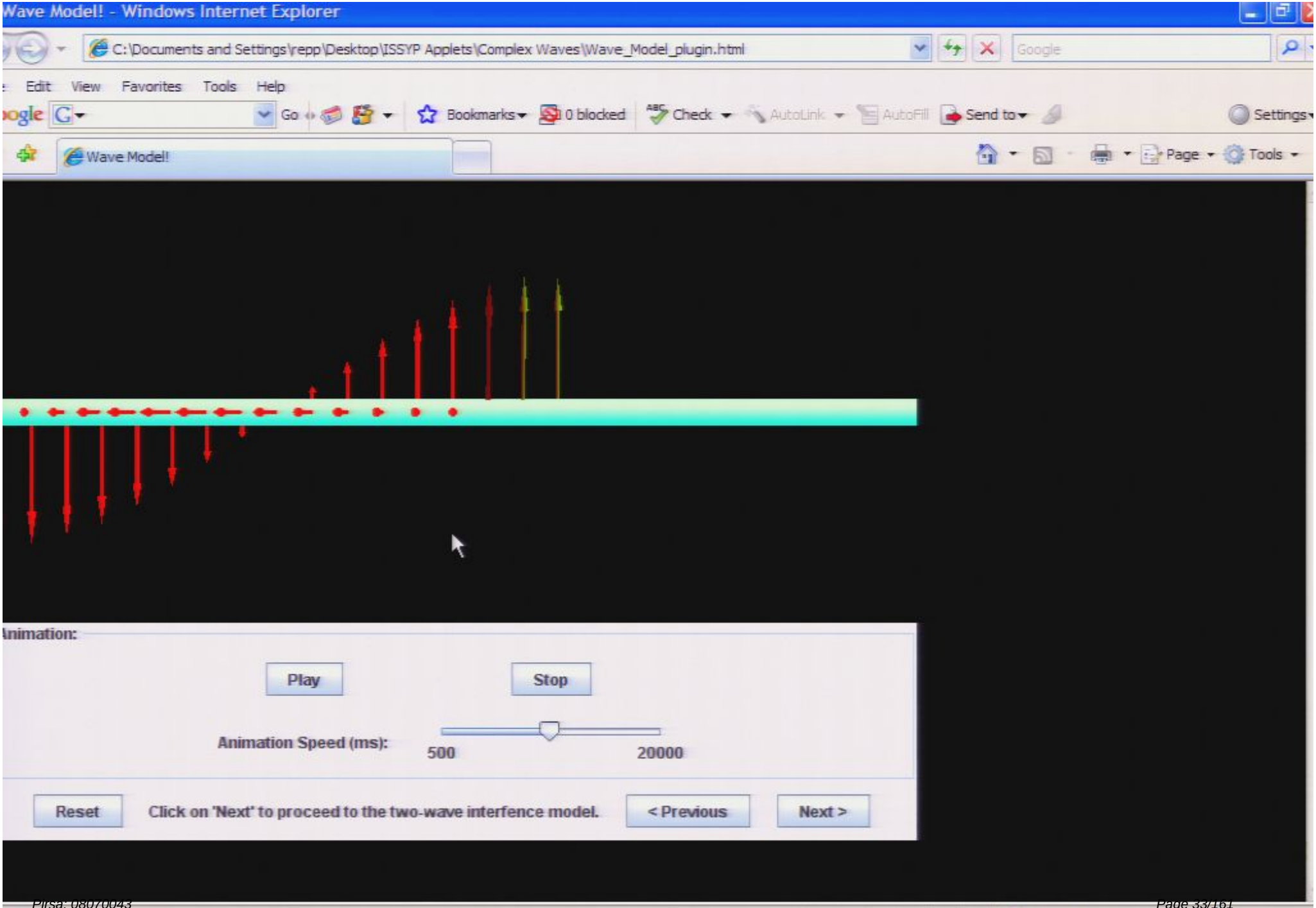
$\hbar = \frac{h}{2\pi}$

$\psi_R =$ Re

Im

$= \cos\left[\frac{1}{\hbar}(px - Et)\right] + i \sin\left[\frac{1}{\hbar}(px - Et)\right]$

$= e^{\frac{i}{\hbar}(px - Et)}$ = complex travelling wave.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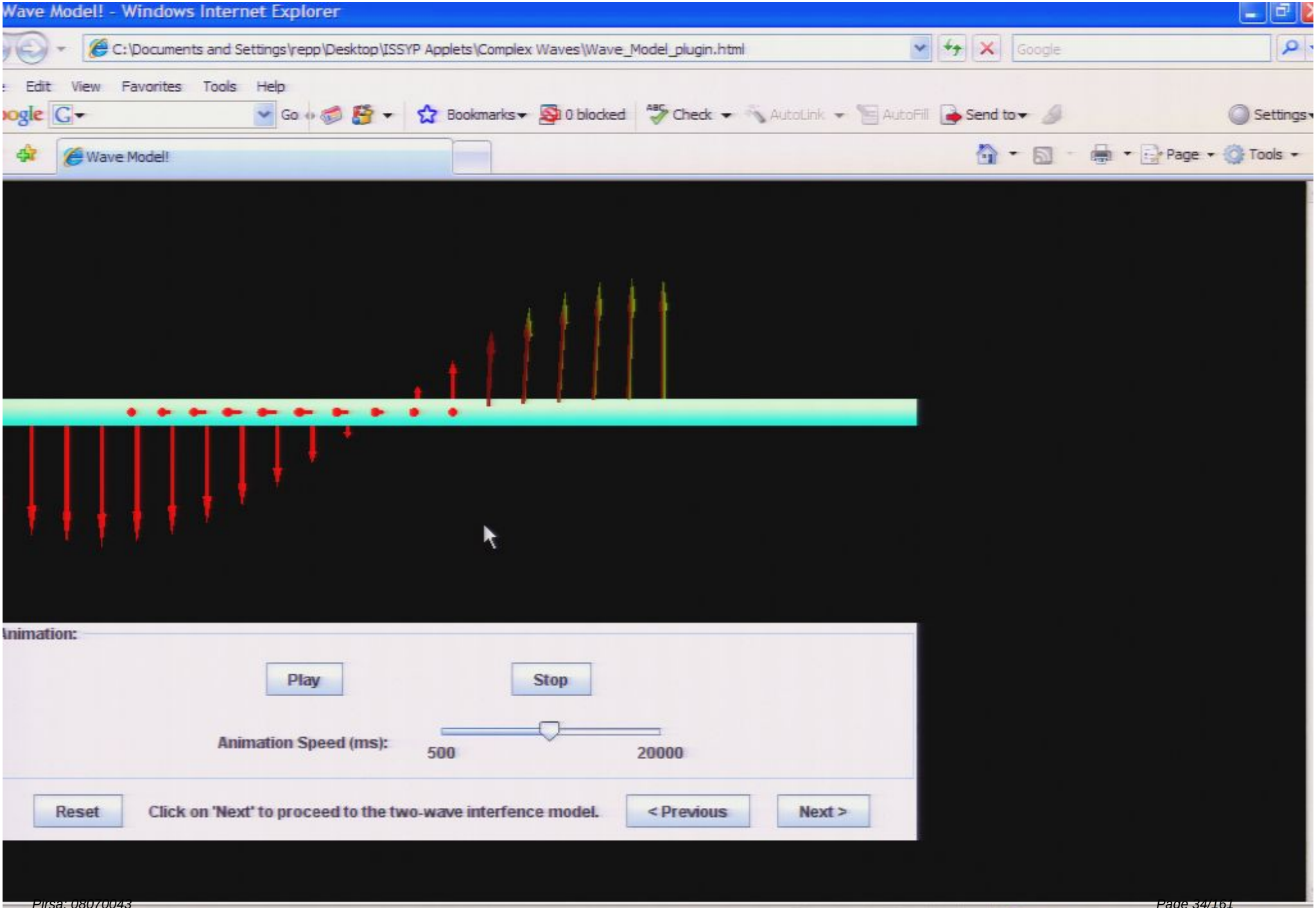
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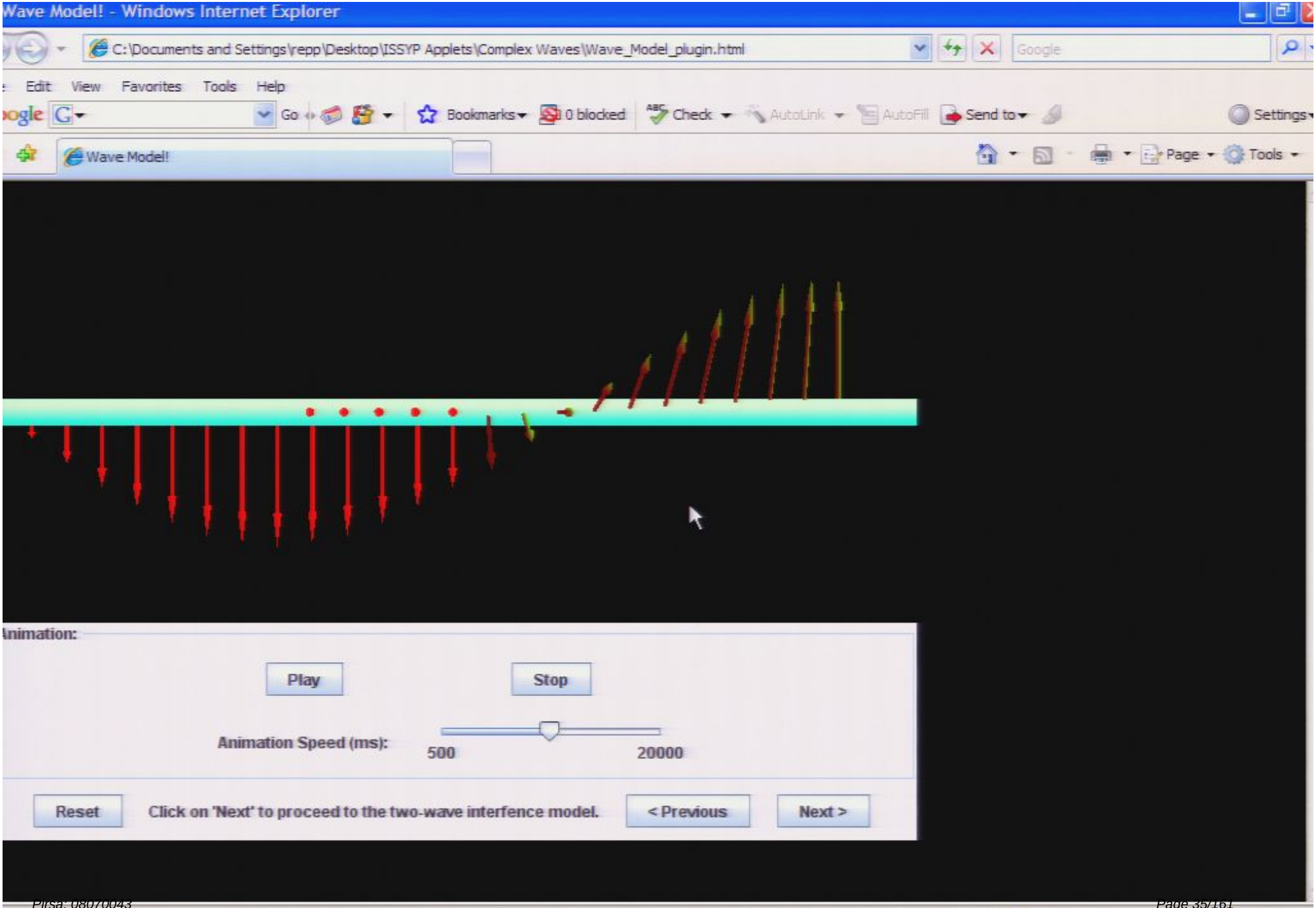
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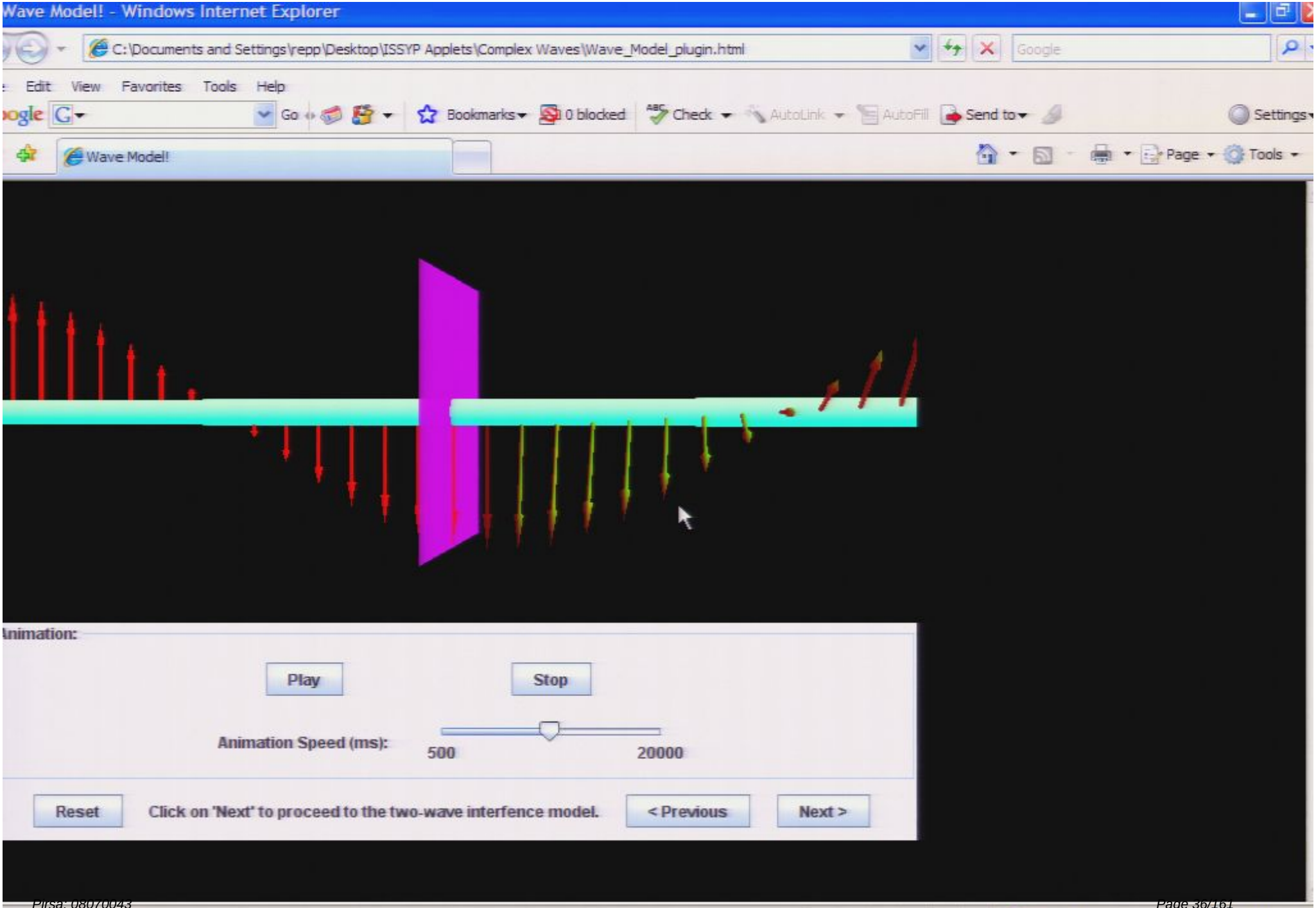
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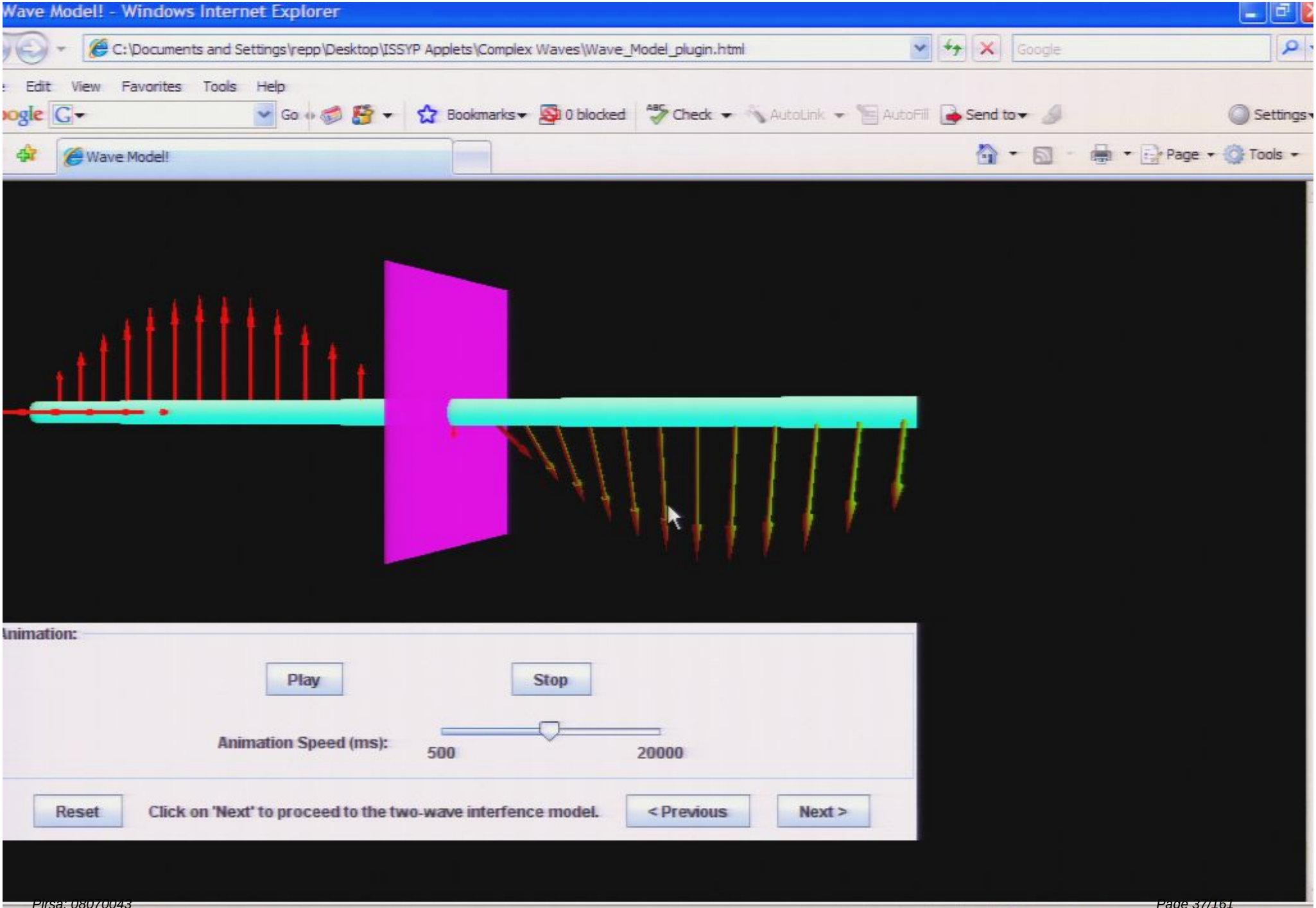
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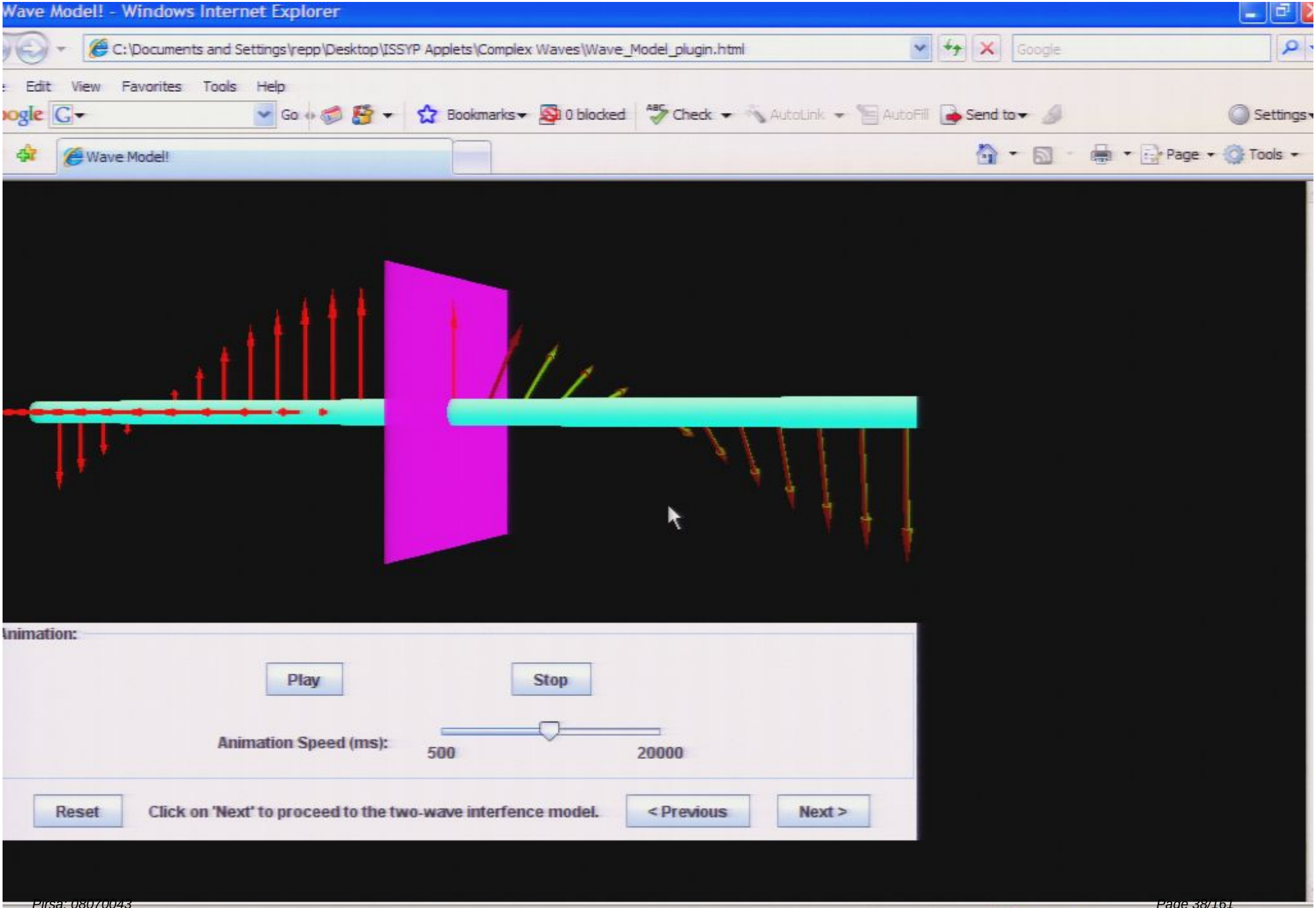
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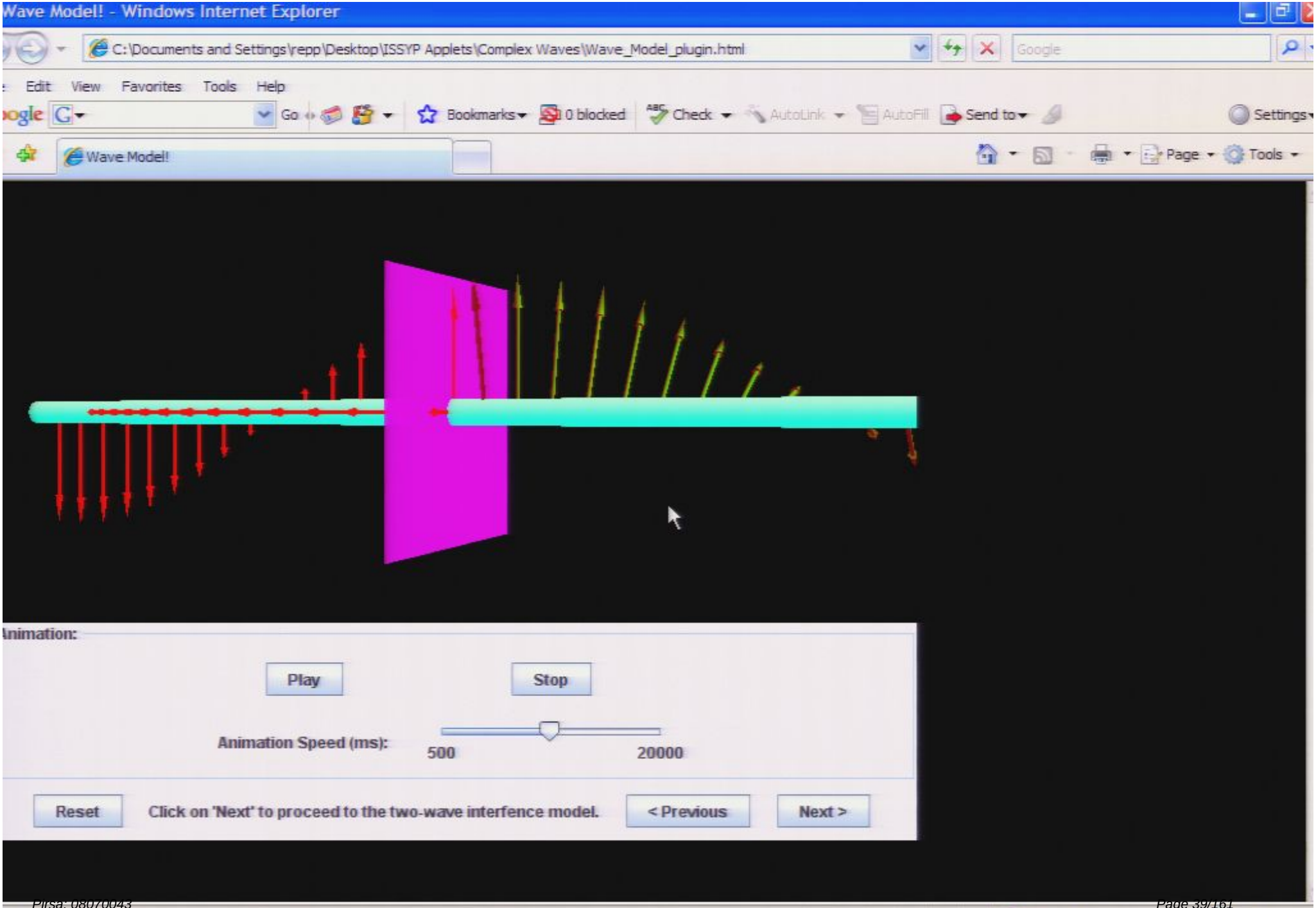
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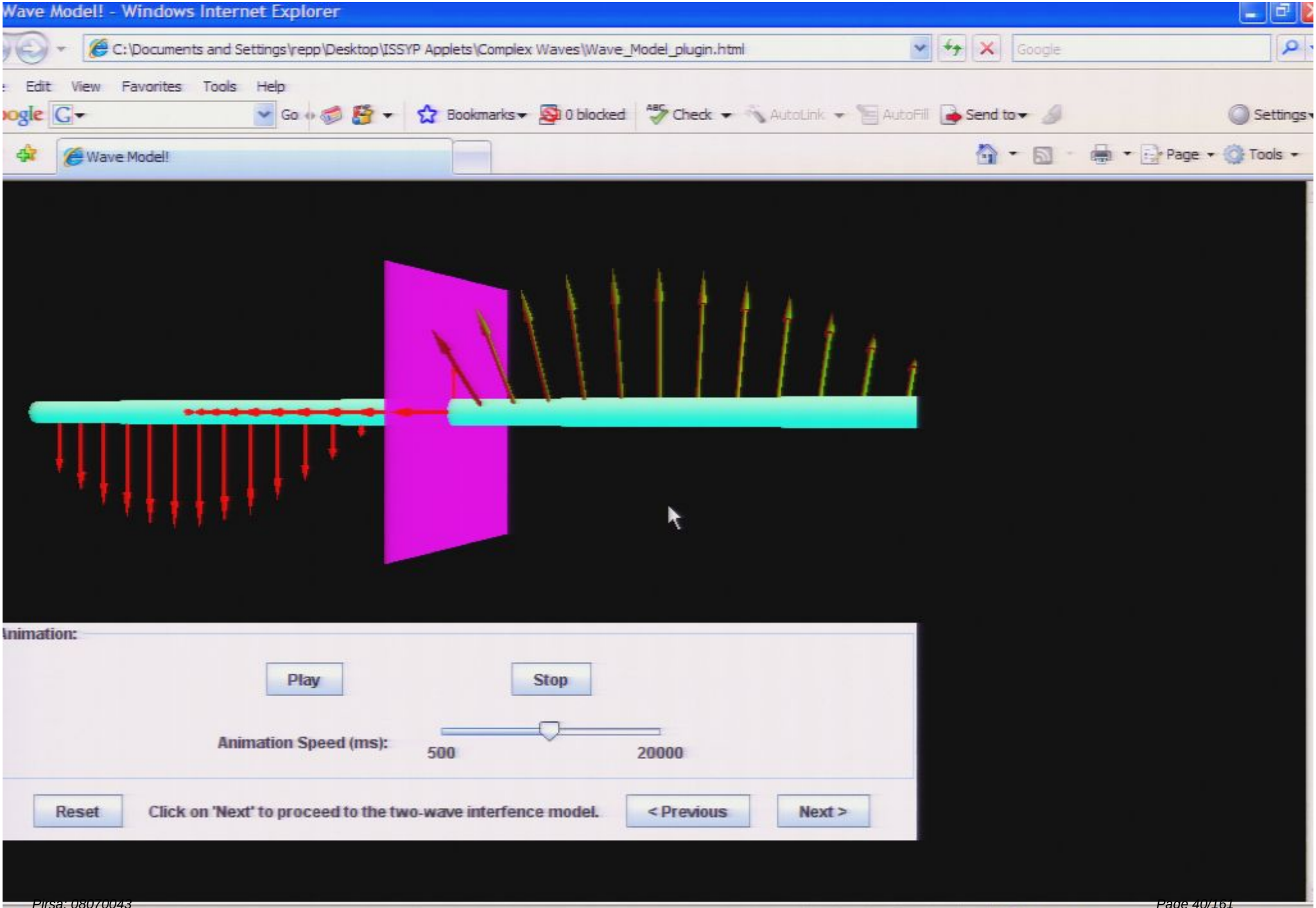
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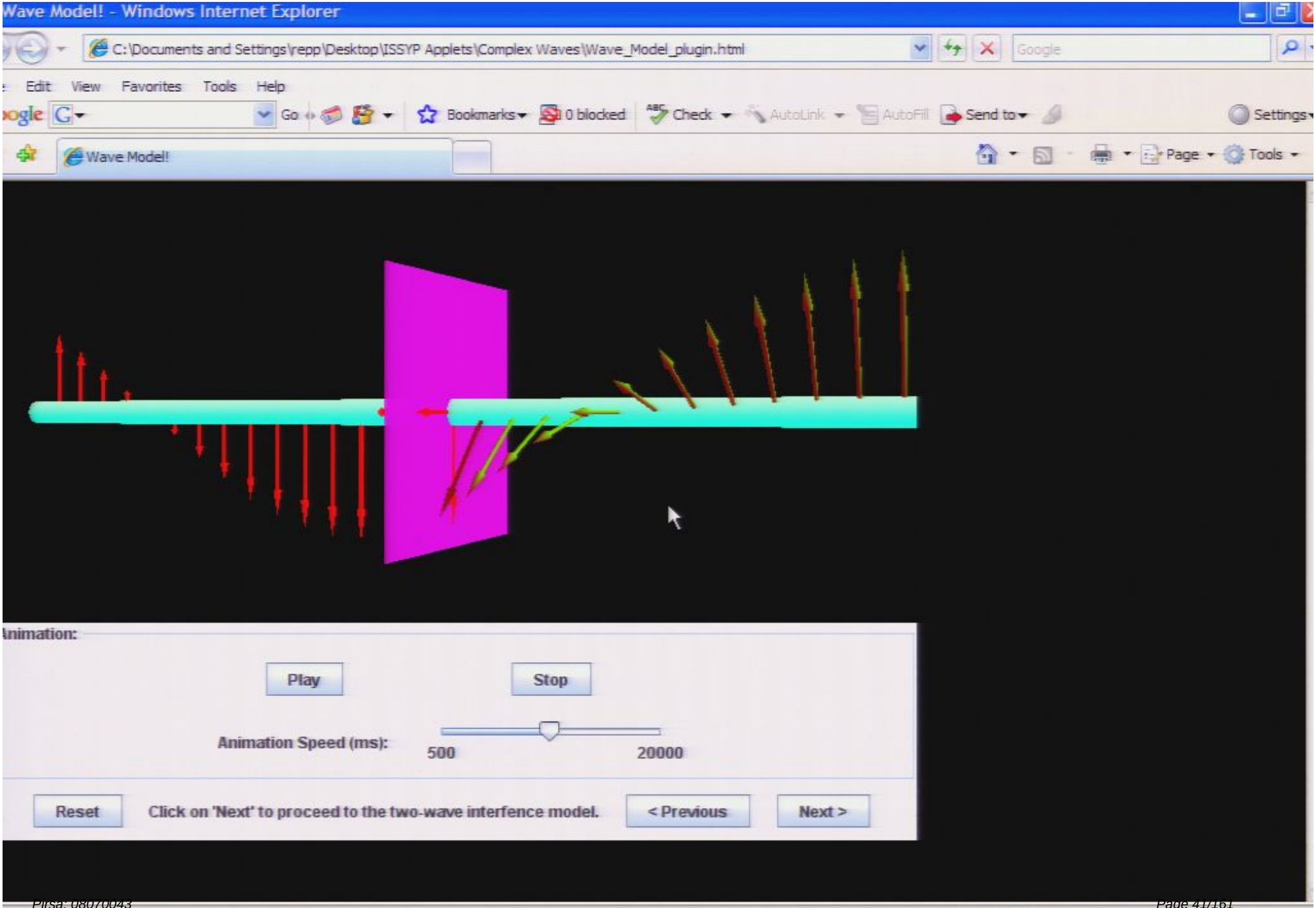
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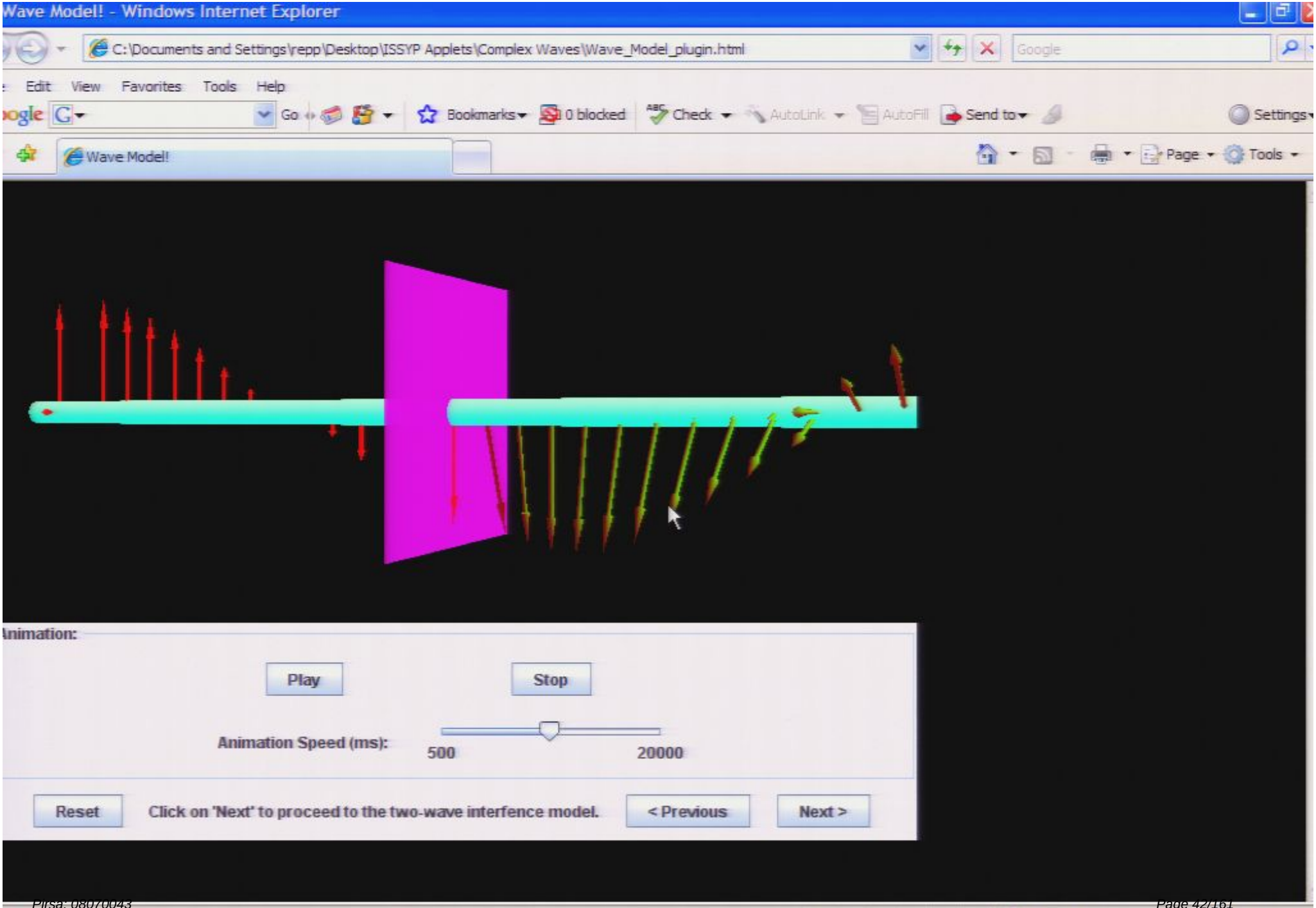
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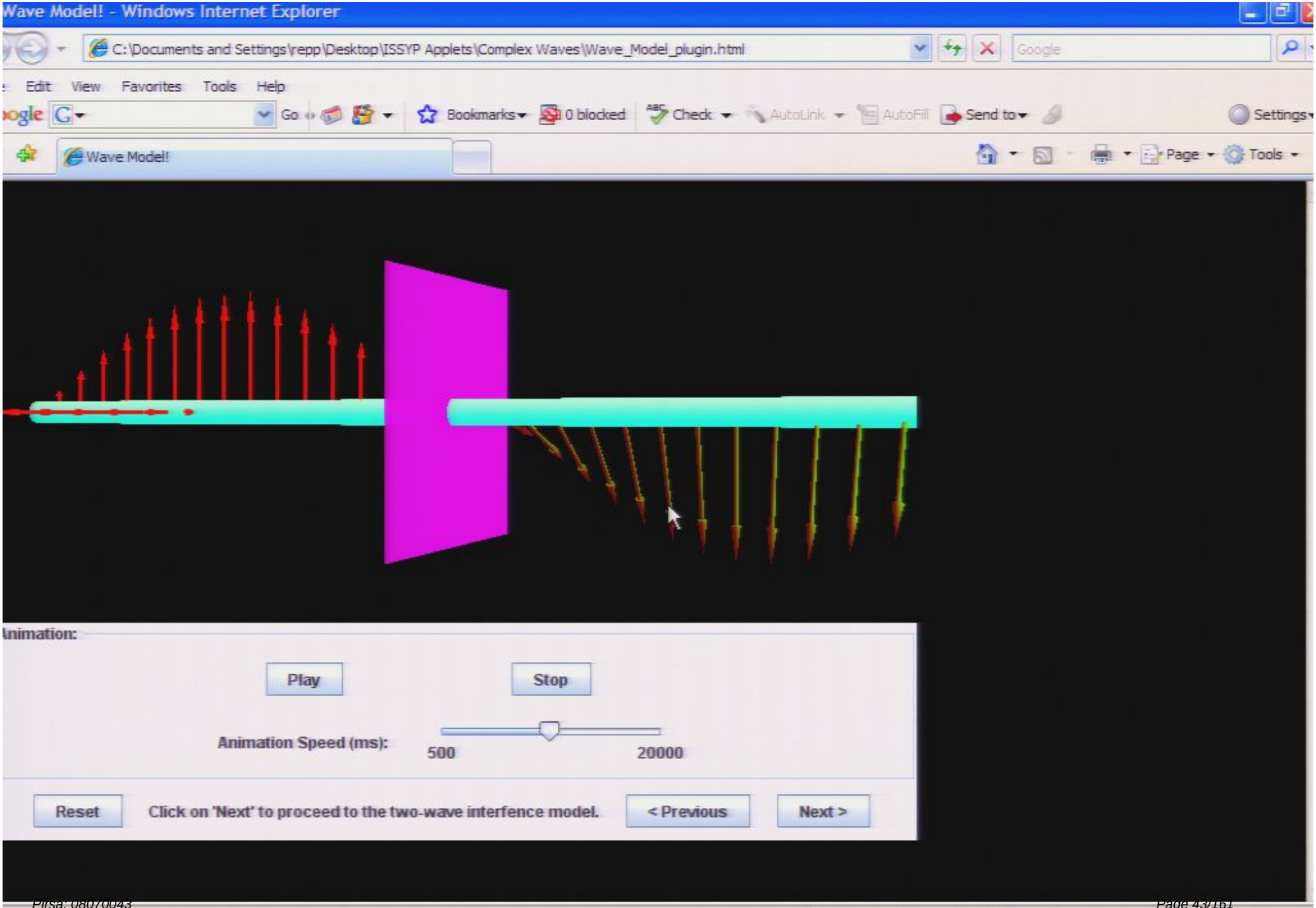
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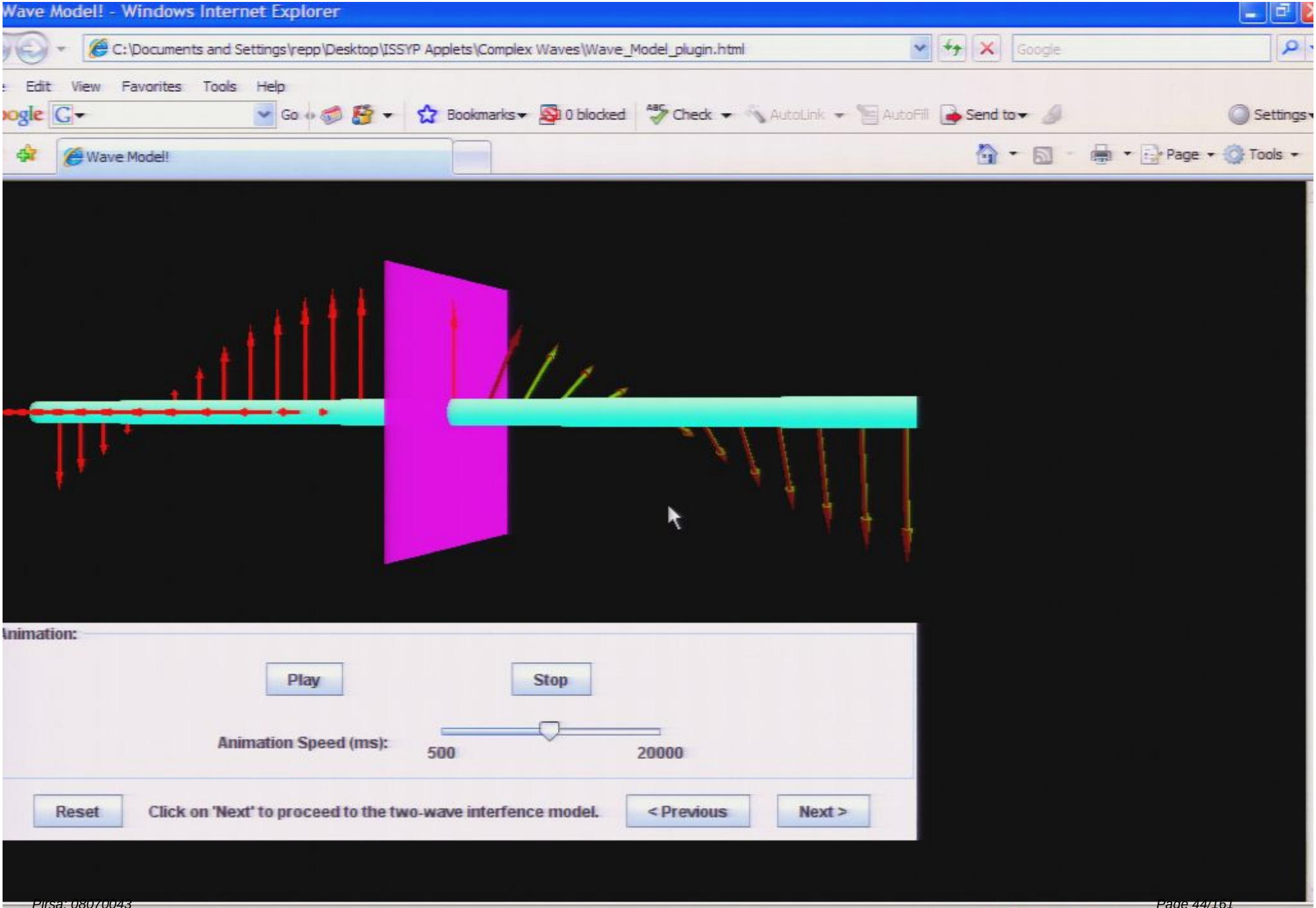
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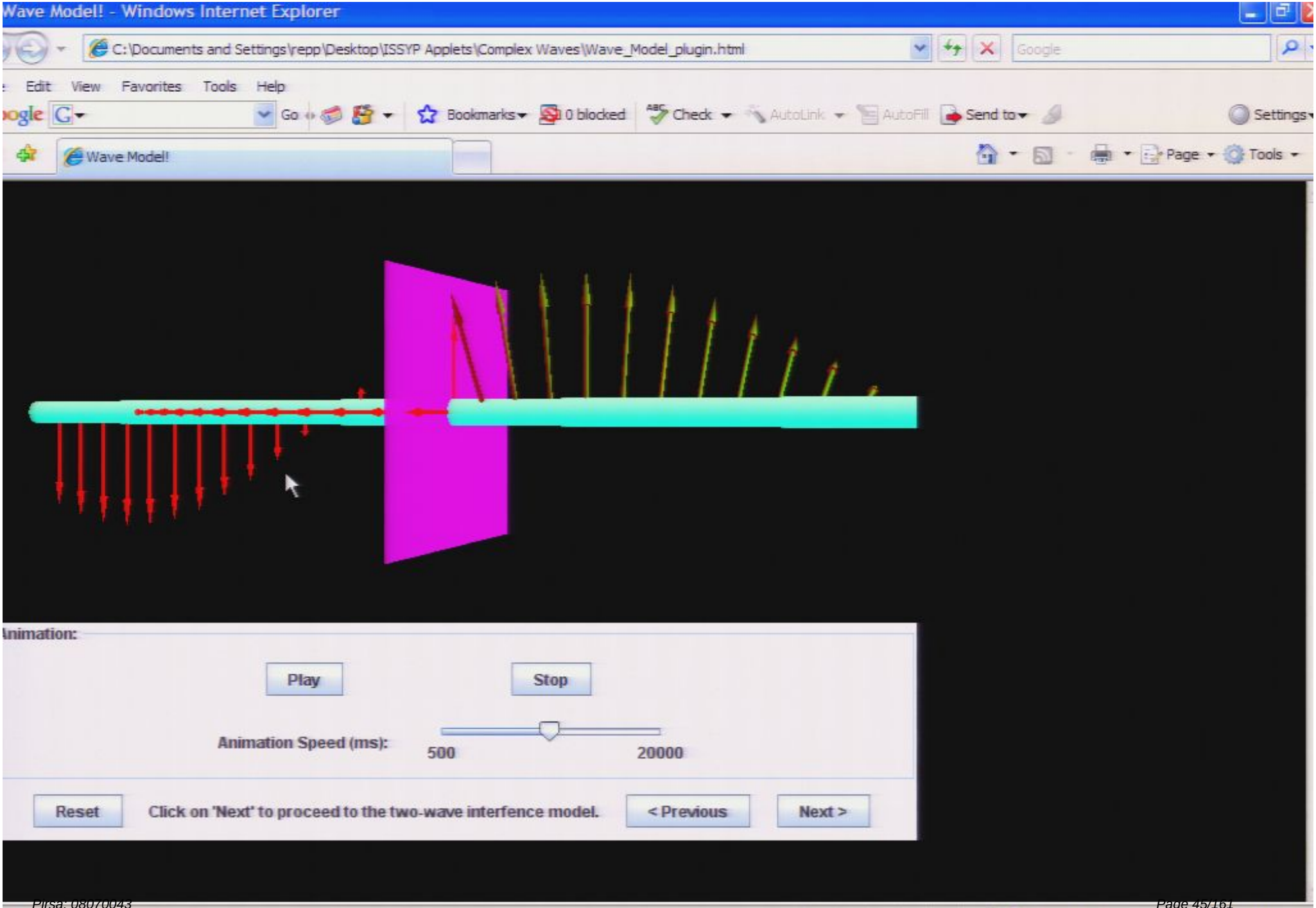
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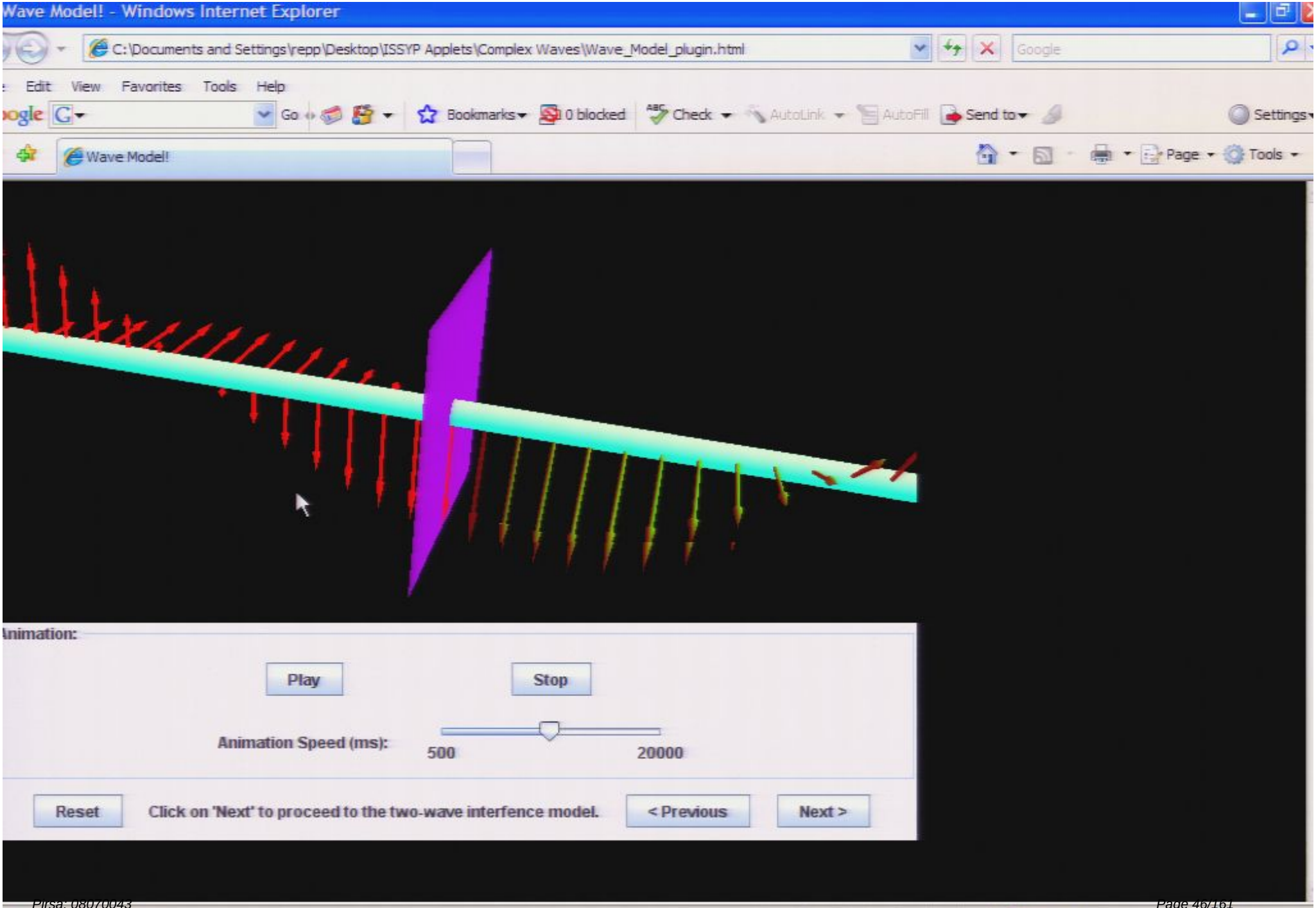
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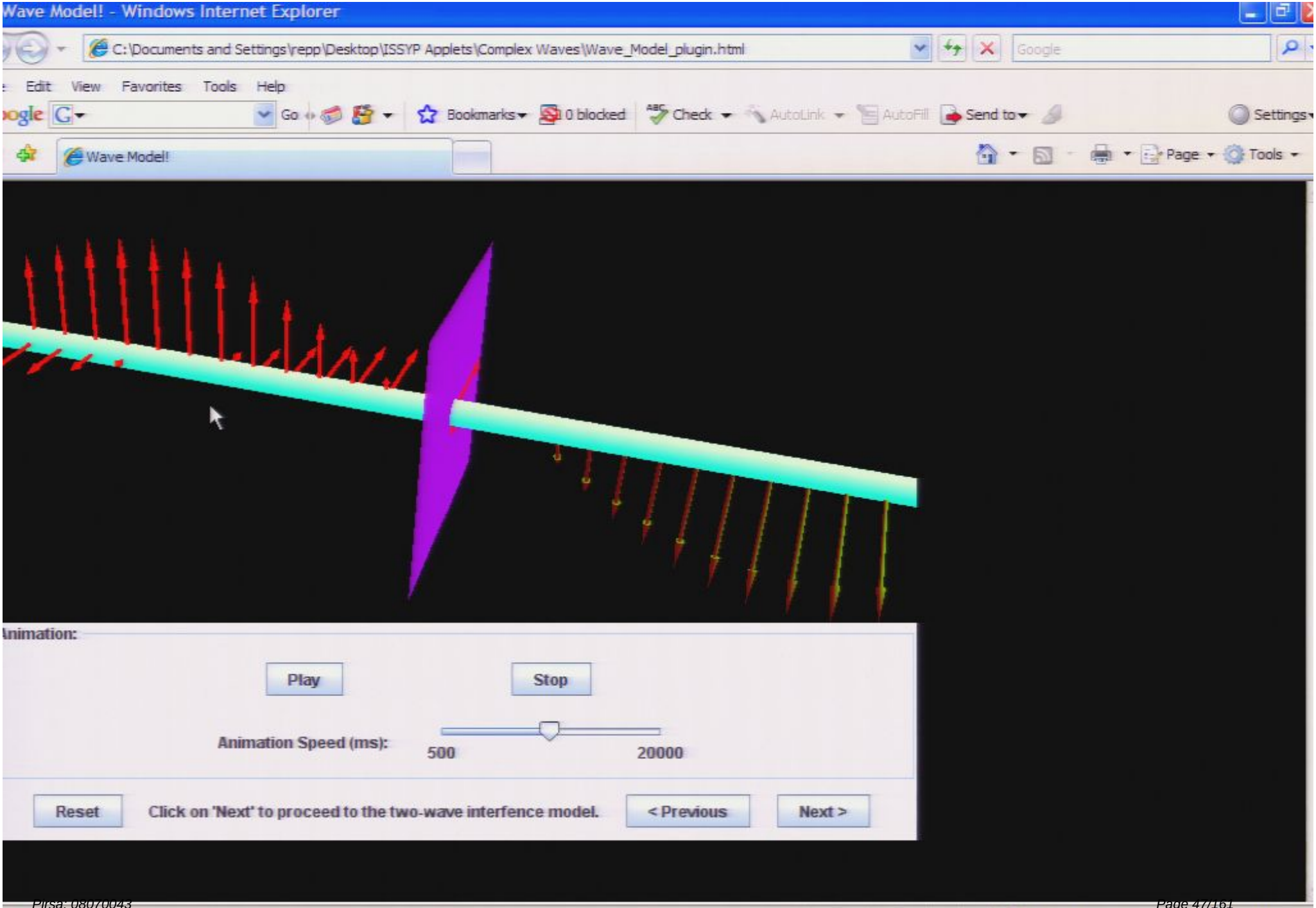
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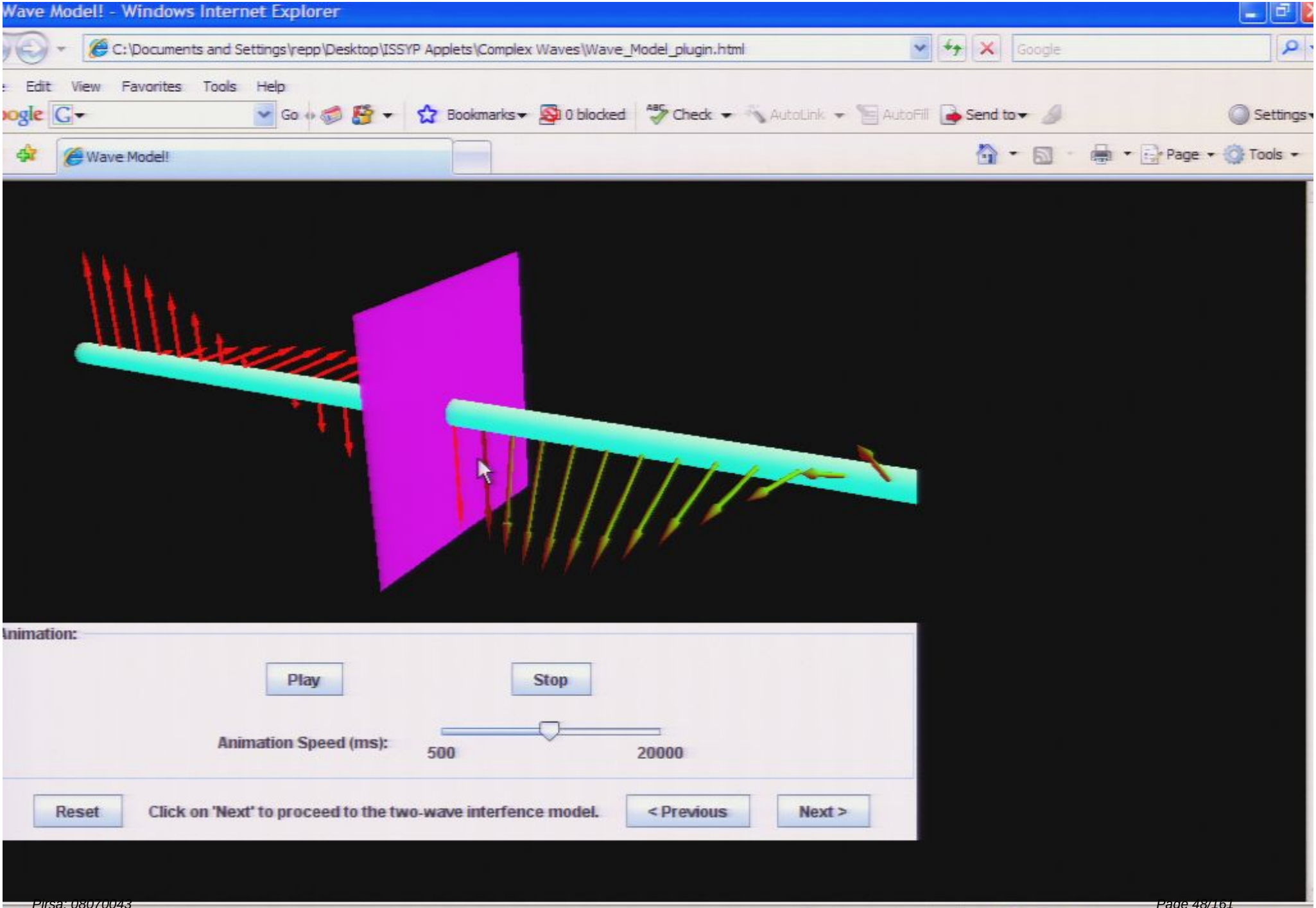
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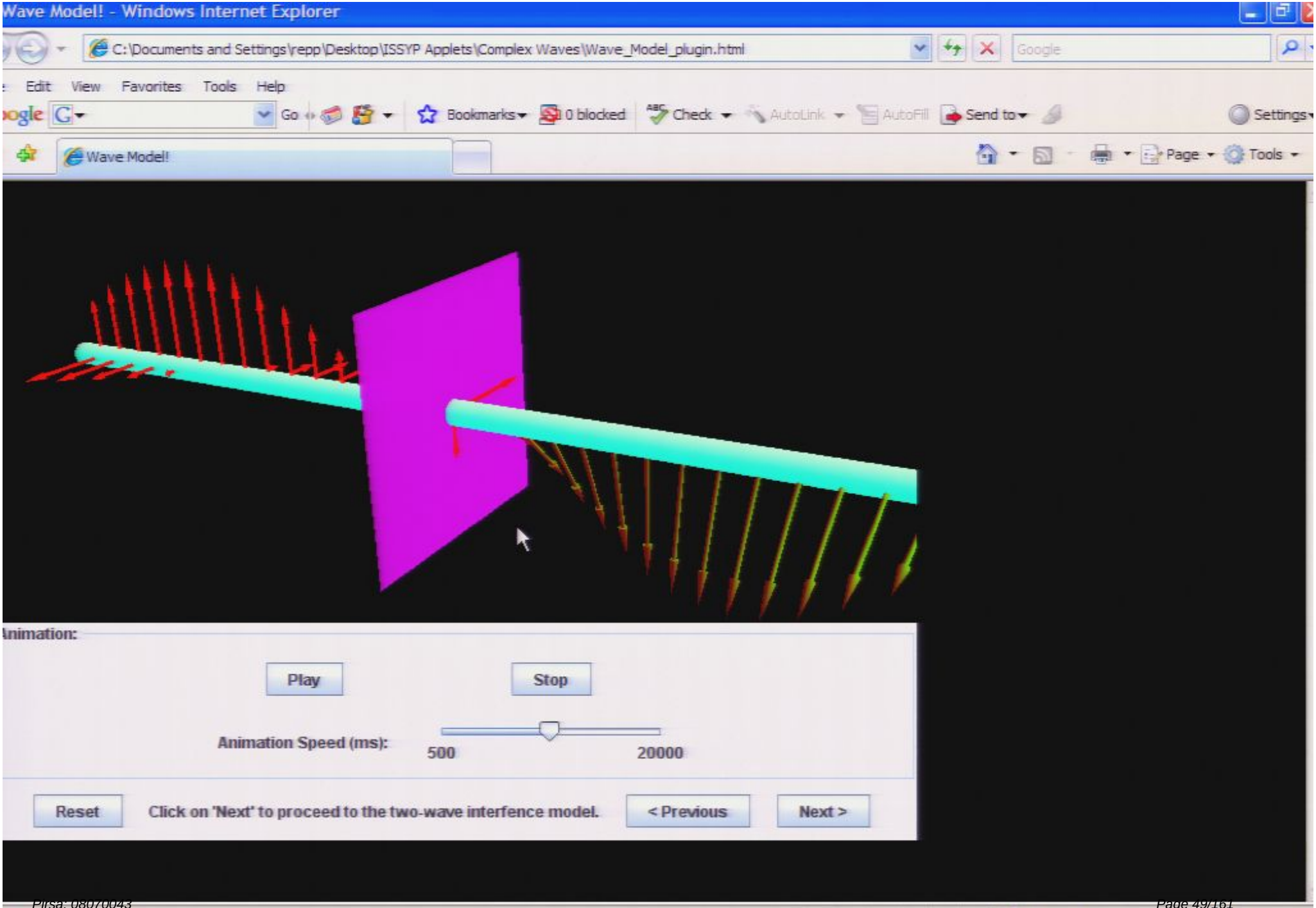
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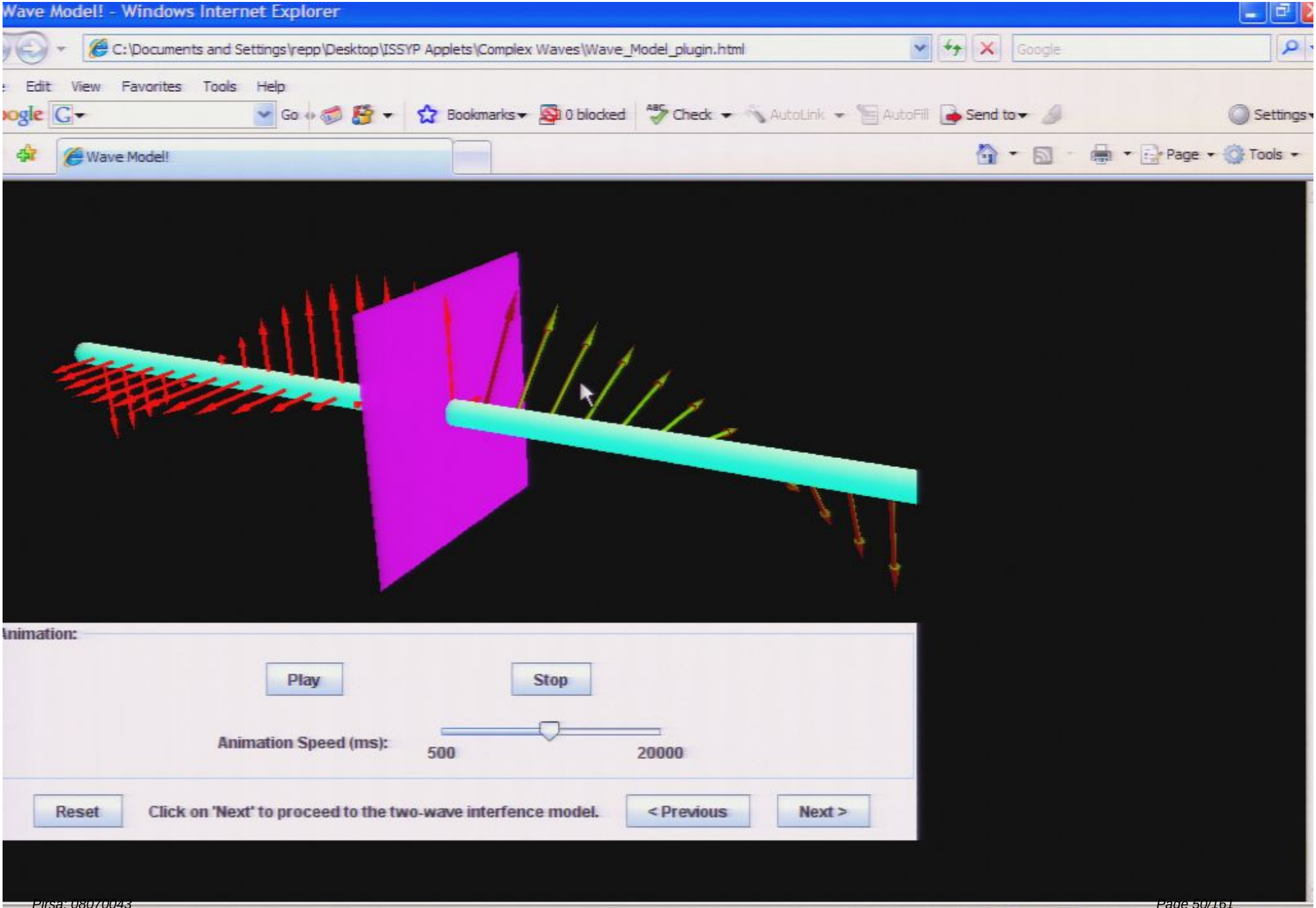
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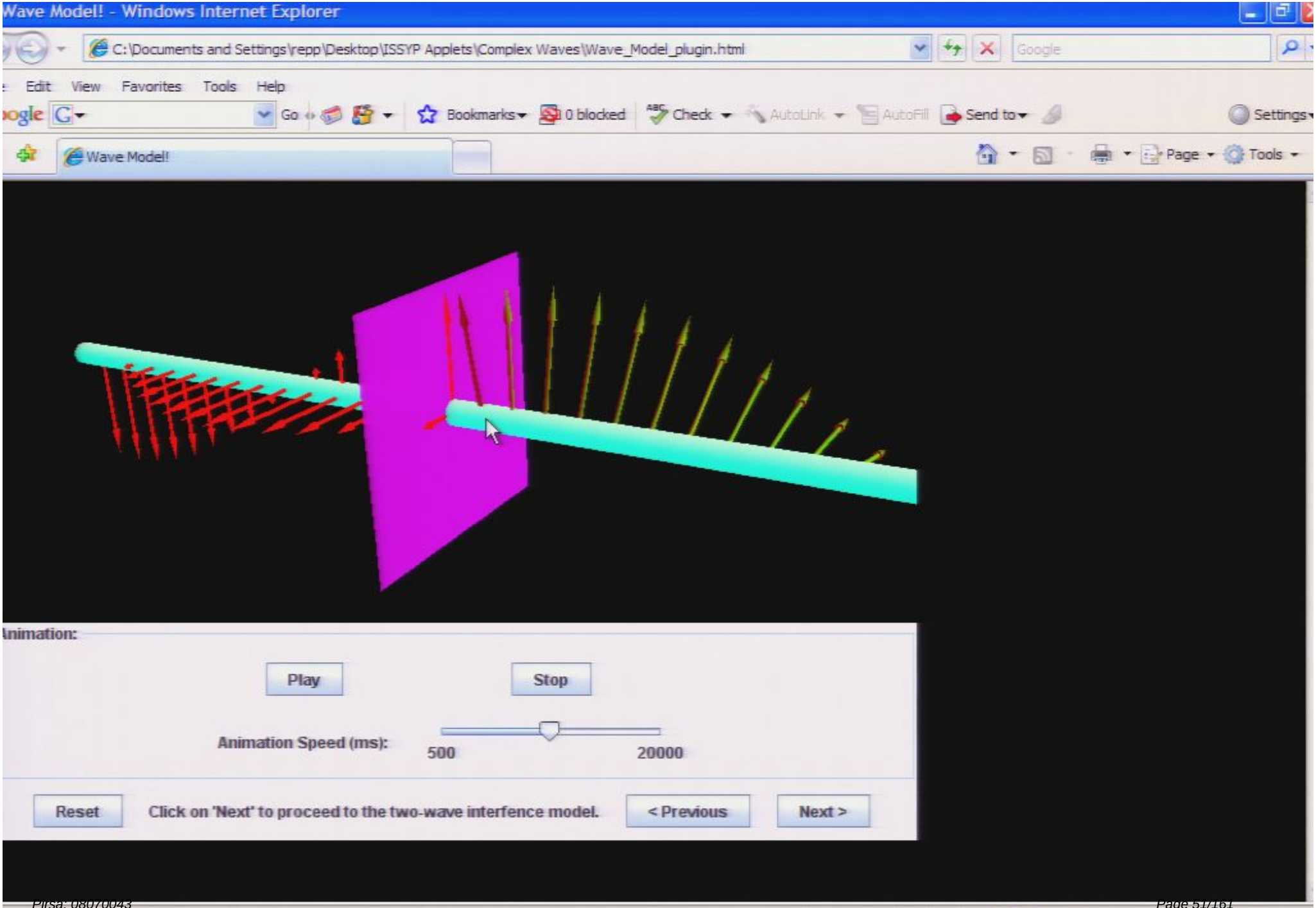
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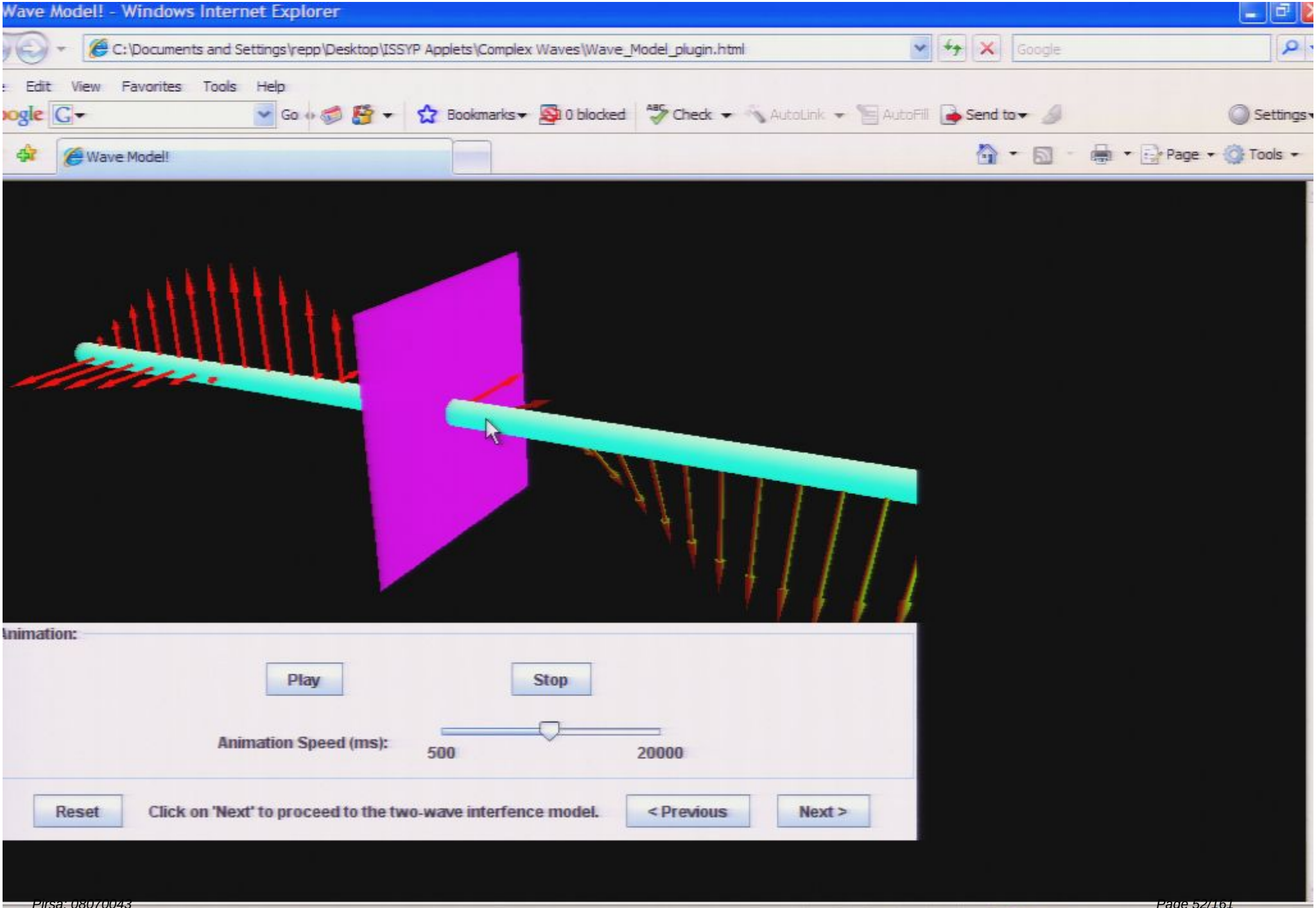
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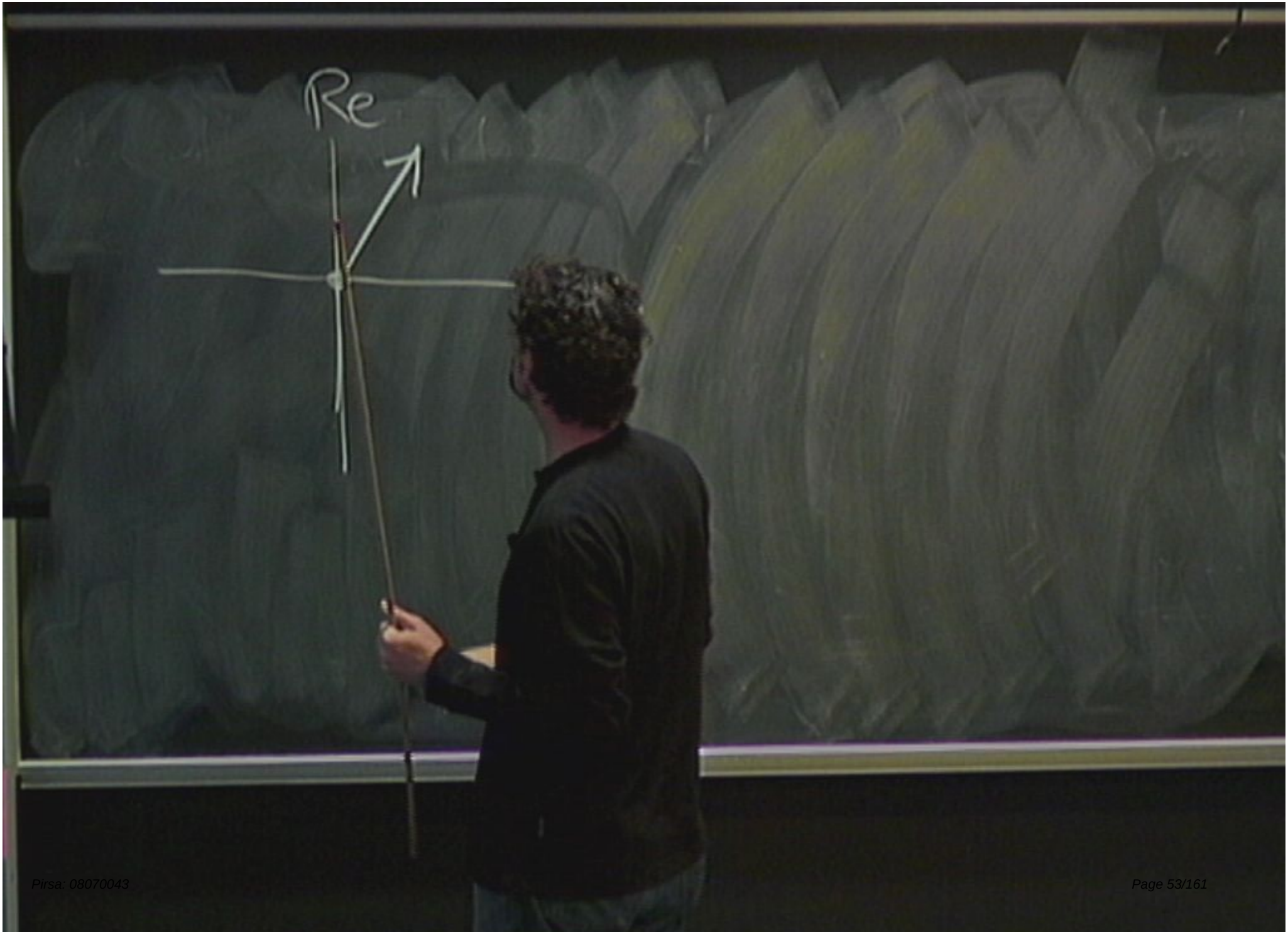
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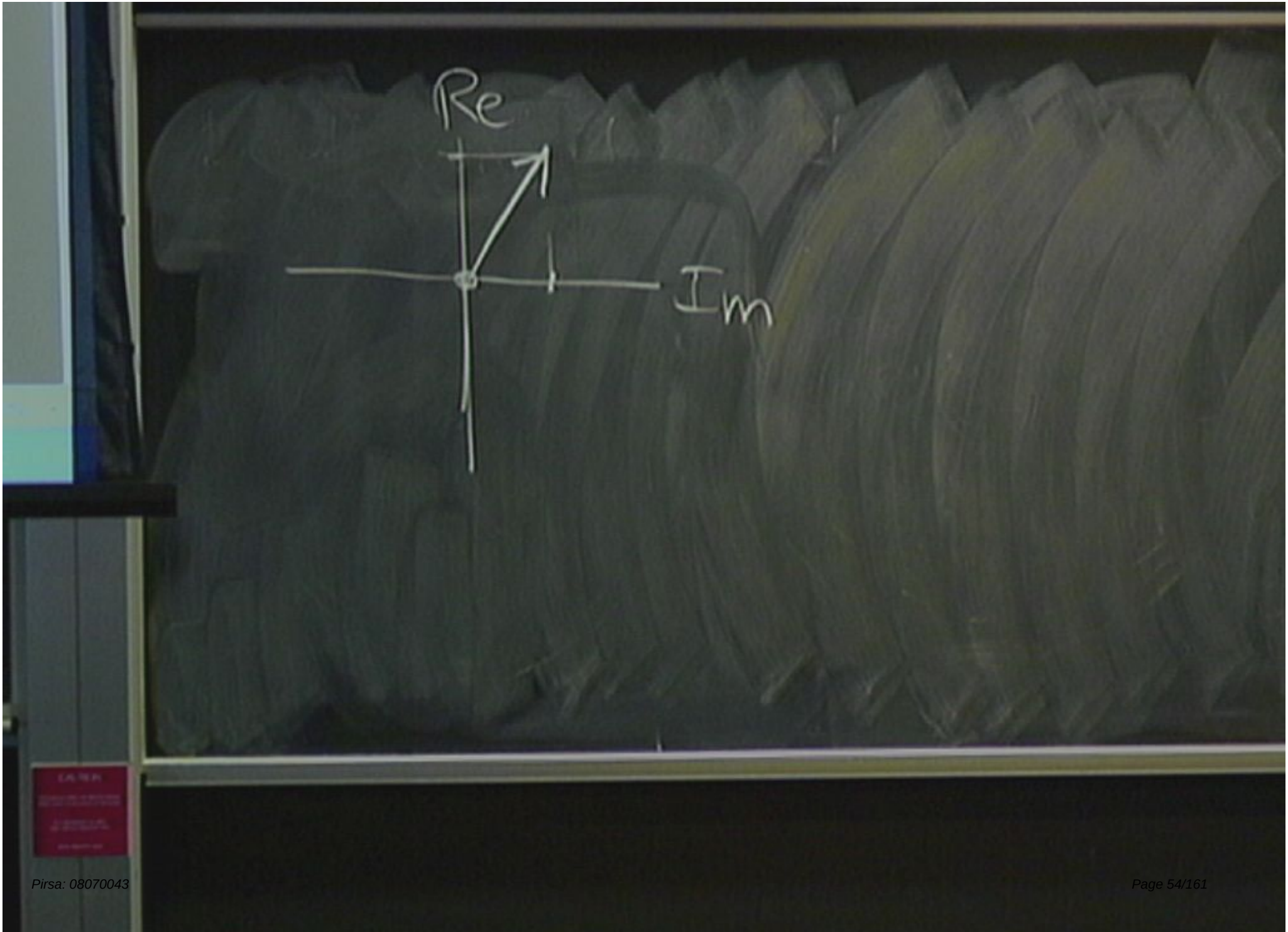
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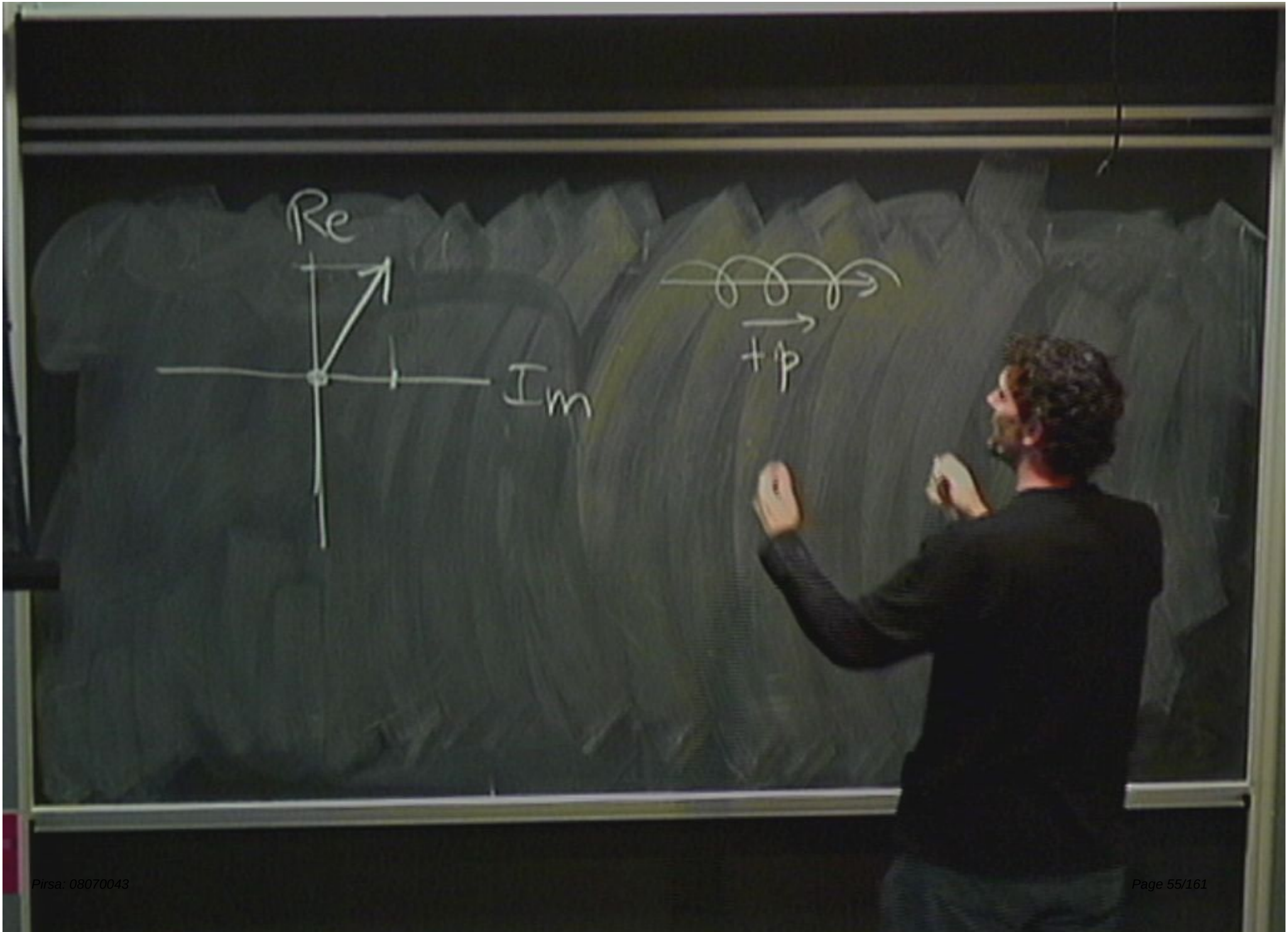
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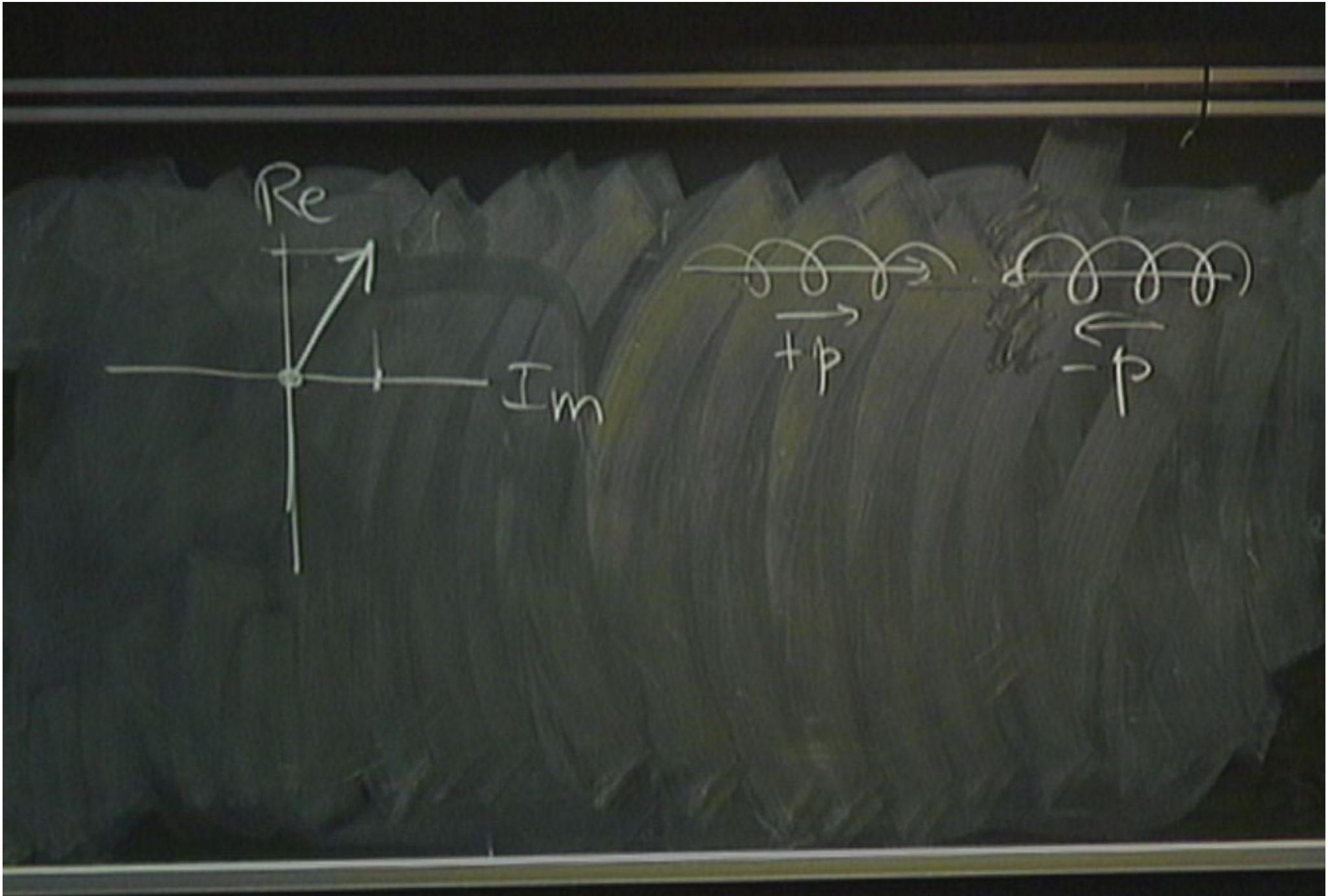
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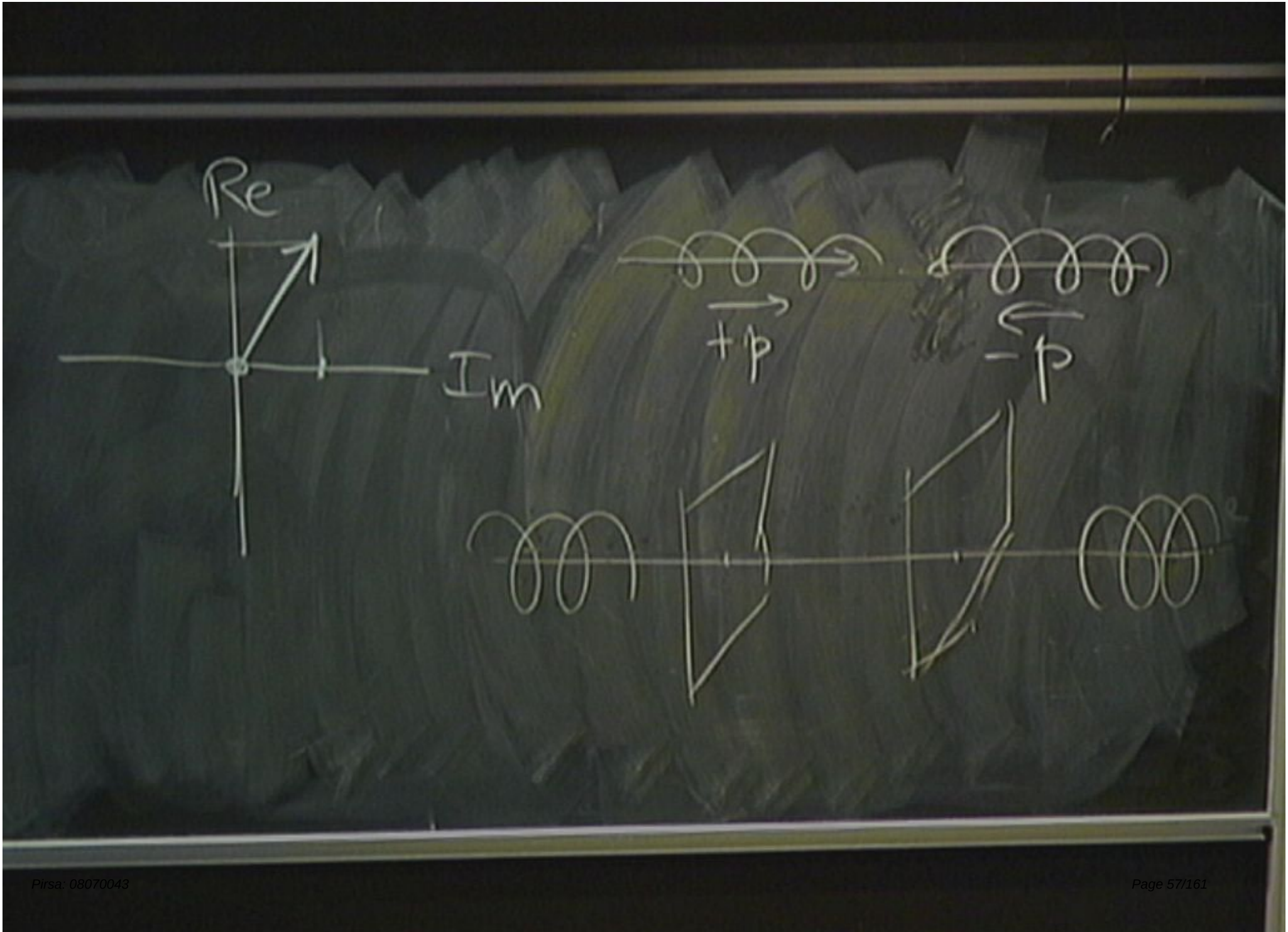
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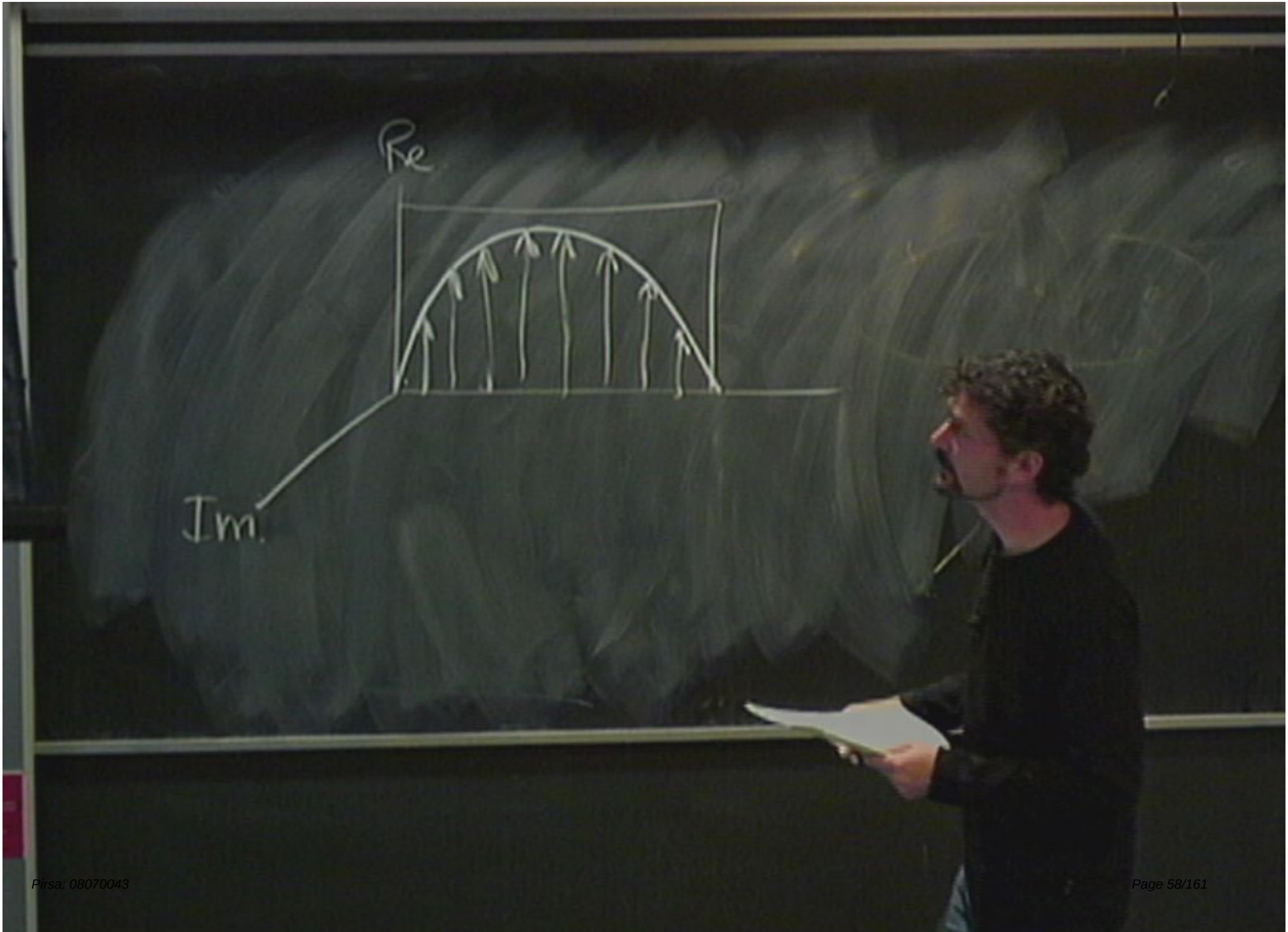
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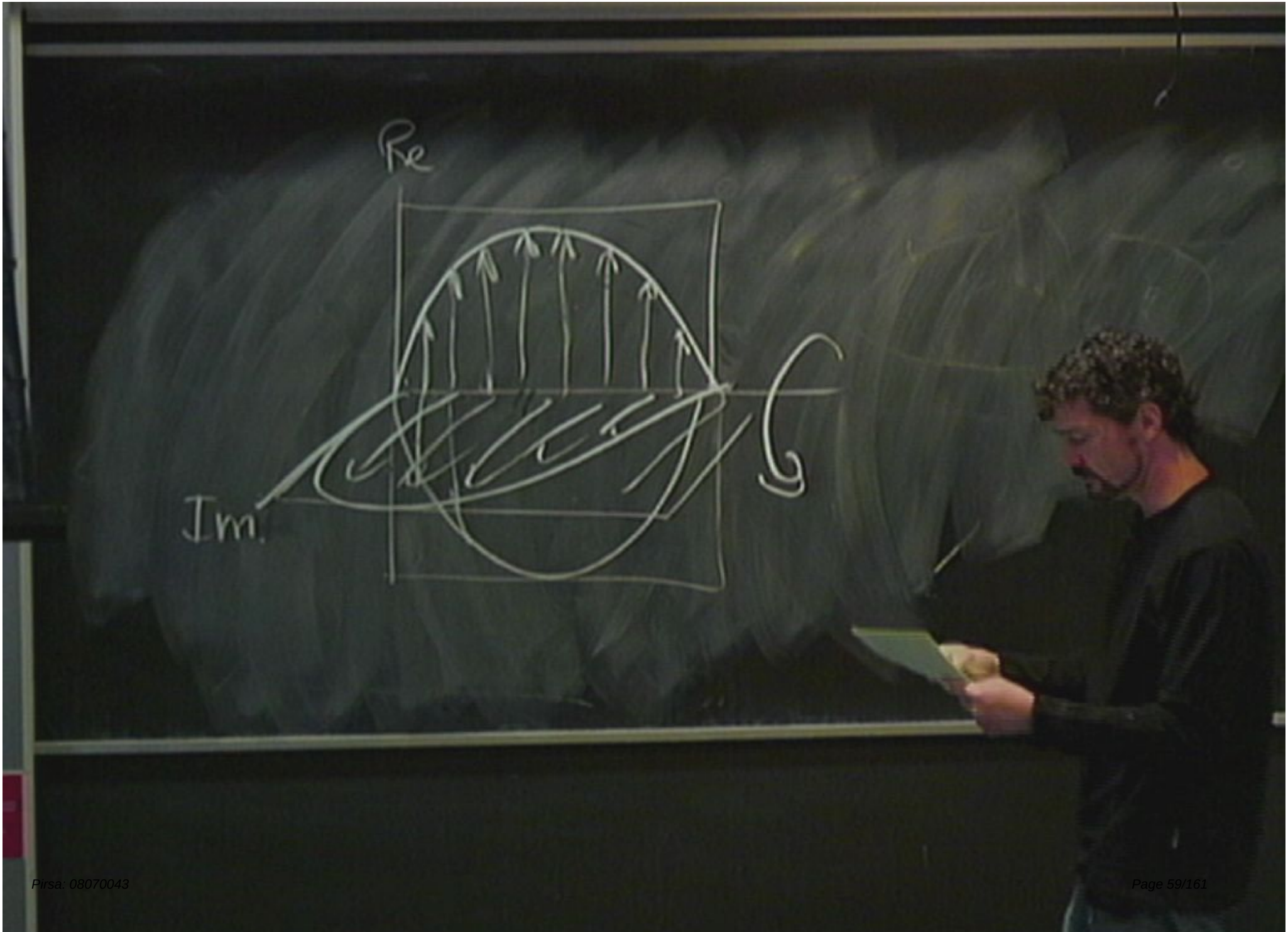
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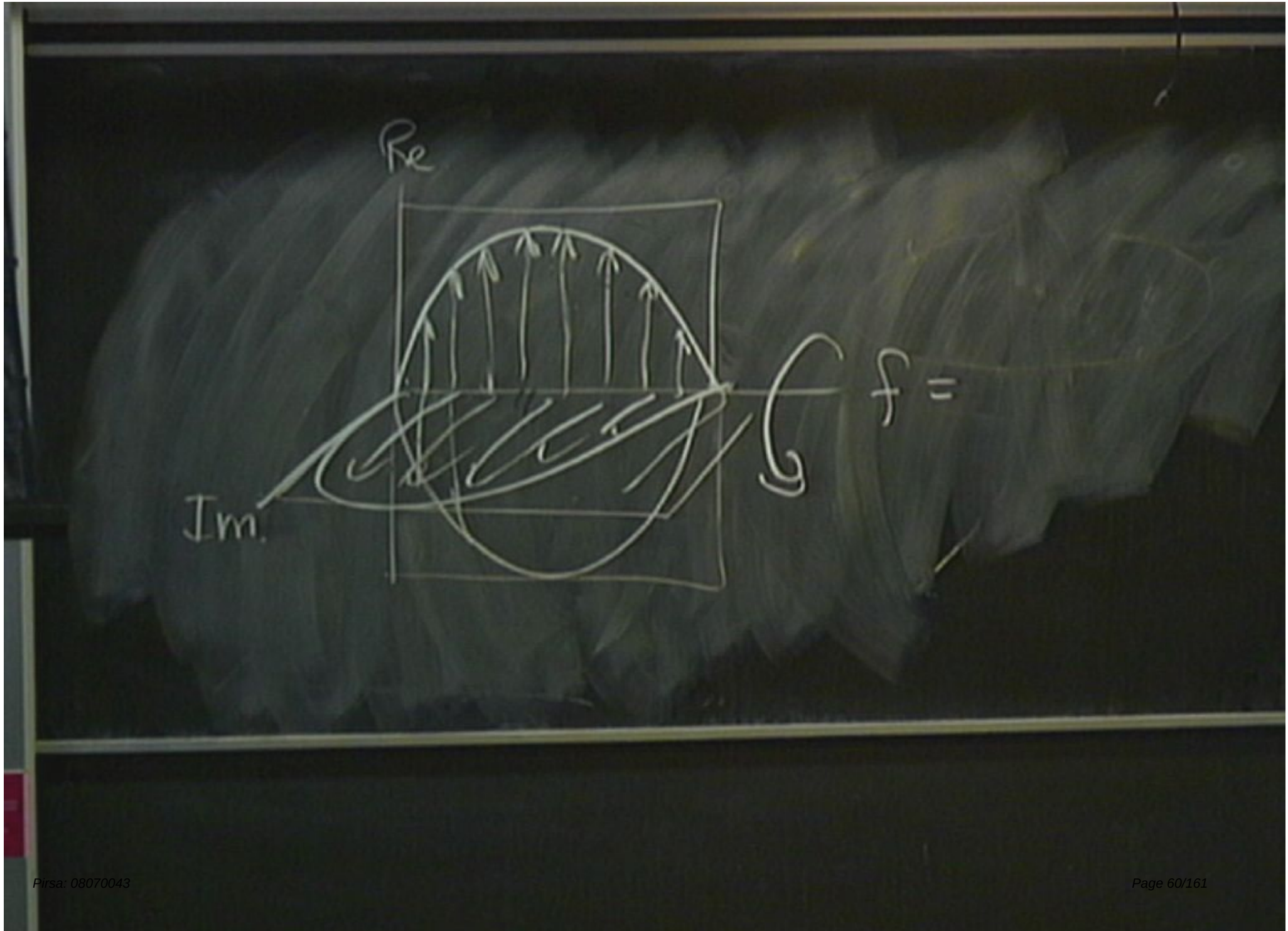
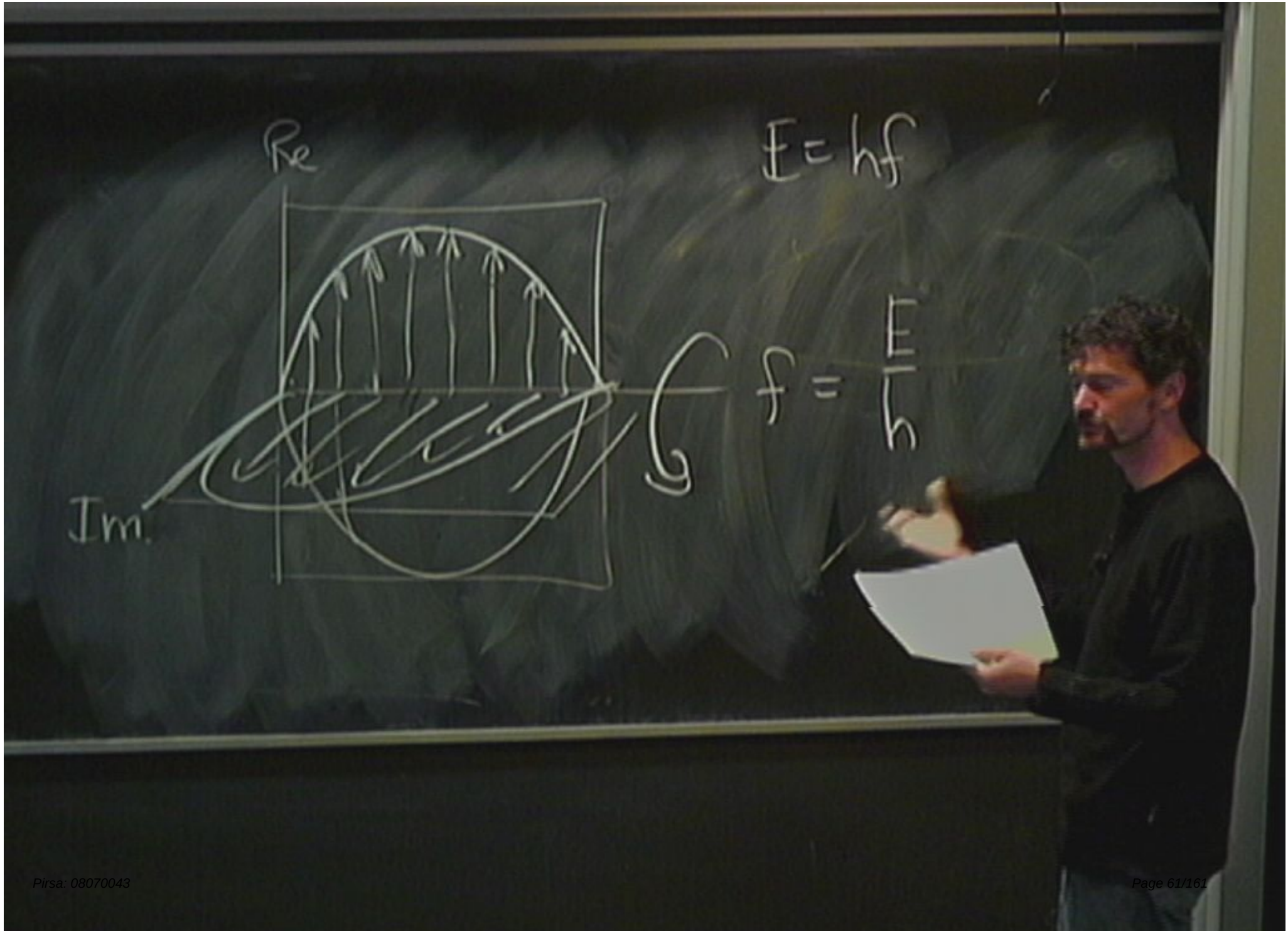

Re
Im.
f =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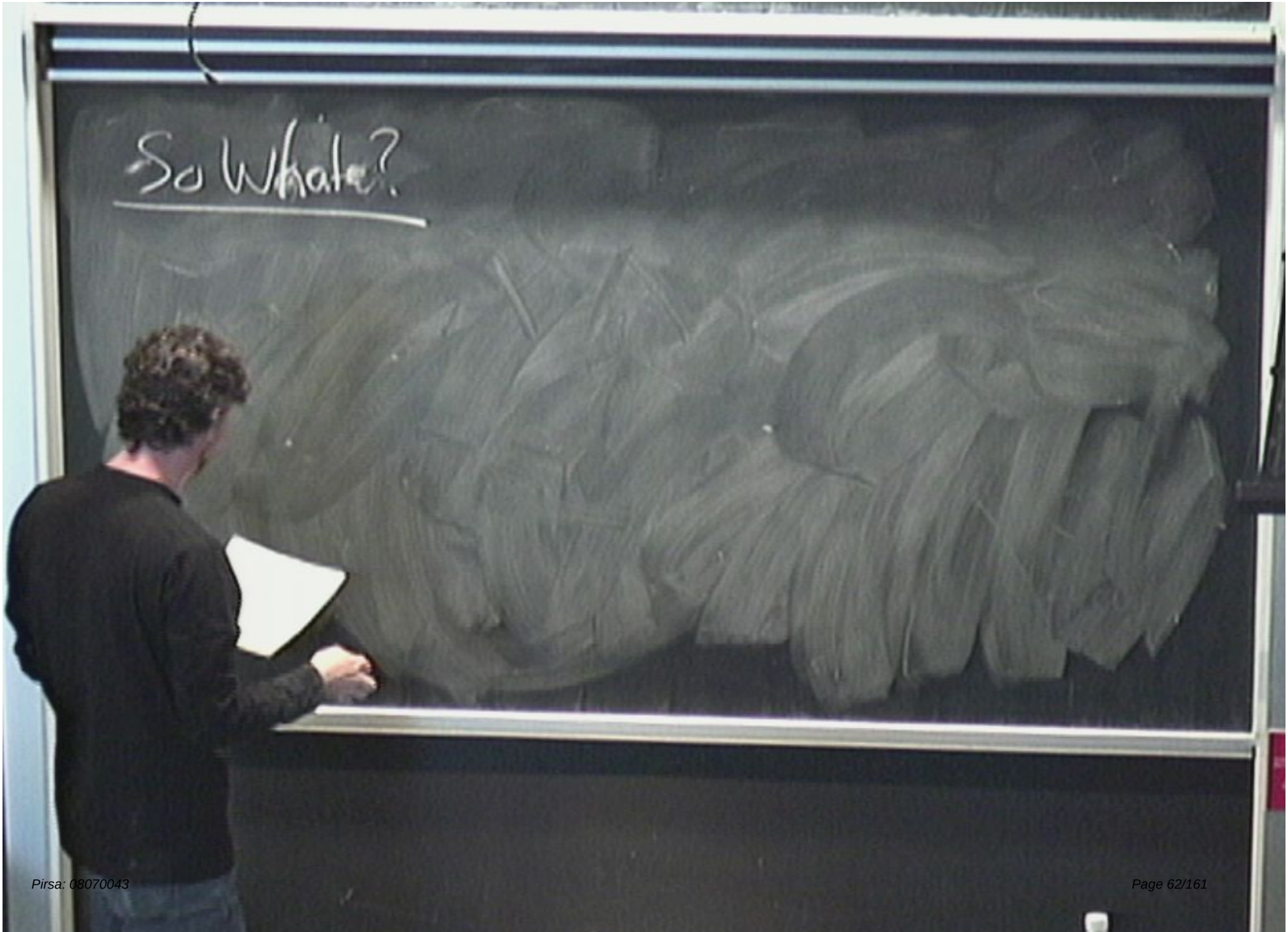
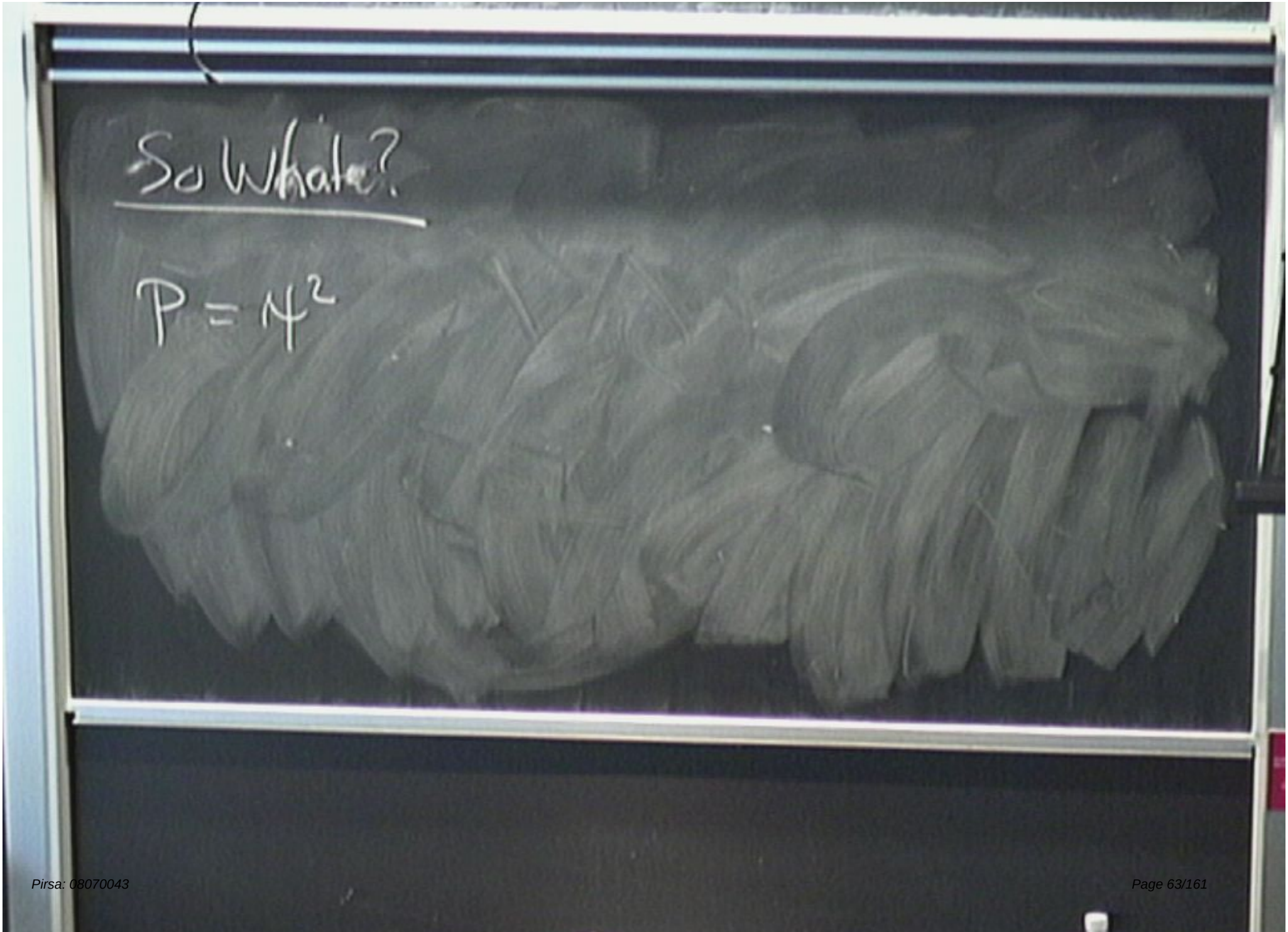
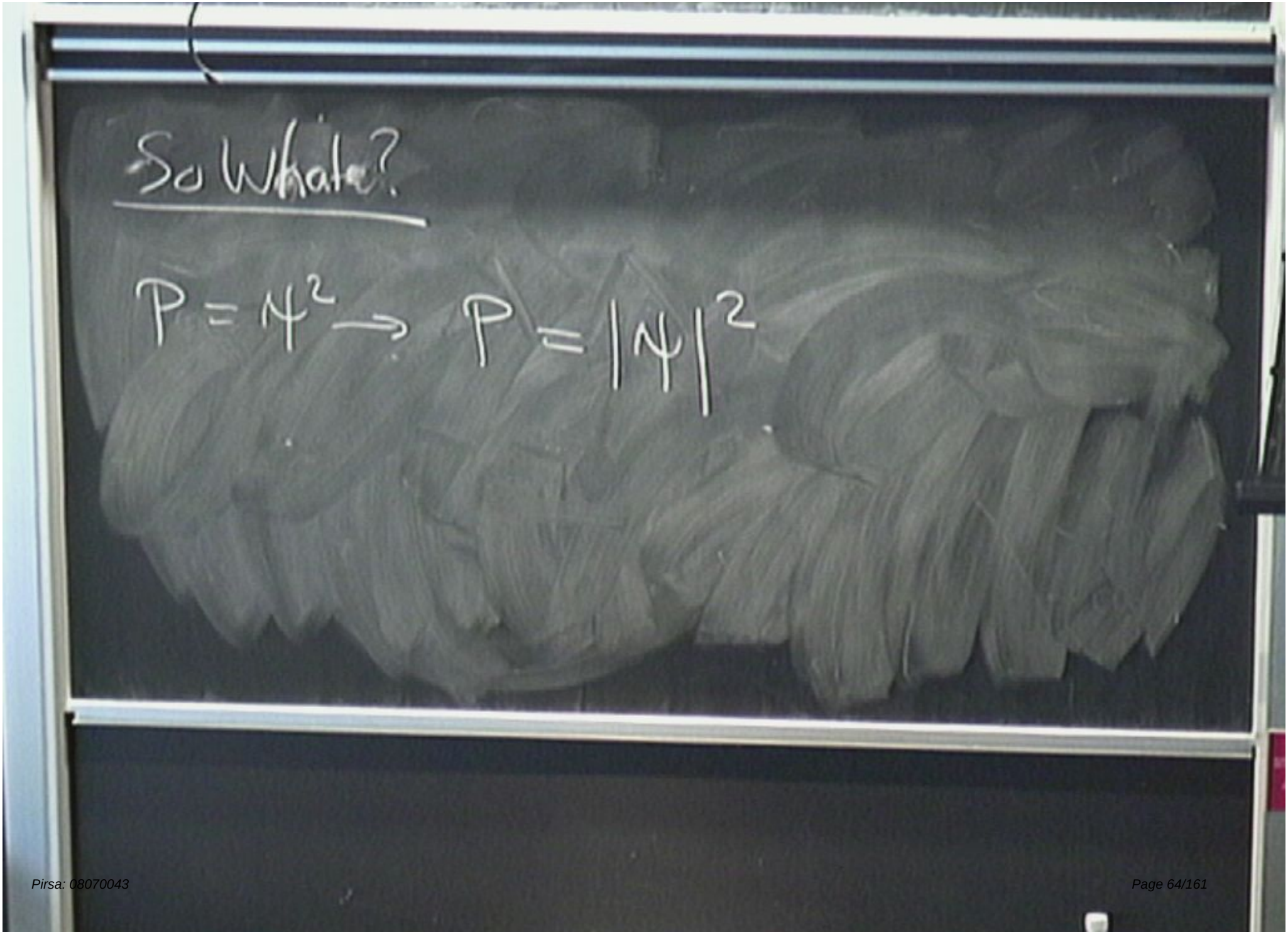
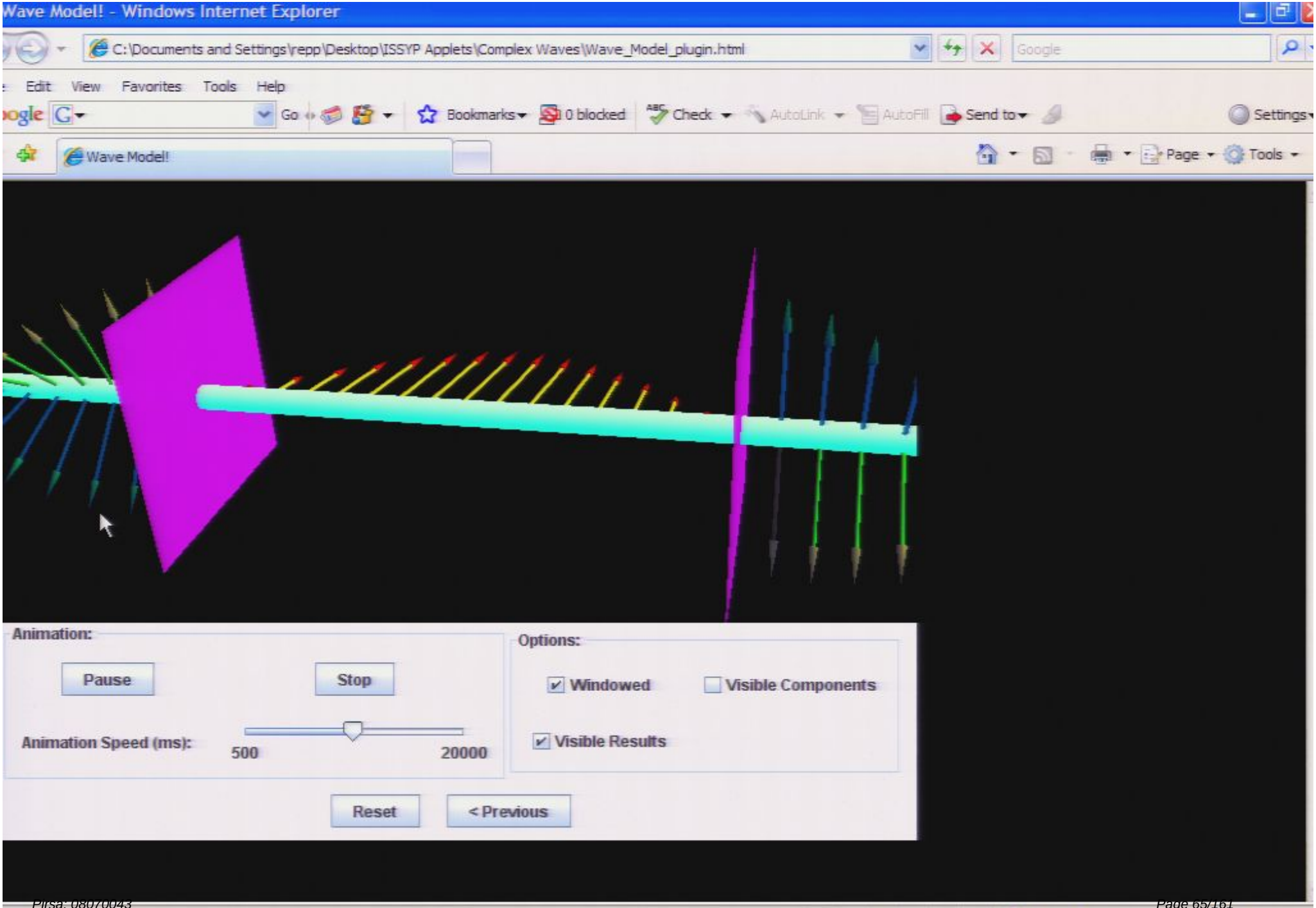
E = hf
f = E/h


So What?


So What?
$P = N^2$


So What?
$P = \Psi^2 \rightarrow P = |\Psi|^2$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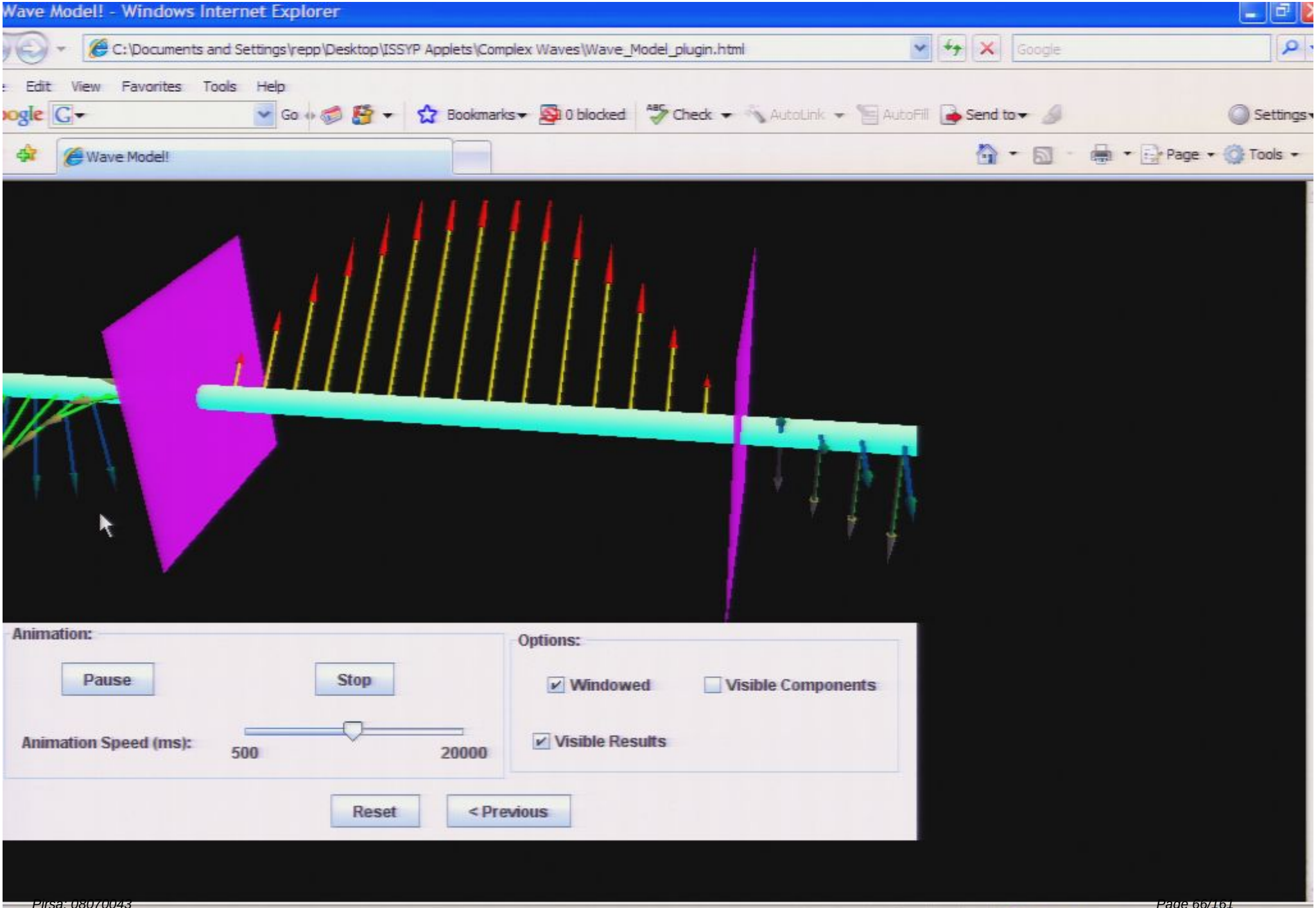
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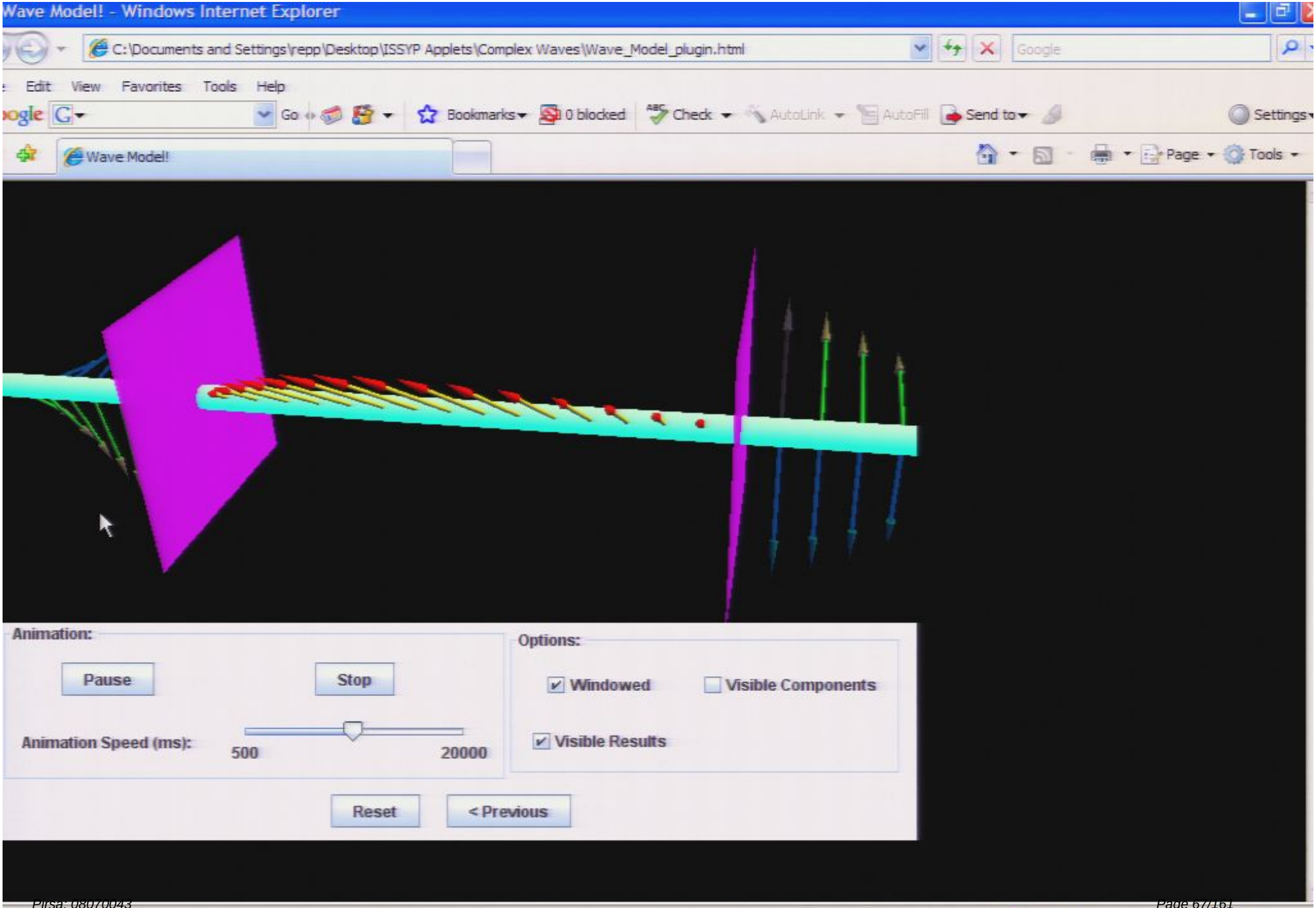

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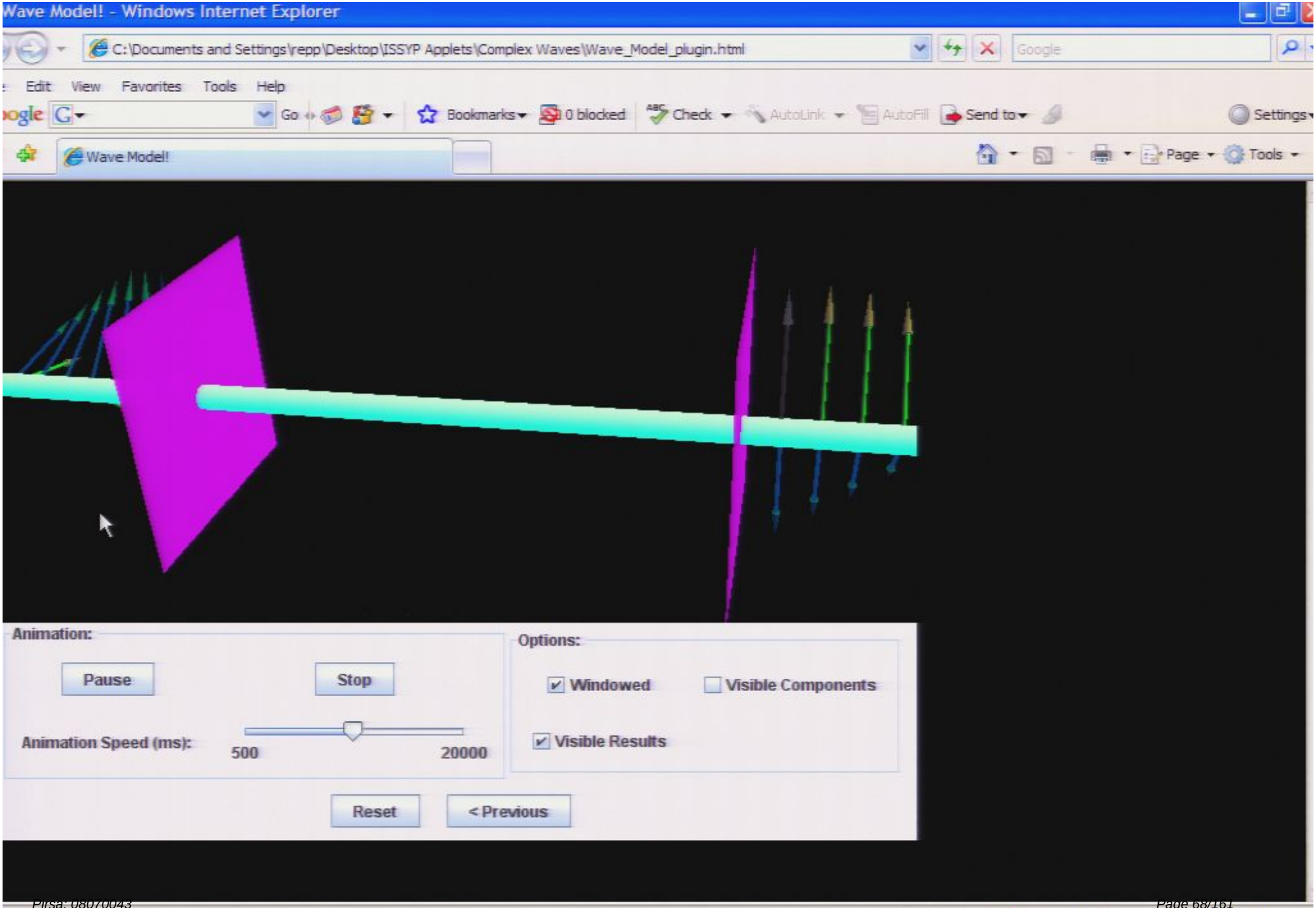
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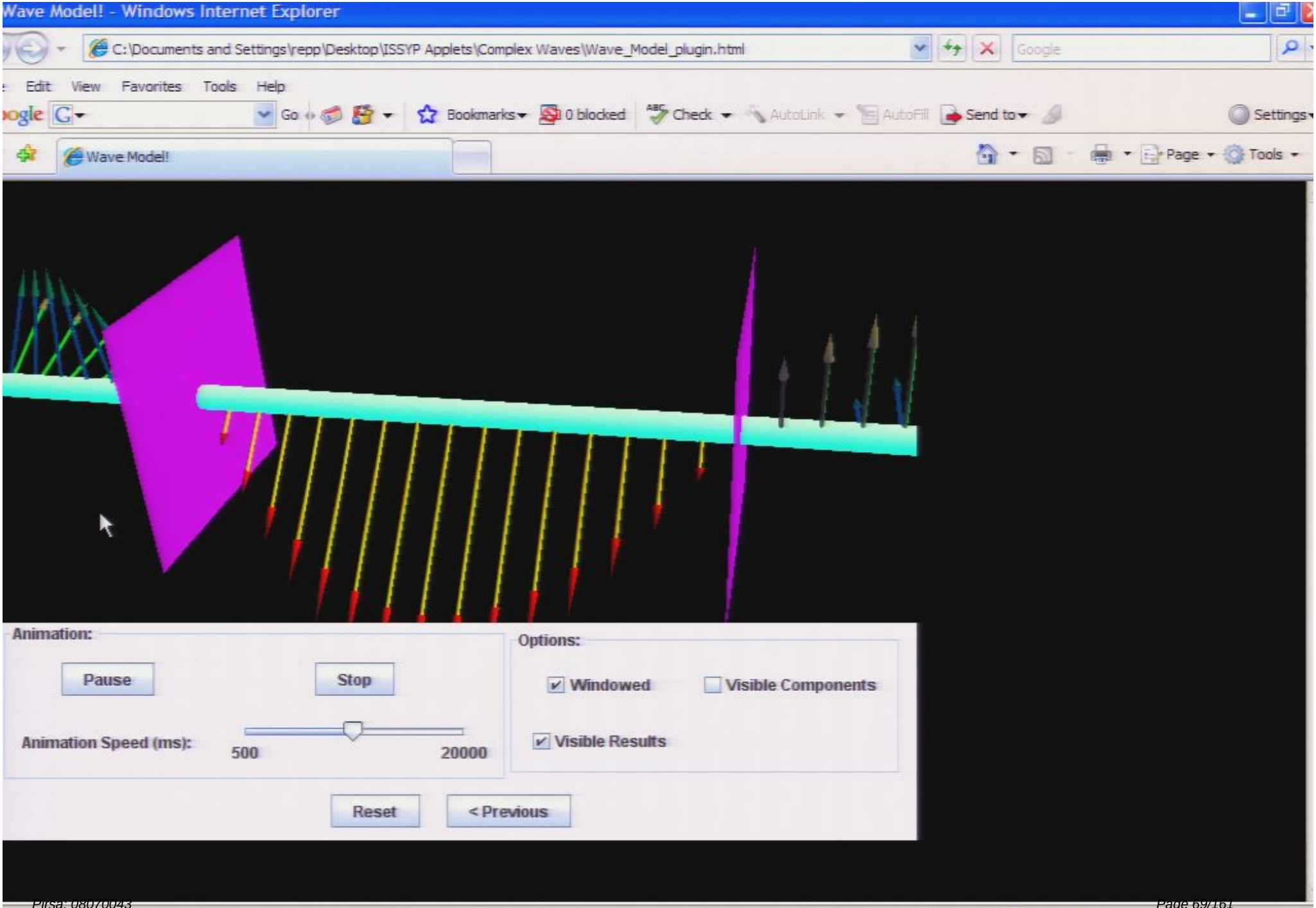
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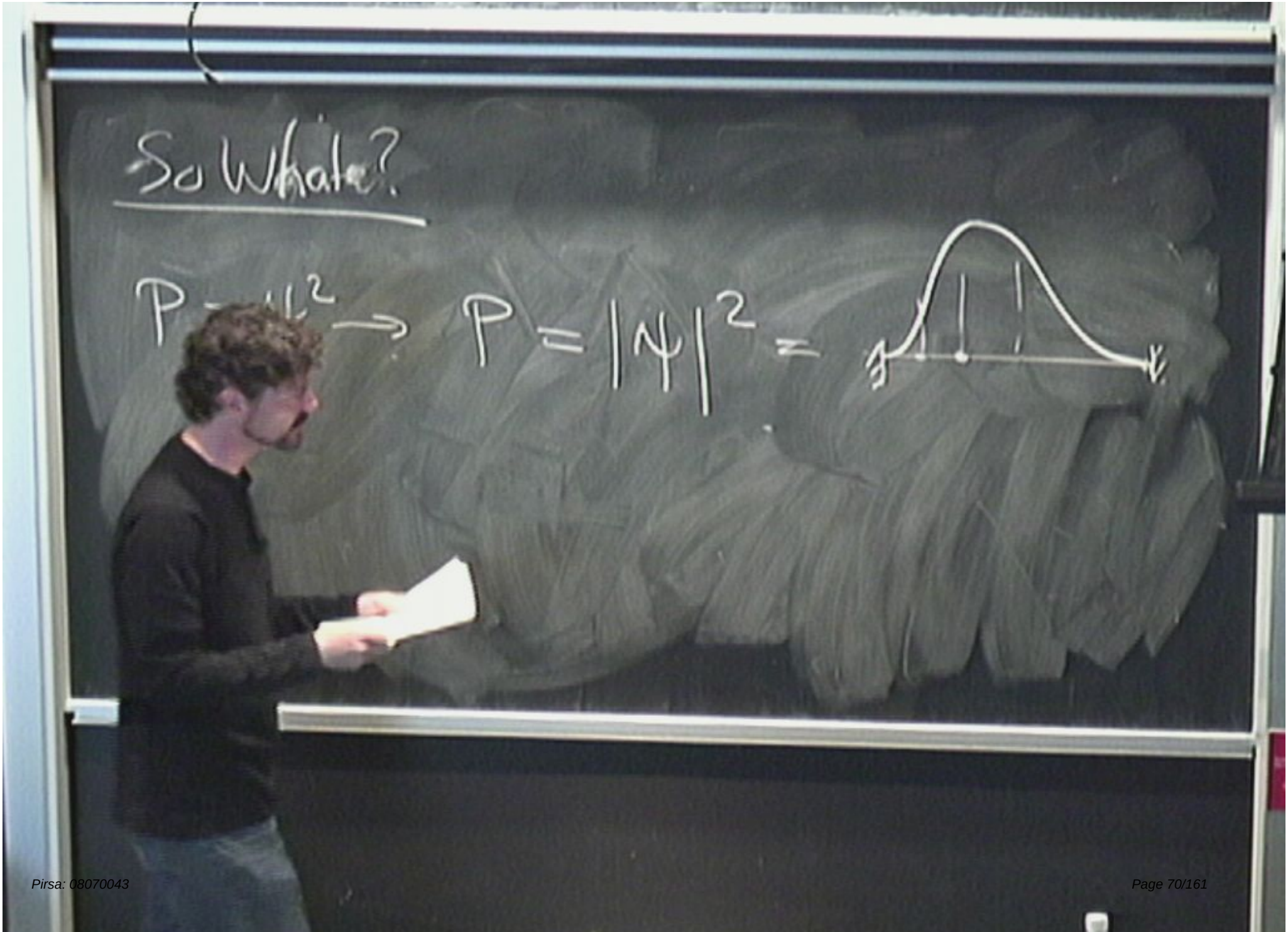
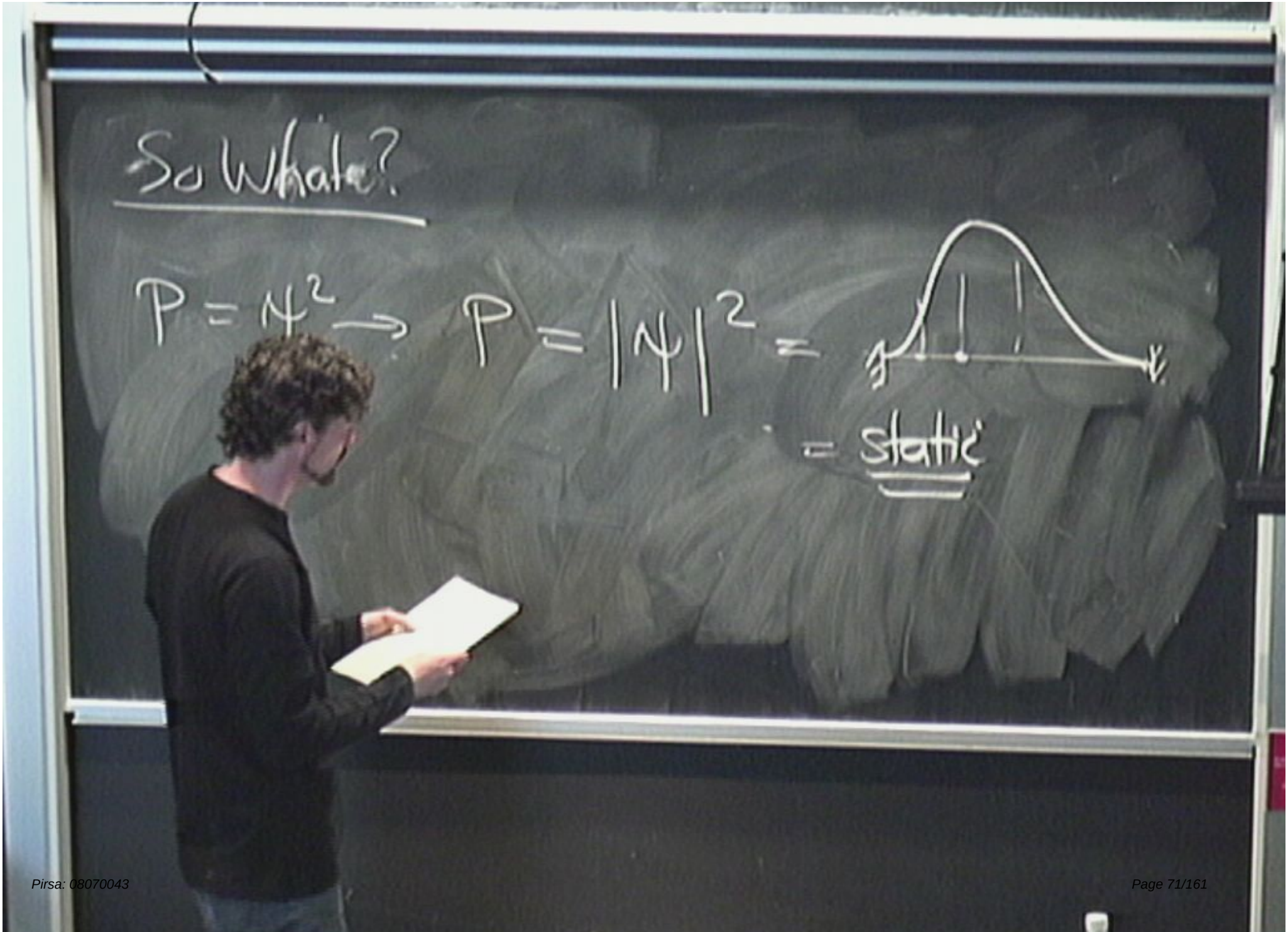
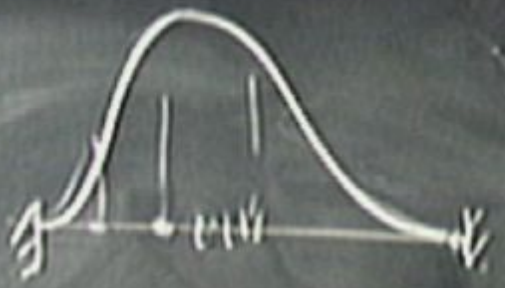

So What?
$P = |\Psi|^2$


So What?
$P = \Psi^2 \rightarrow P = |\Psi|^2 =$
= static

So What?

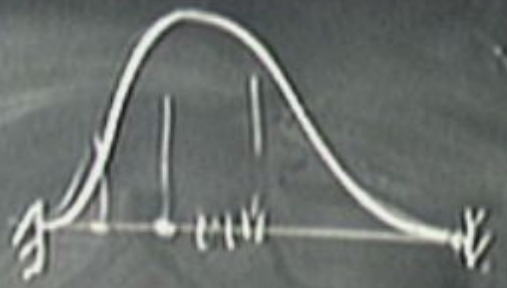
$P = \Psi^2 \rightarrow P = |\Psi|^2 =$



= static

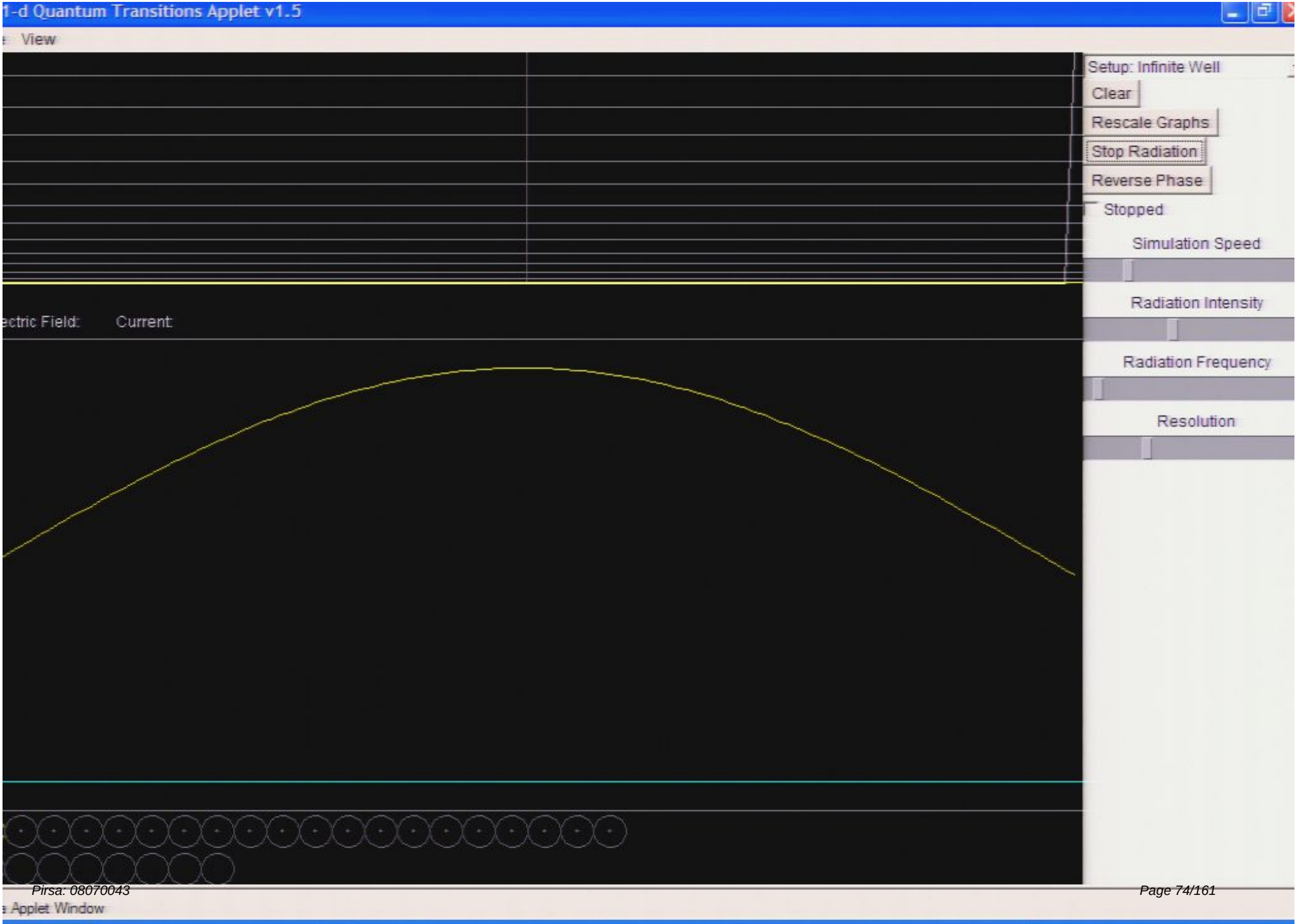
→ stationary state

So What?

$P = \Psi^2 \rightarrow P = |\Psi|^2 =$ 

= static

→ stationary state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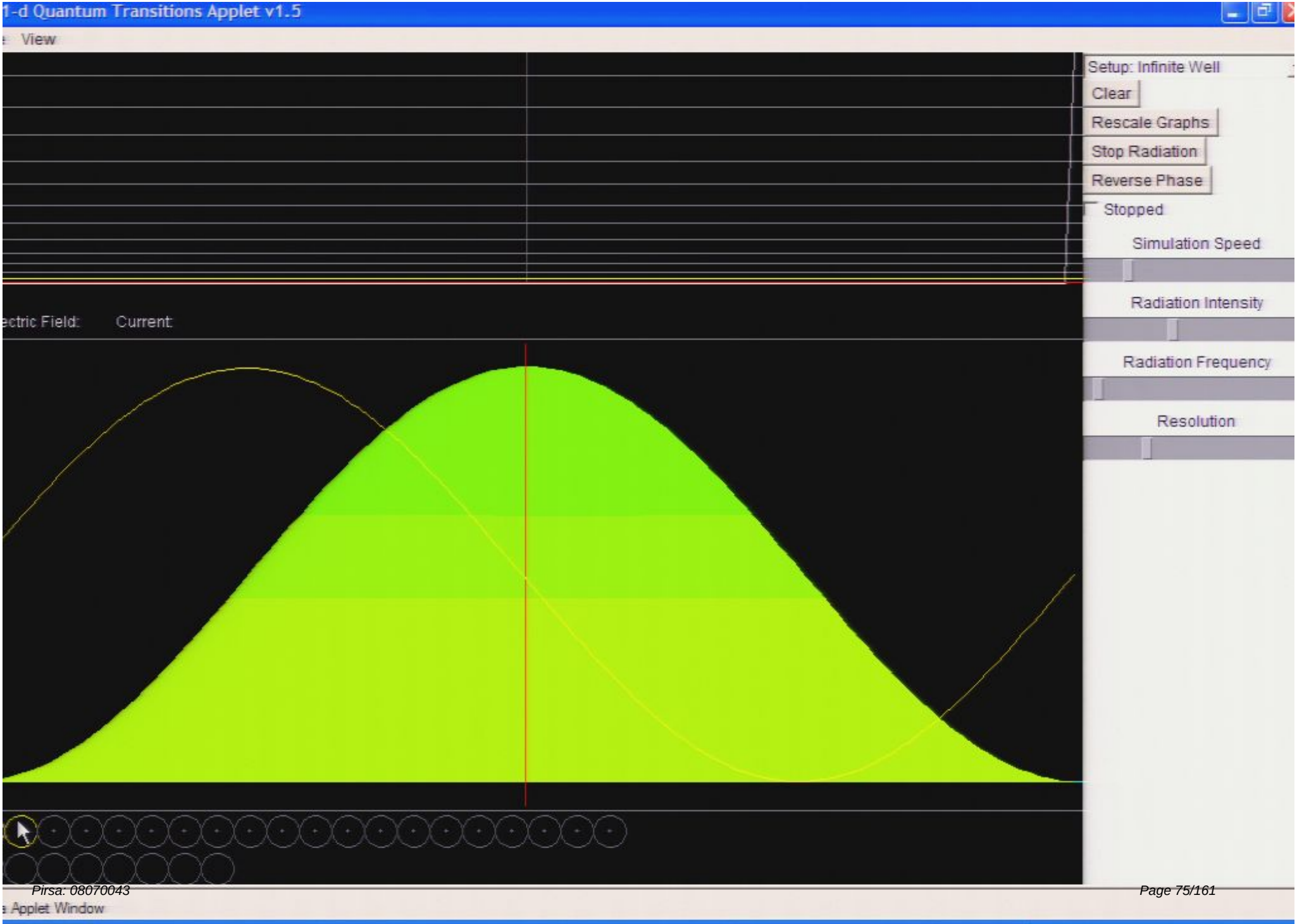
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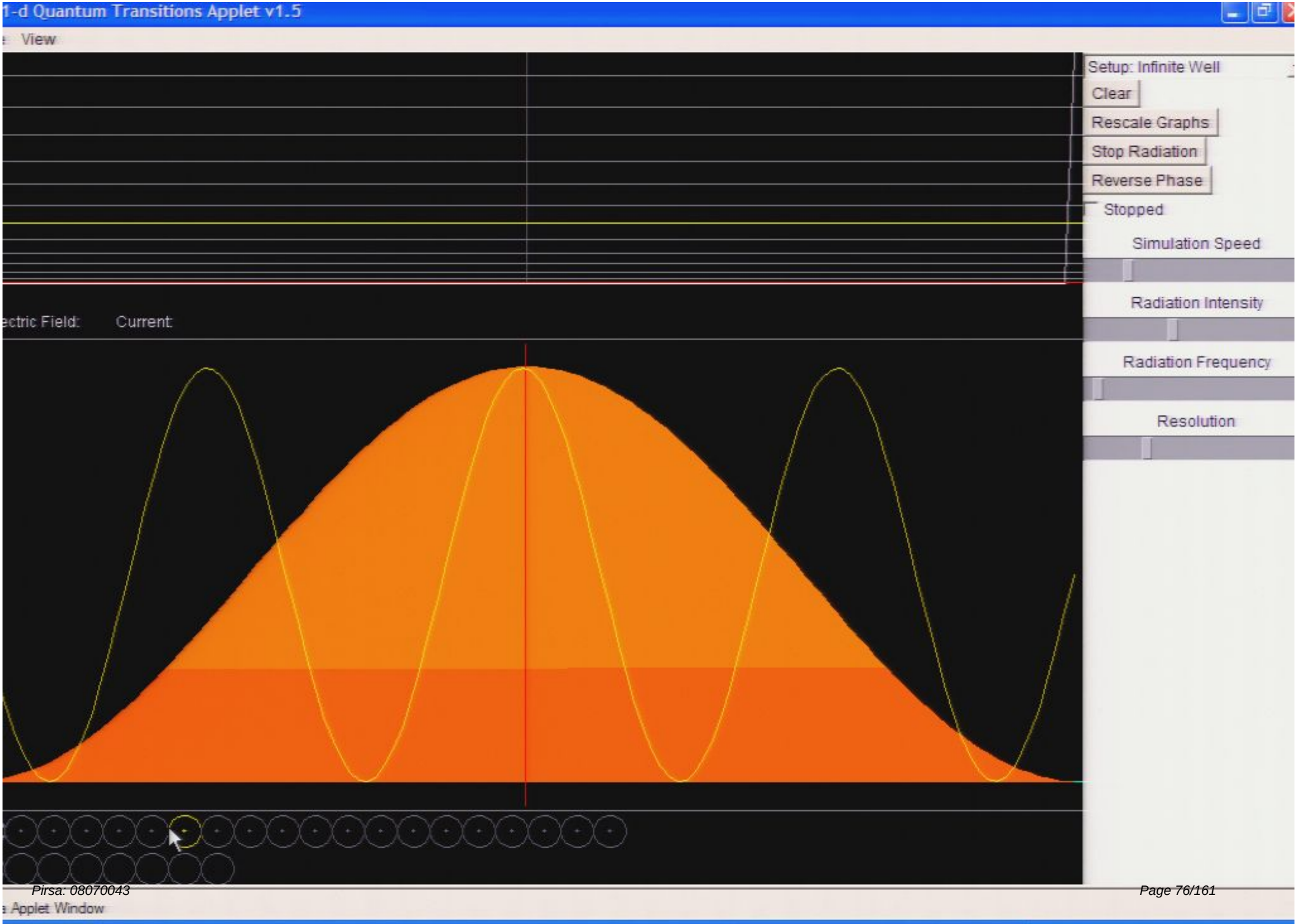
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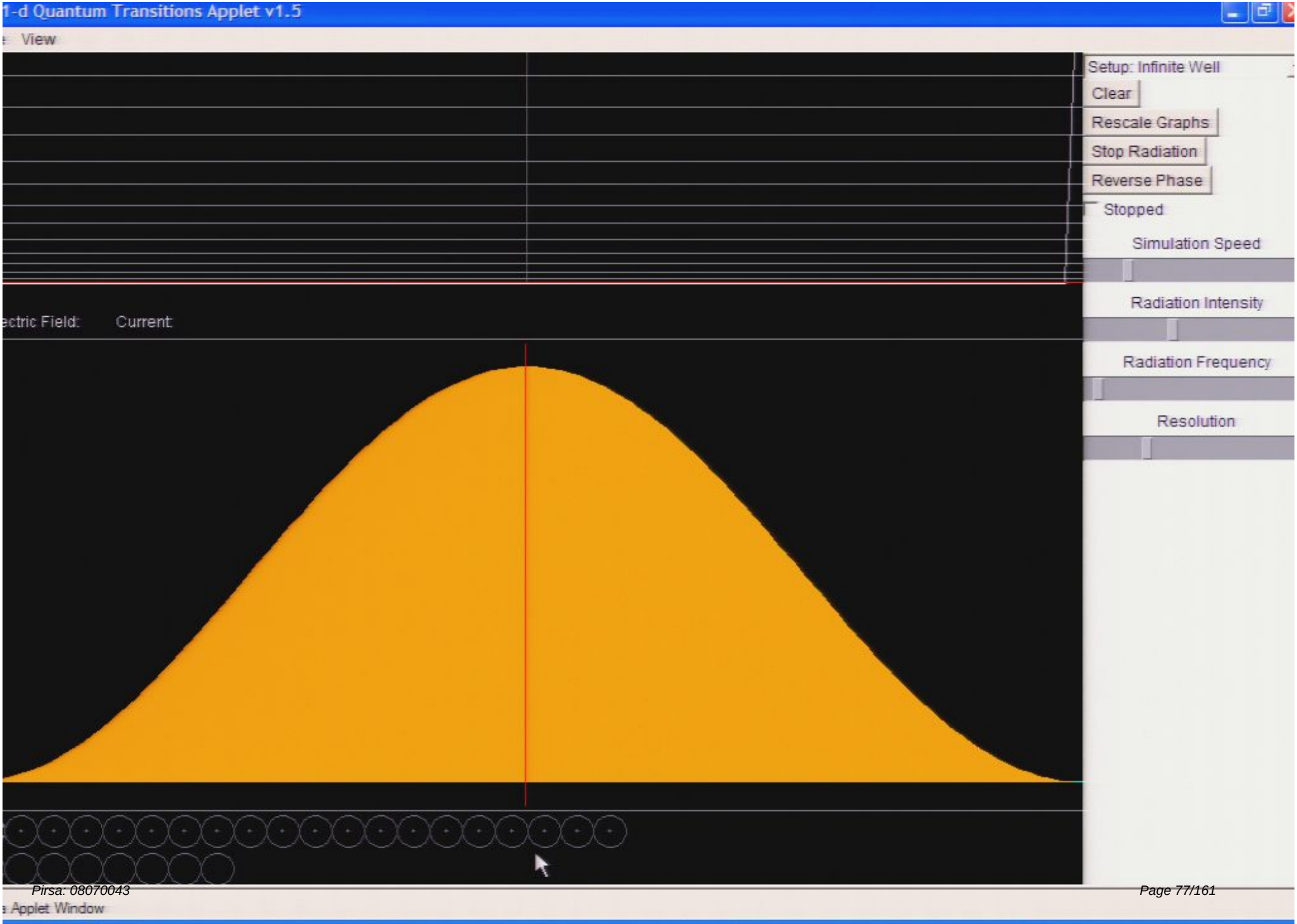
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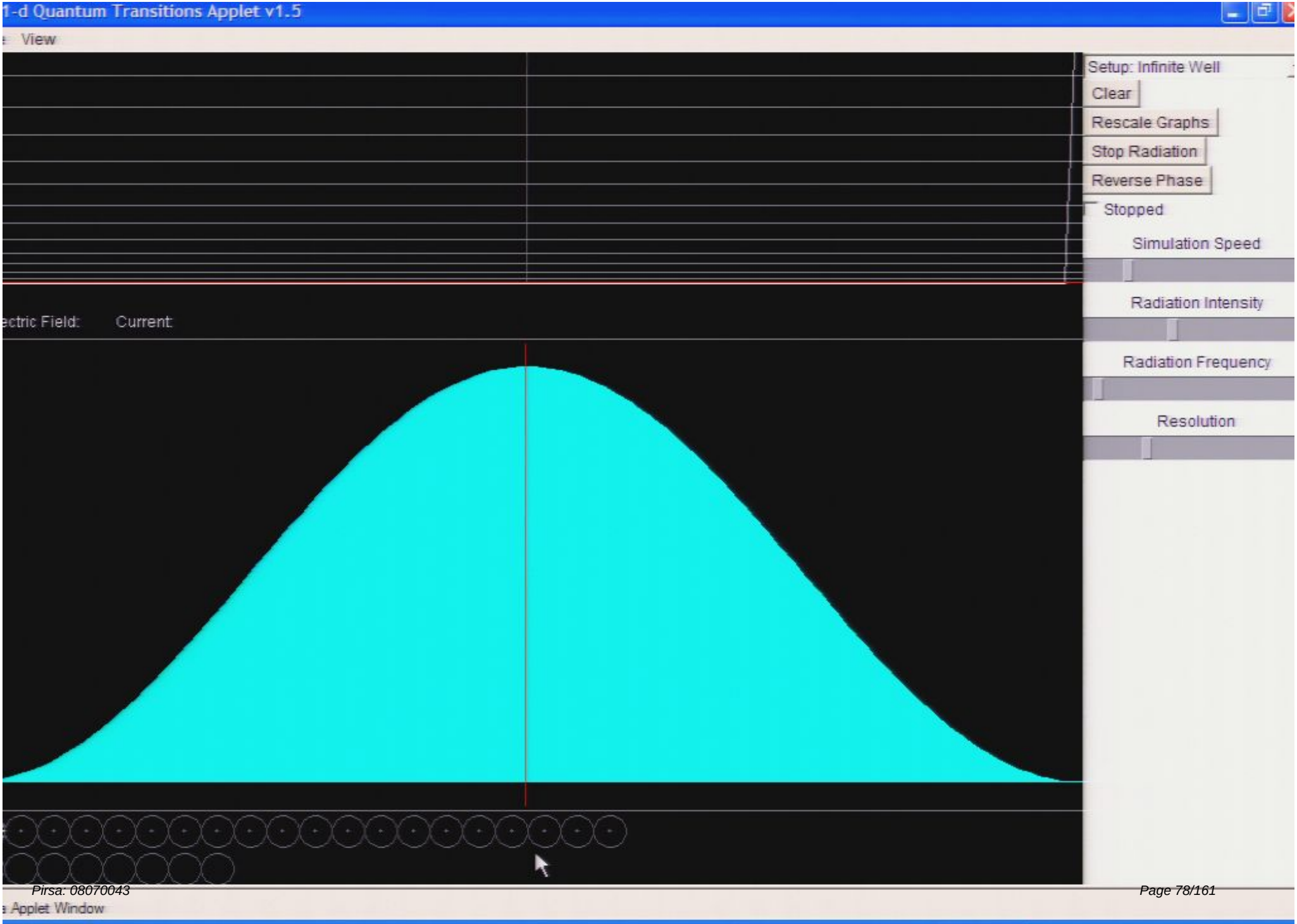
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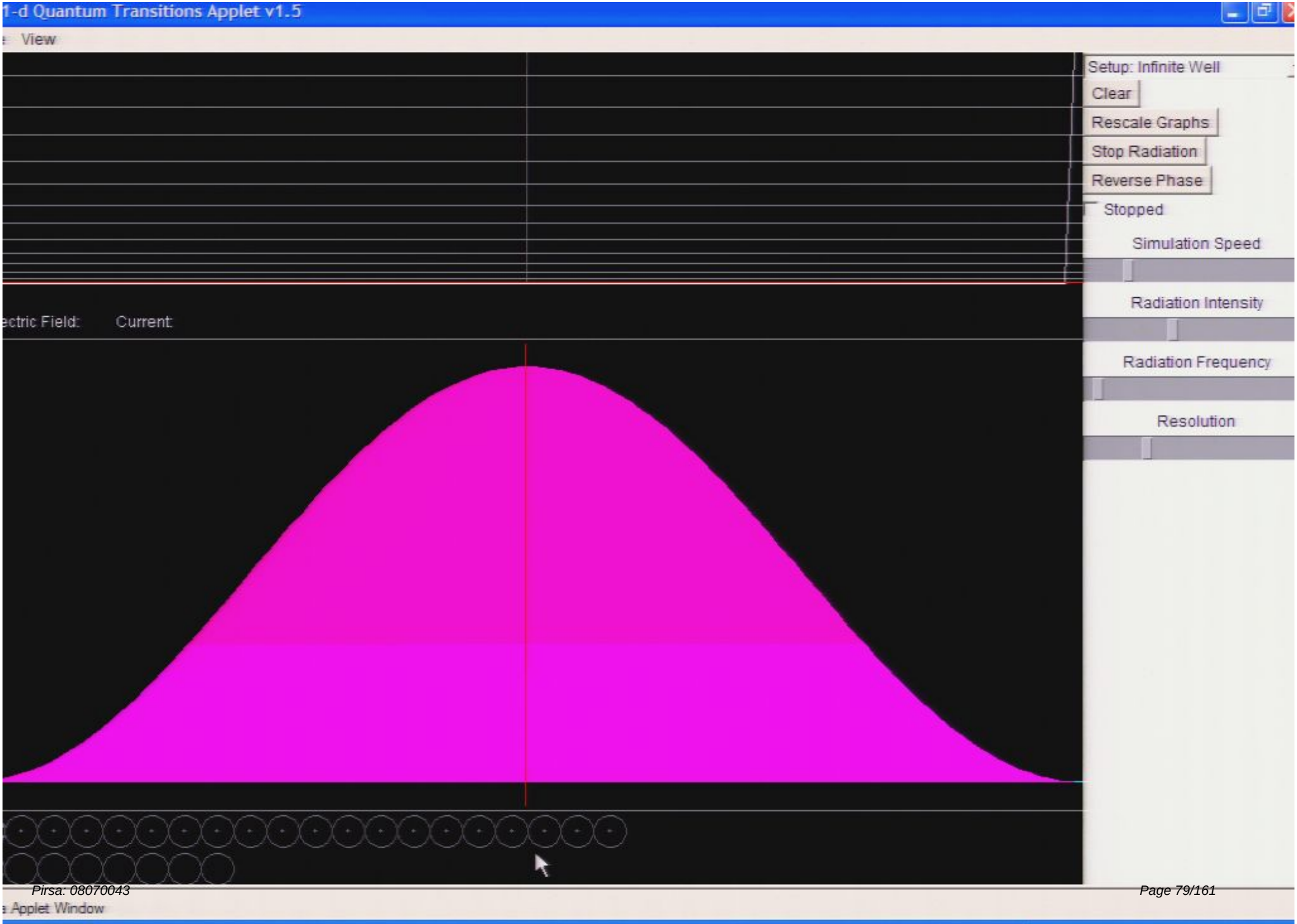
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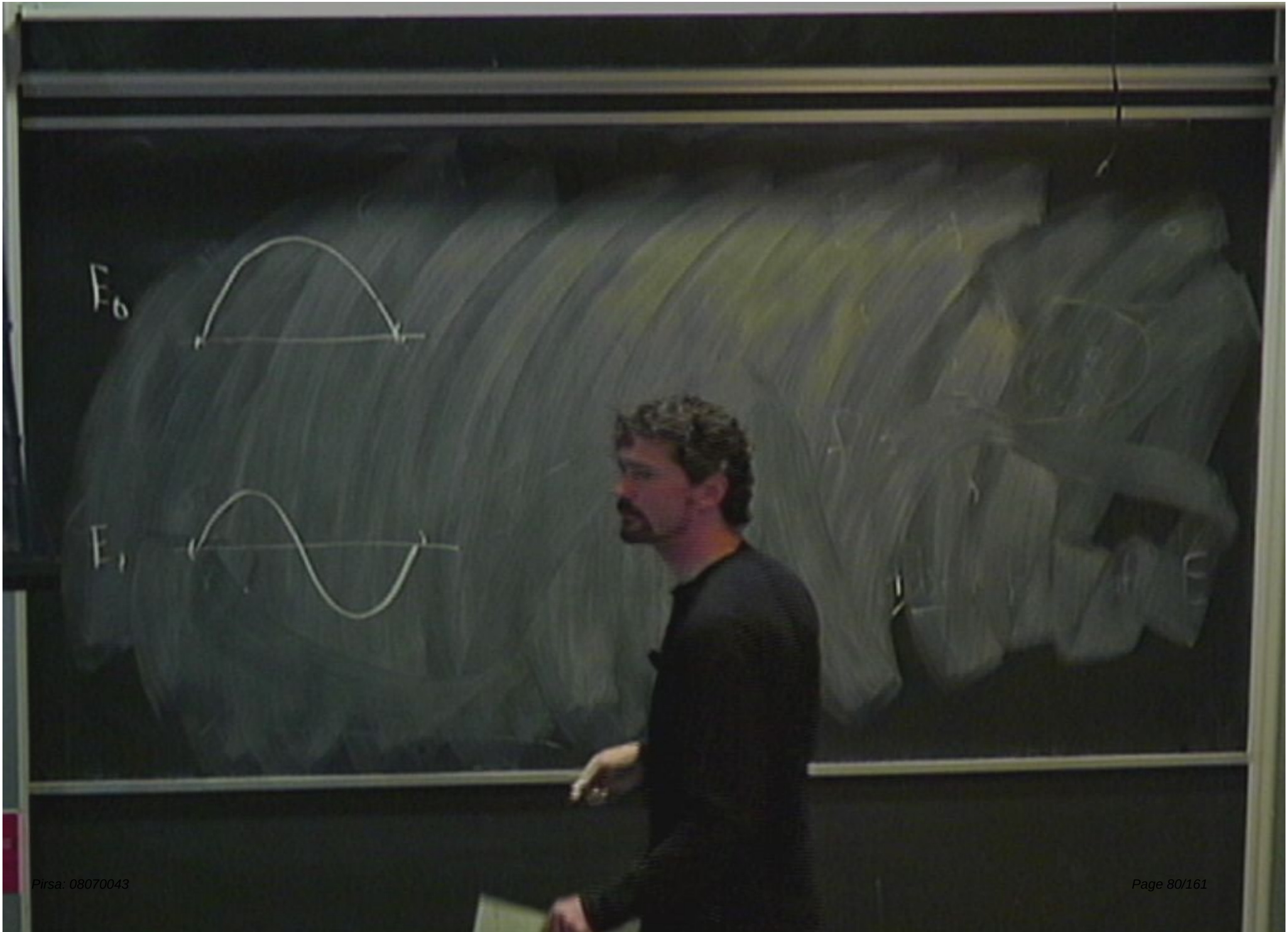
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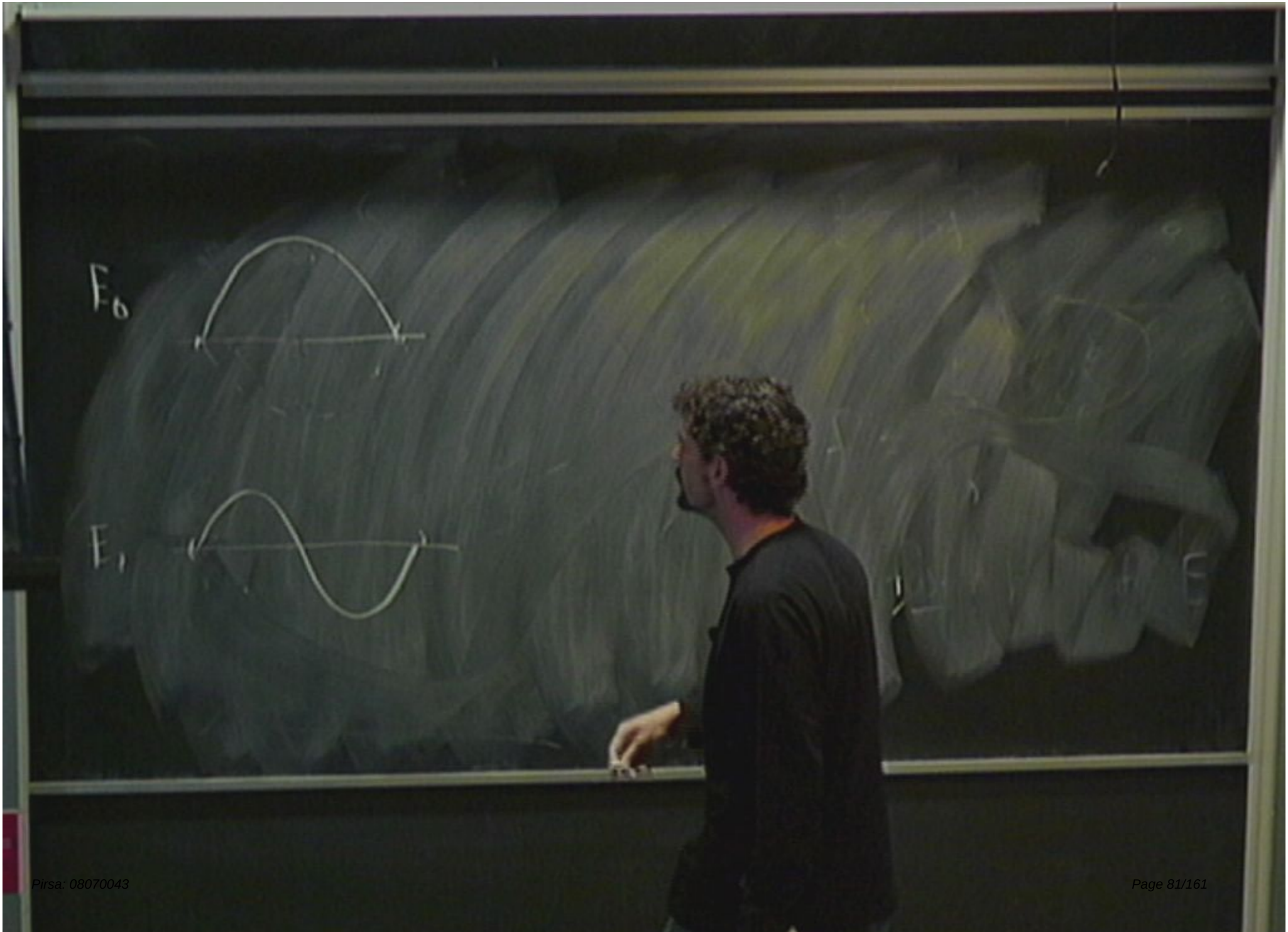
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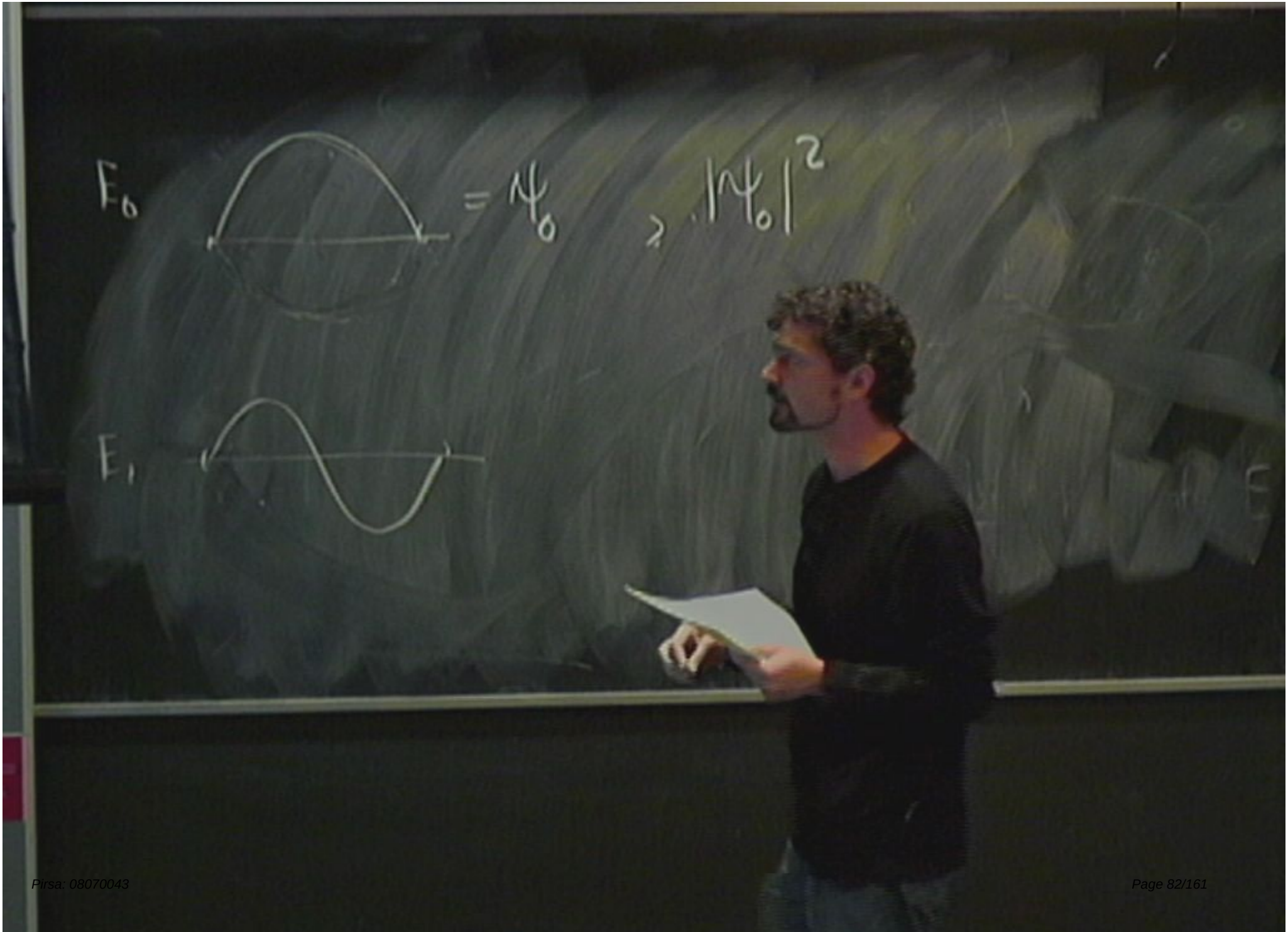
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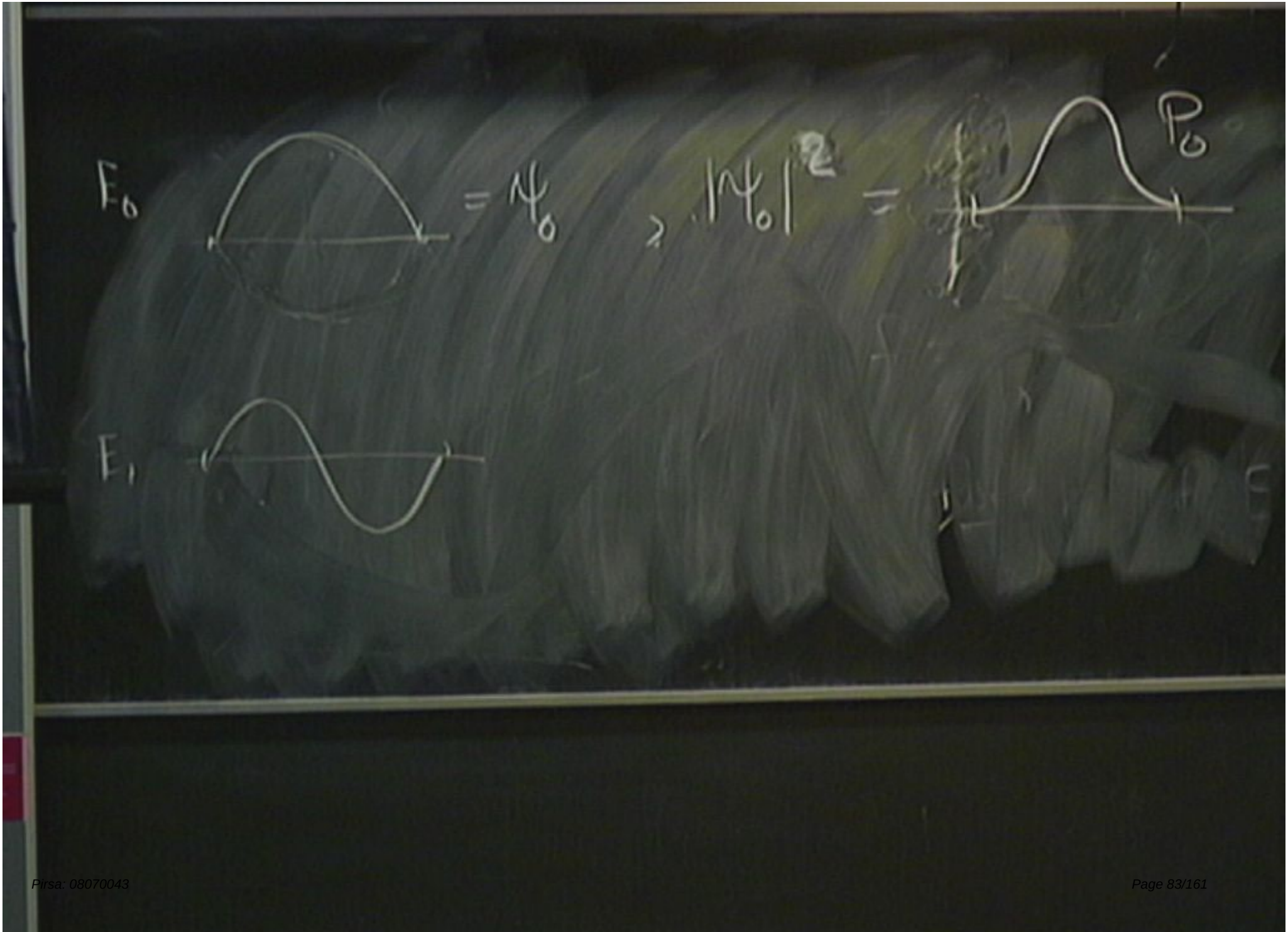
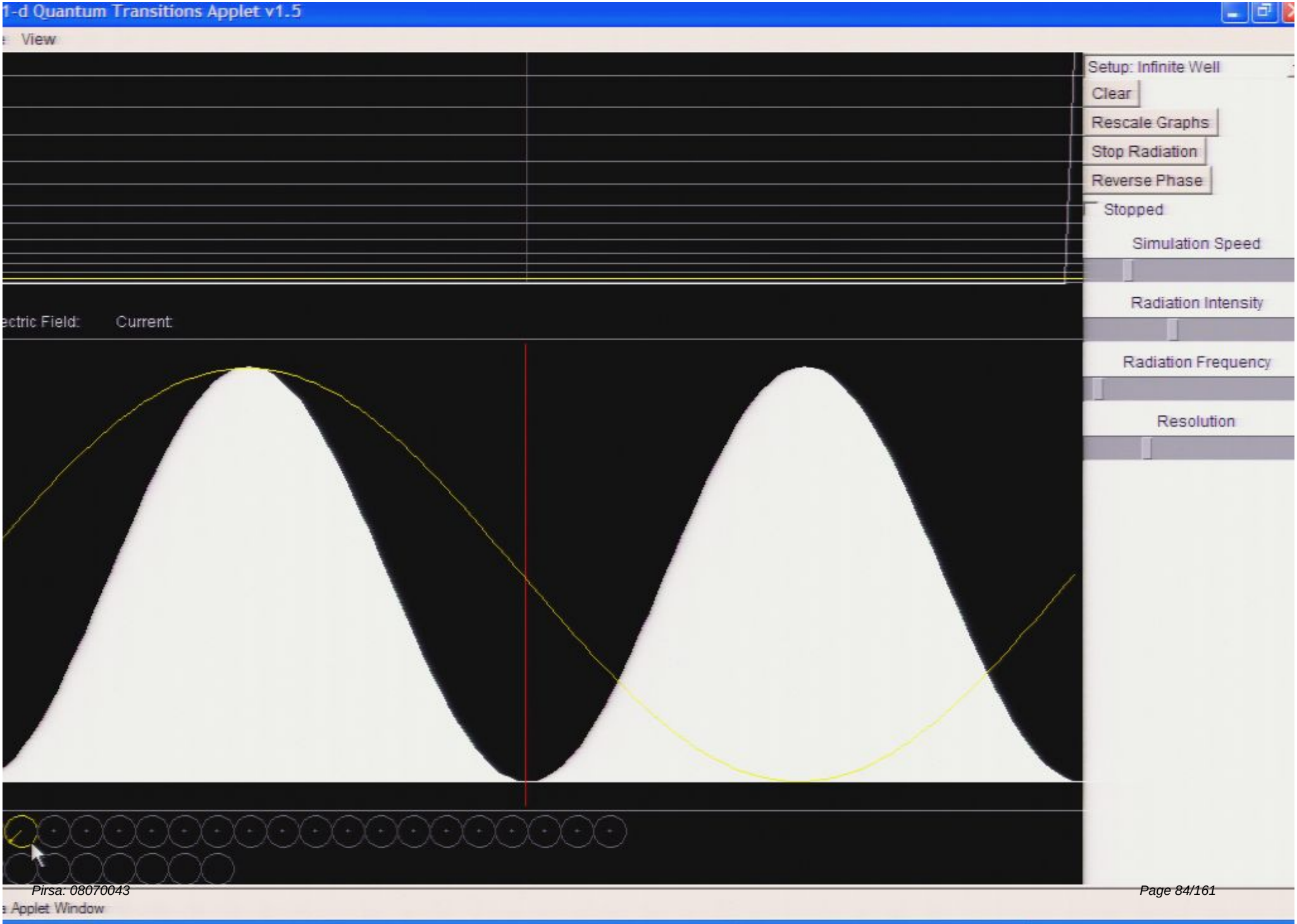
$= \Psi_0$
$\rightarrow |\Psi_0|^2$
E_1


E_0
$= \psi_0$
$\rightarrow |\psi_0|^2 =$
P_0
E_1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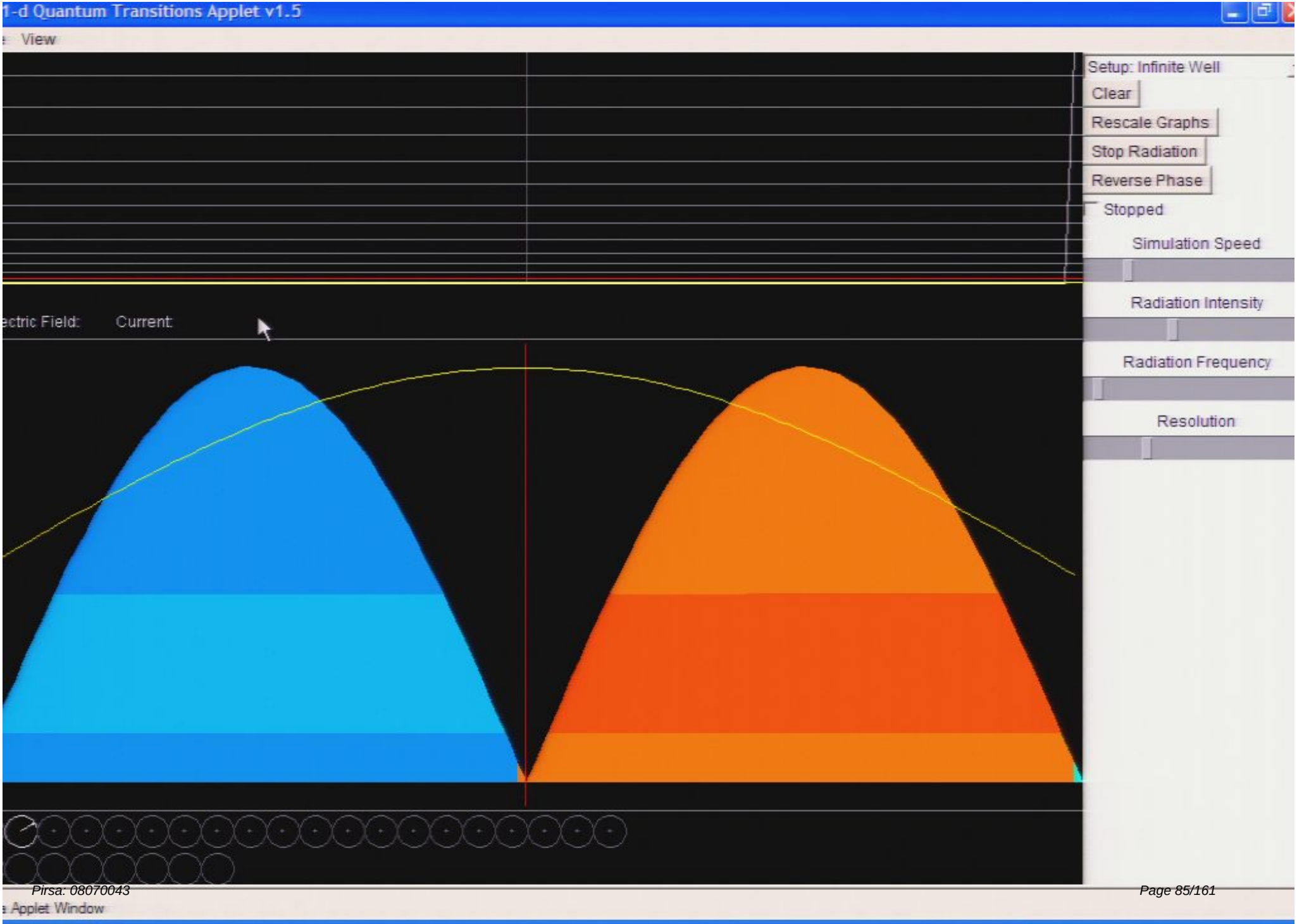
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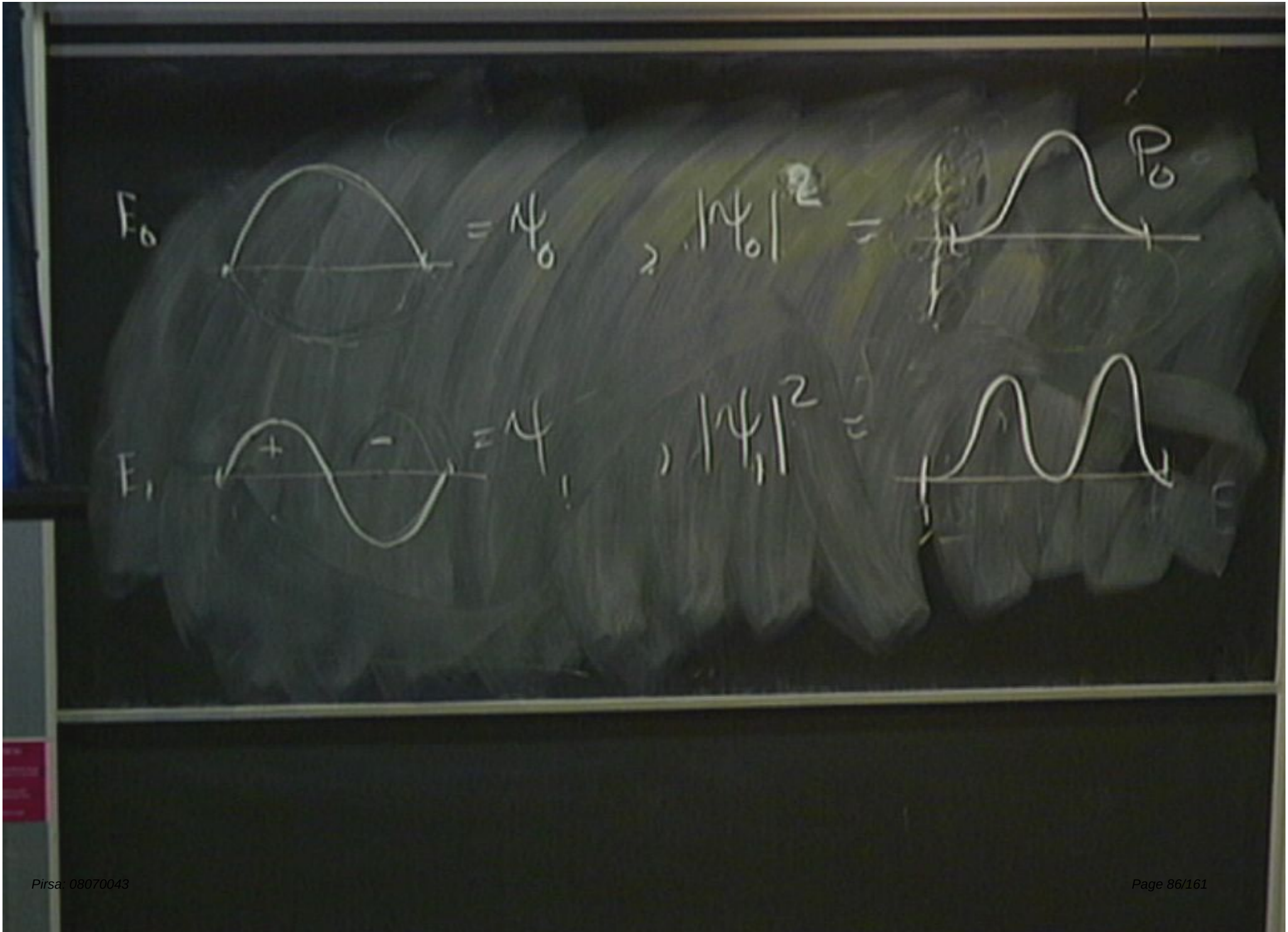
E_0
$= \psi_0$
$\rightarrow |\psi_0|^2 =$
P_0
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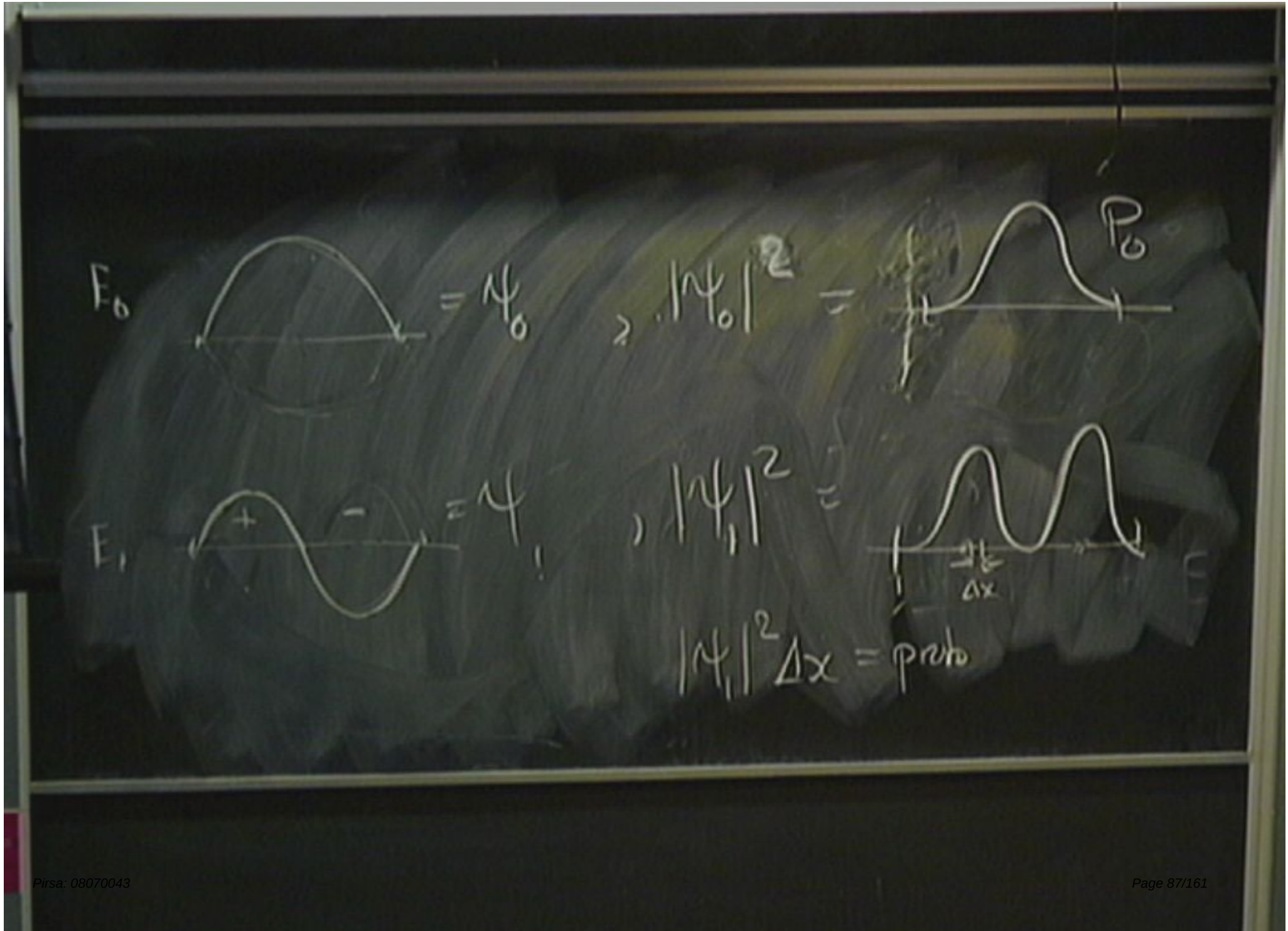
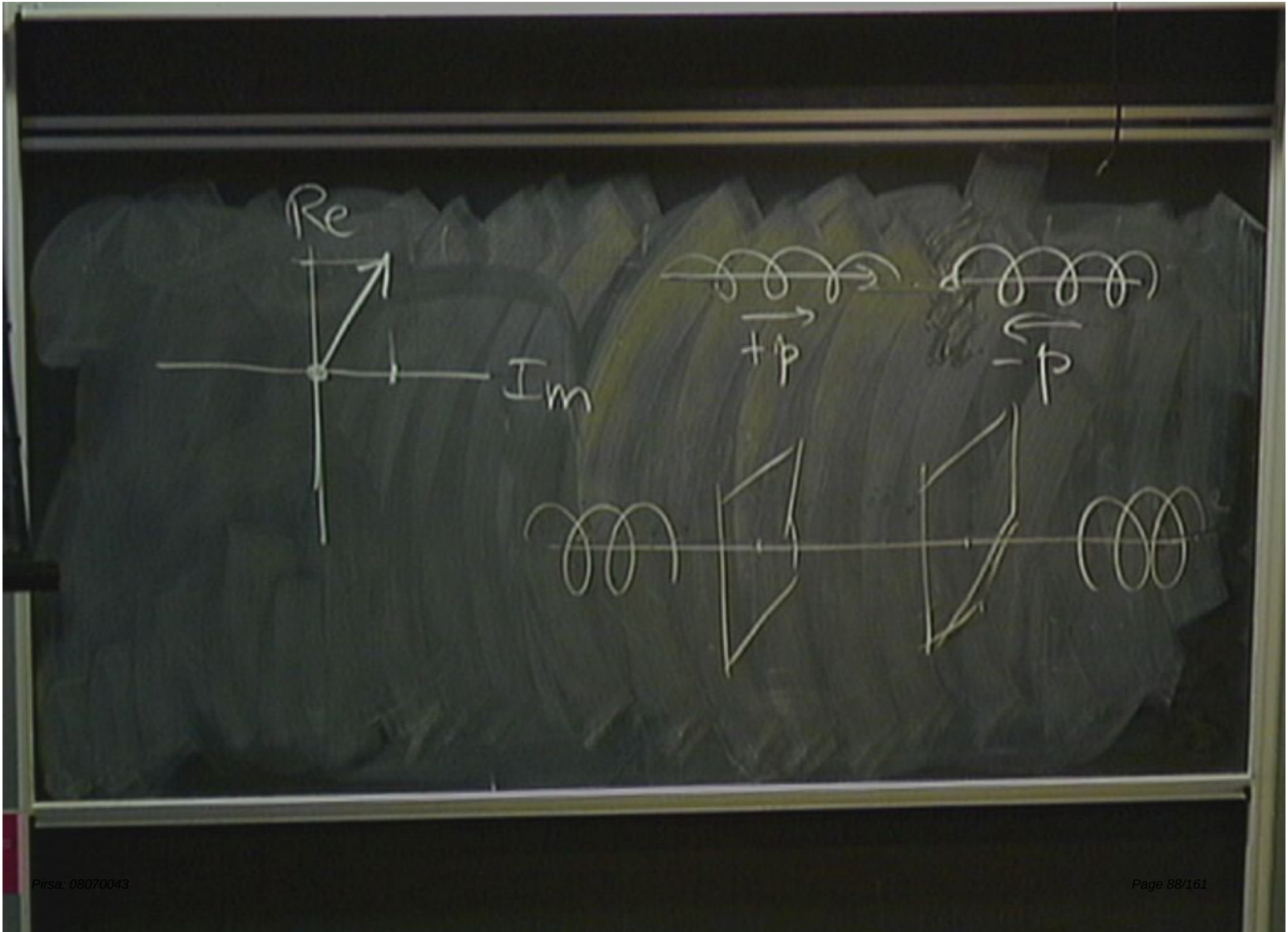
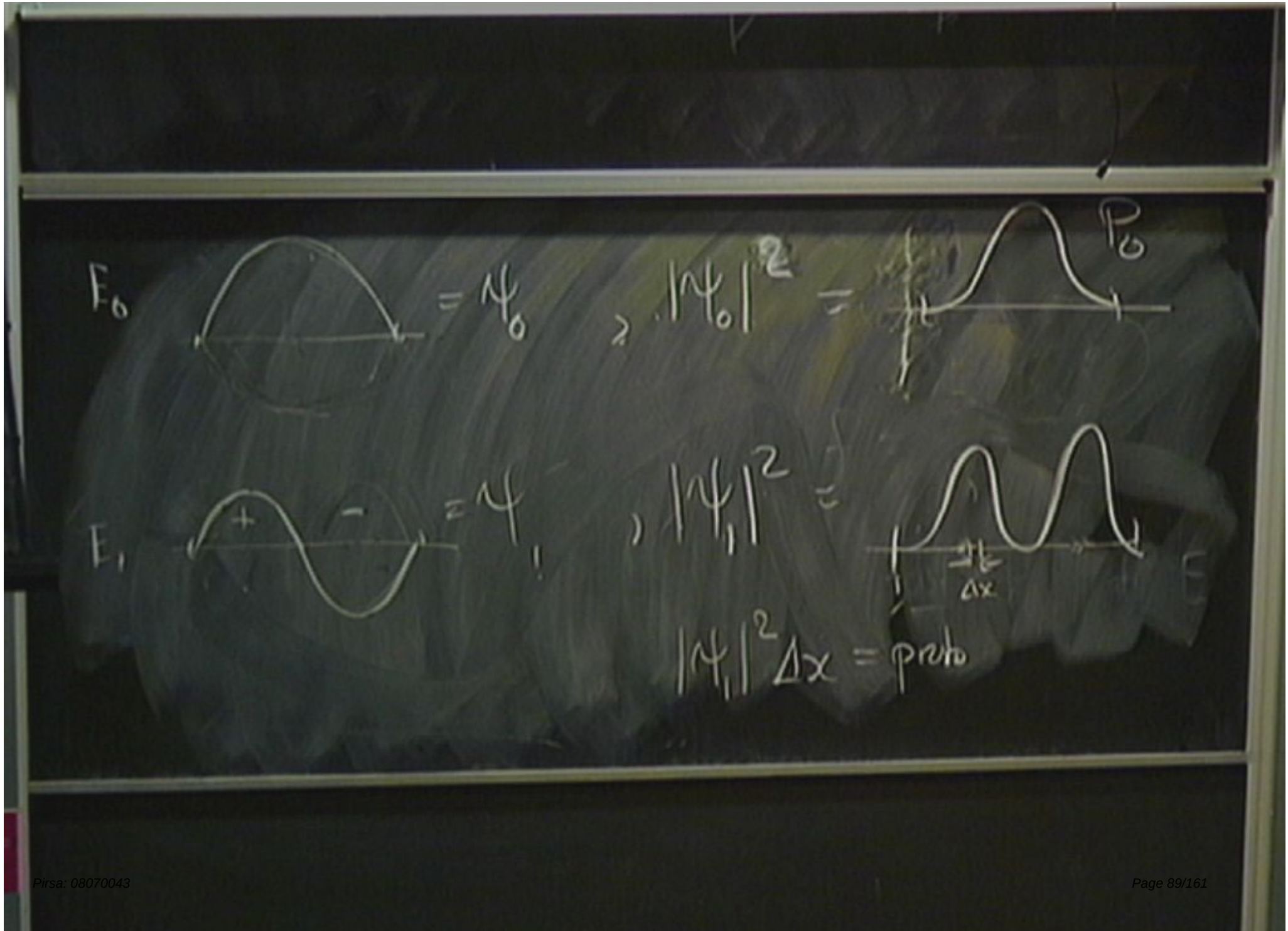
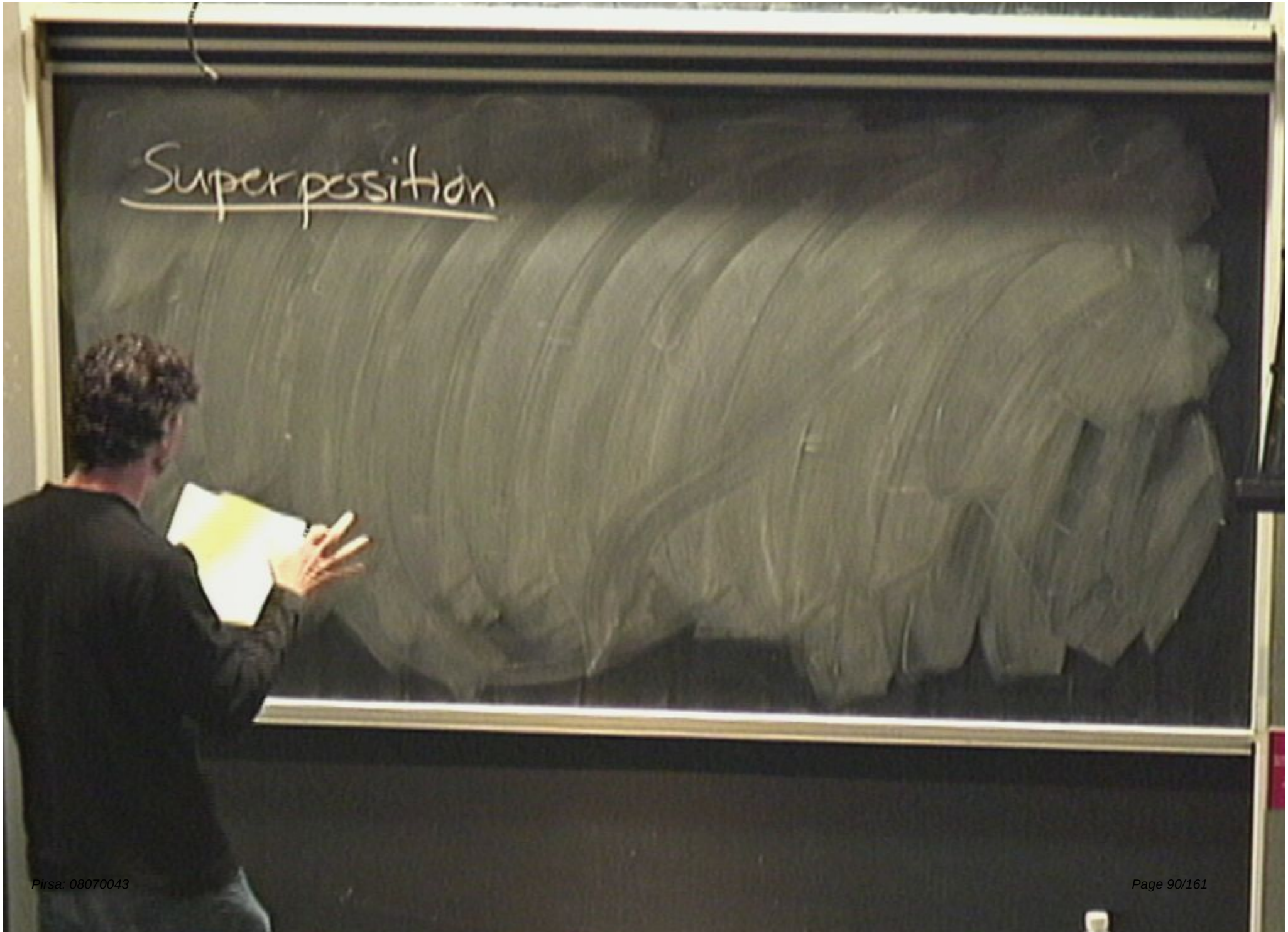
$= \psi_1$
$\rightarrow |\psi_1|^2 =$


E_0
$= \psi_0$
$\rightarrow |\psi_0|^2 =$
P_0
E_1
+
−
$= \psi_1$
$\rightarrow |\psi_1|^2 =$
Δx
$|\psi_1|^2 \Delta x = \text{prob}$


Re
Im
+p
-p

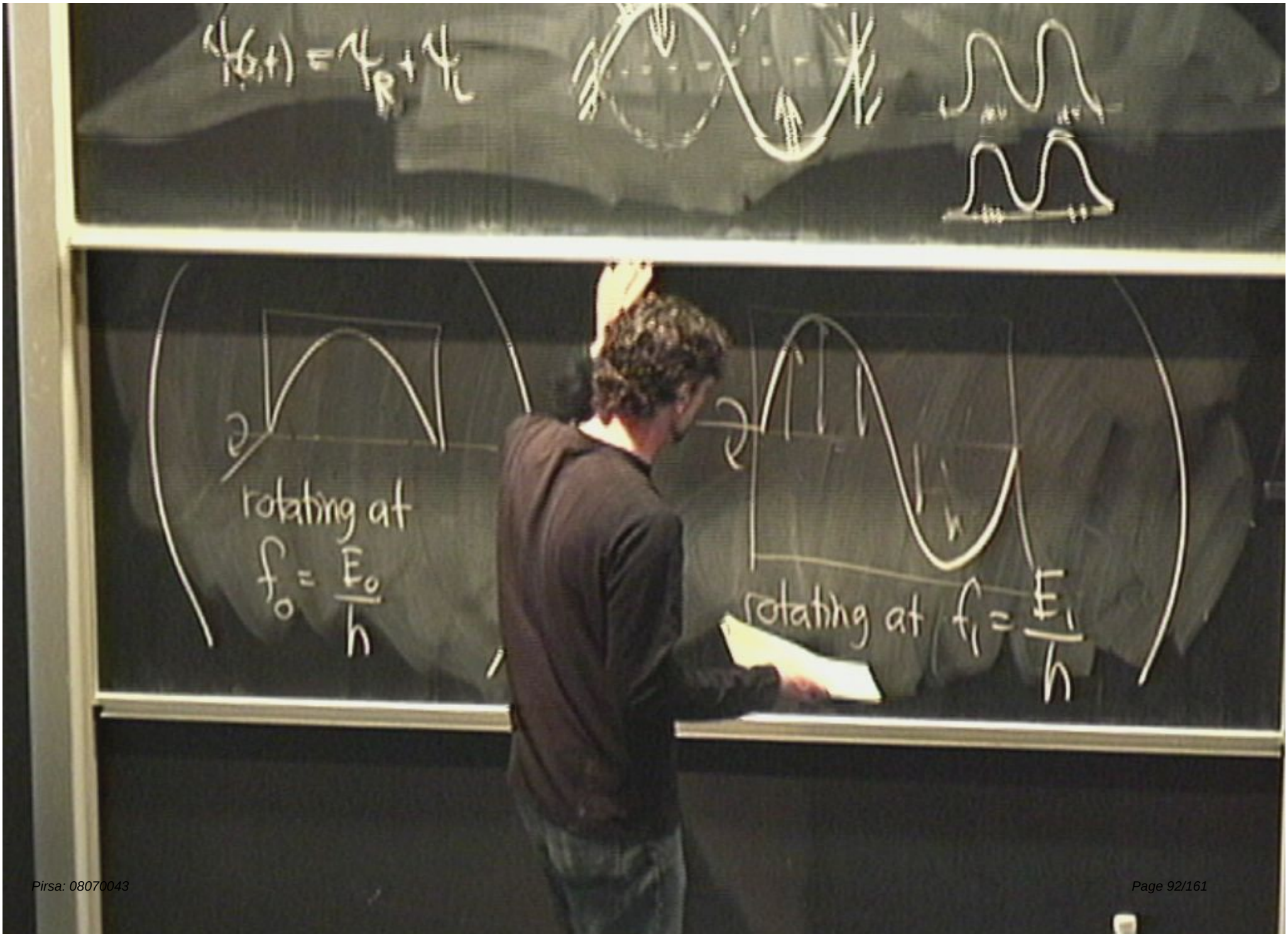

E_0
$= \psi_0$
$\rightarrow |\psi_0|^2 =$
P_0
E_1
$+$
$-$
$= \psi_1$
$\rightarrow |\psi_1|^2 =$
Δx
$|\psi_1|^2 \Delta x = \text{prob}$

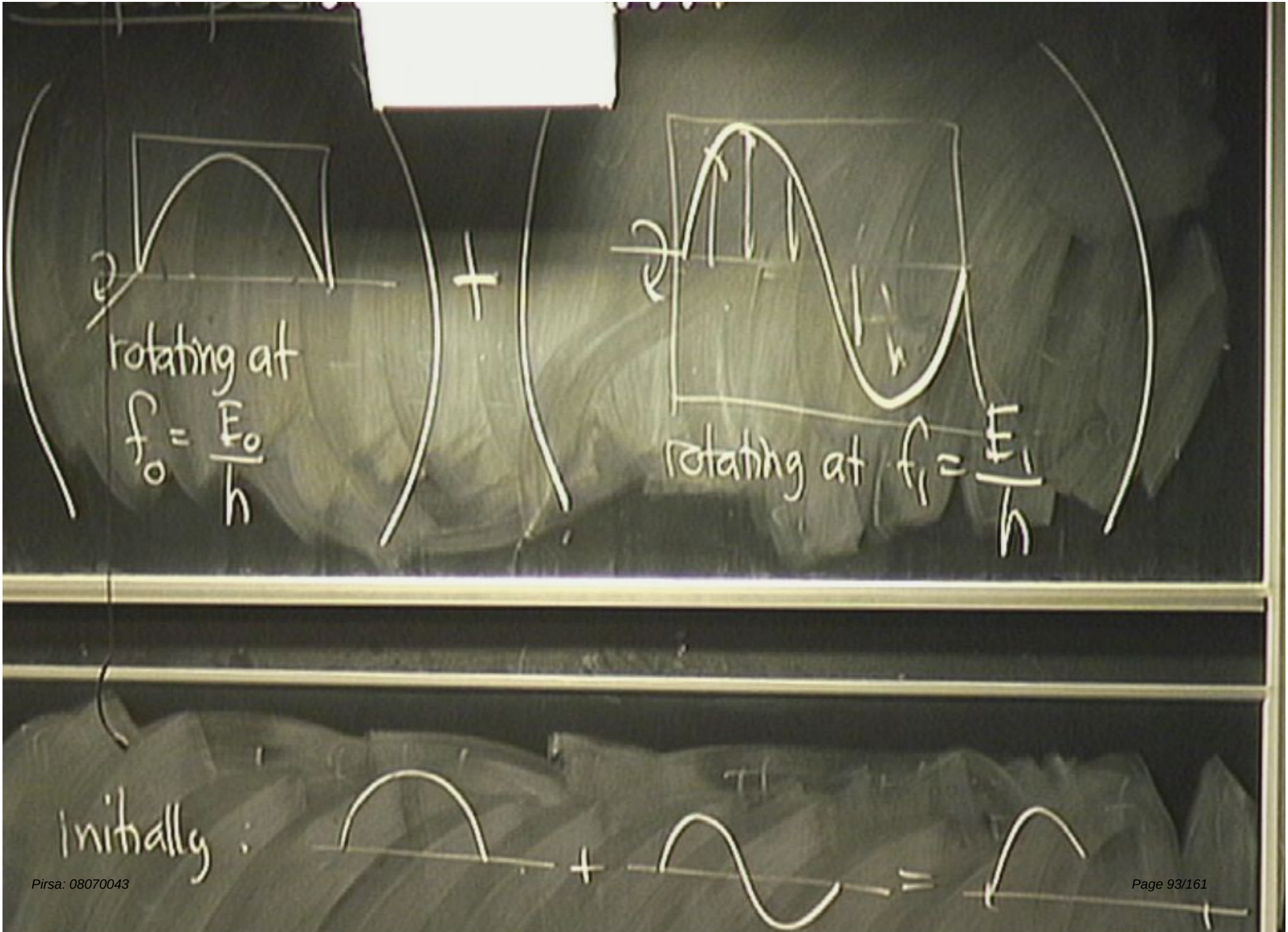

Superposition

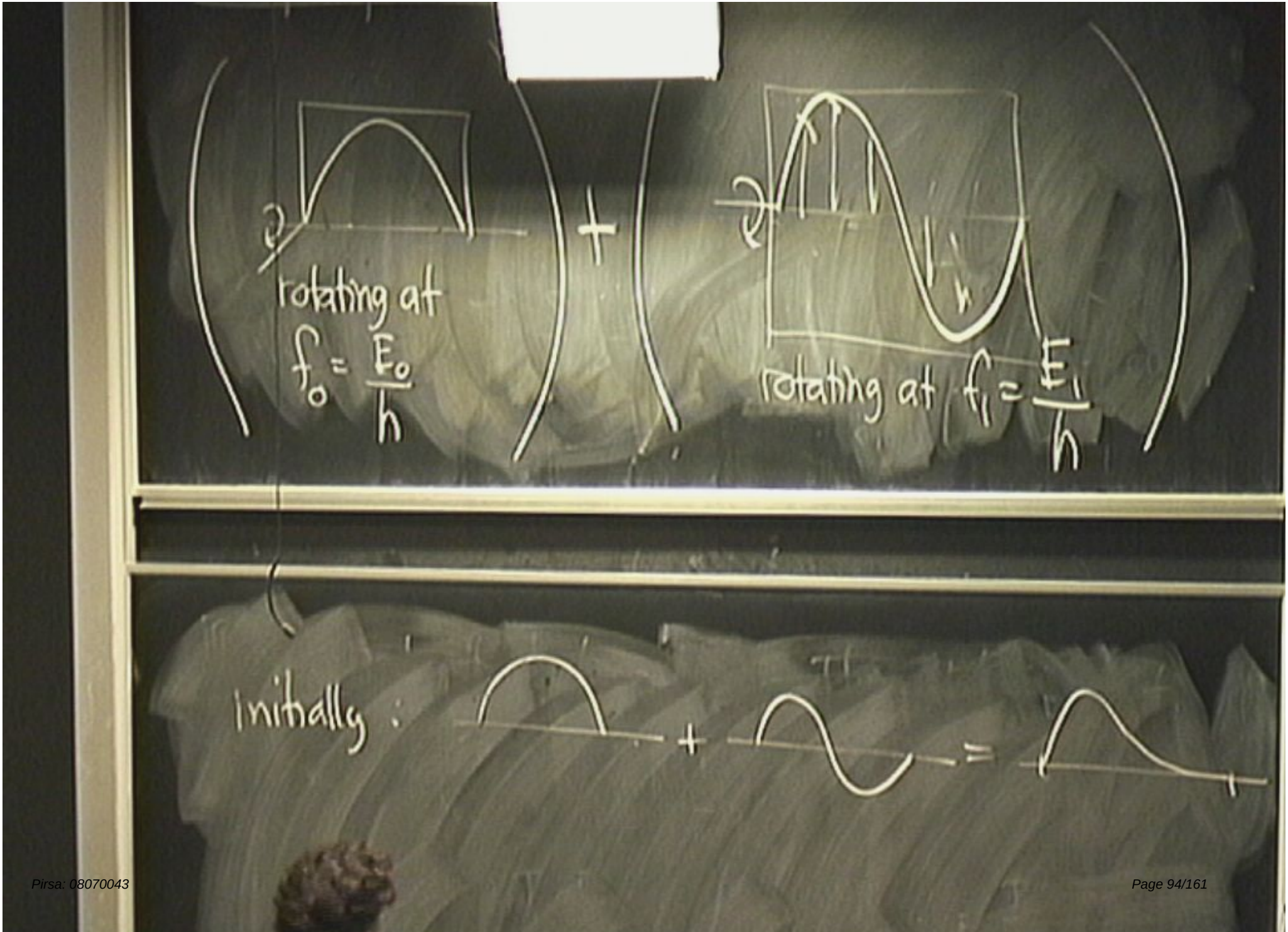
Superposition

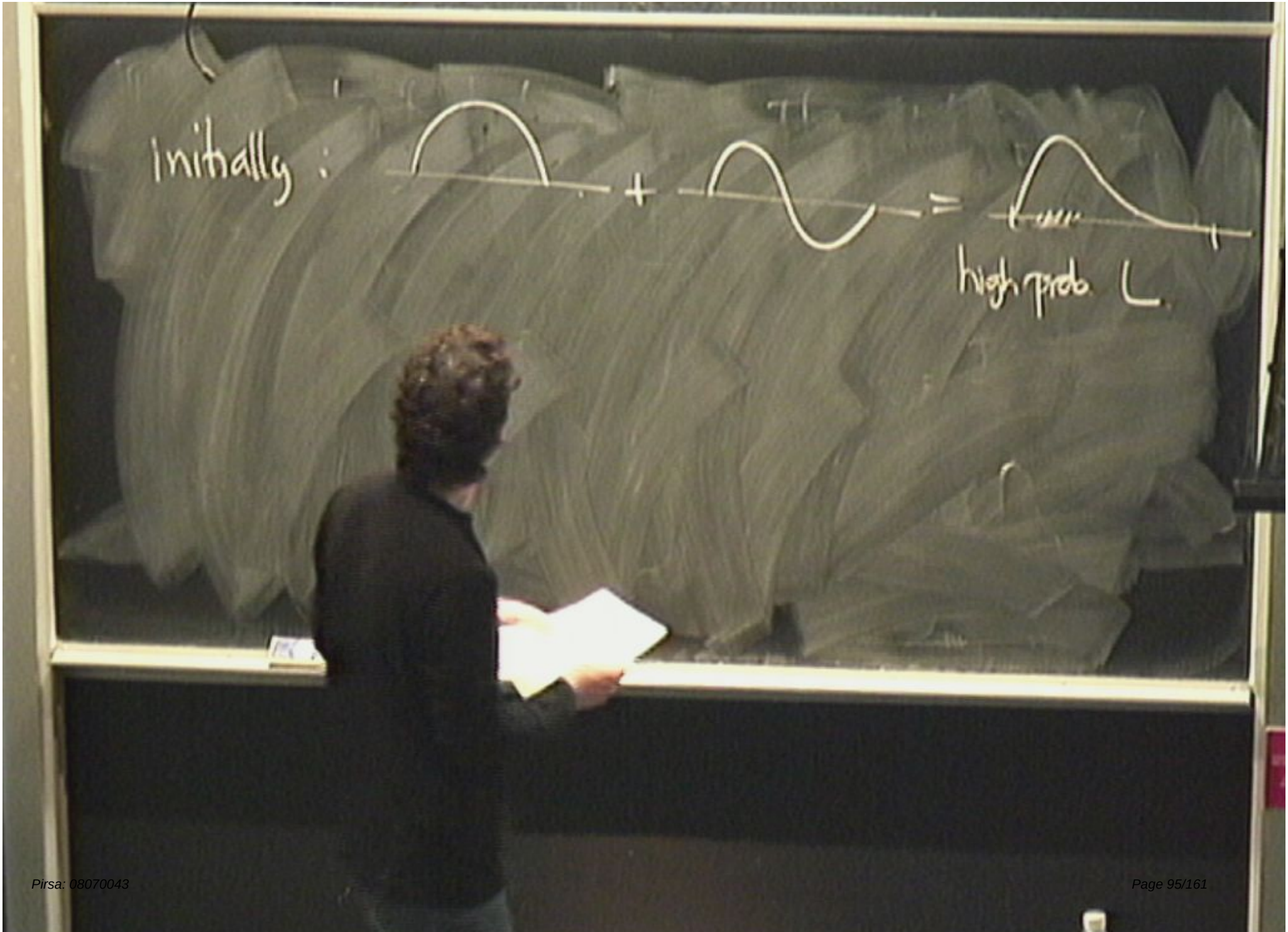
rotating at

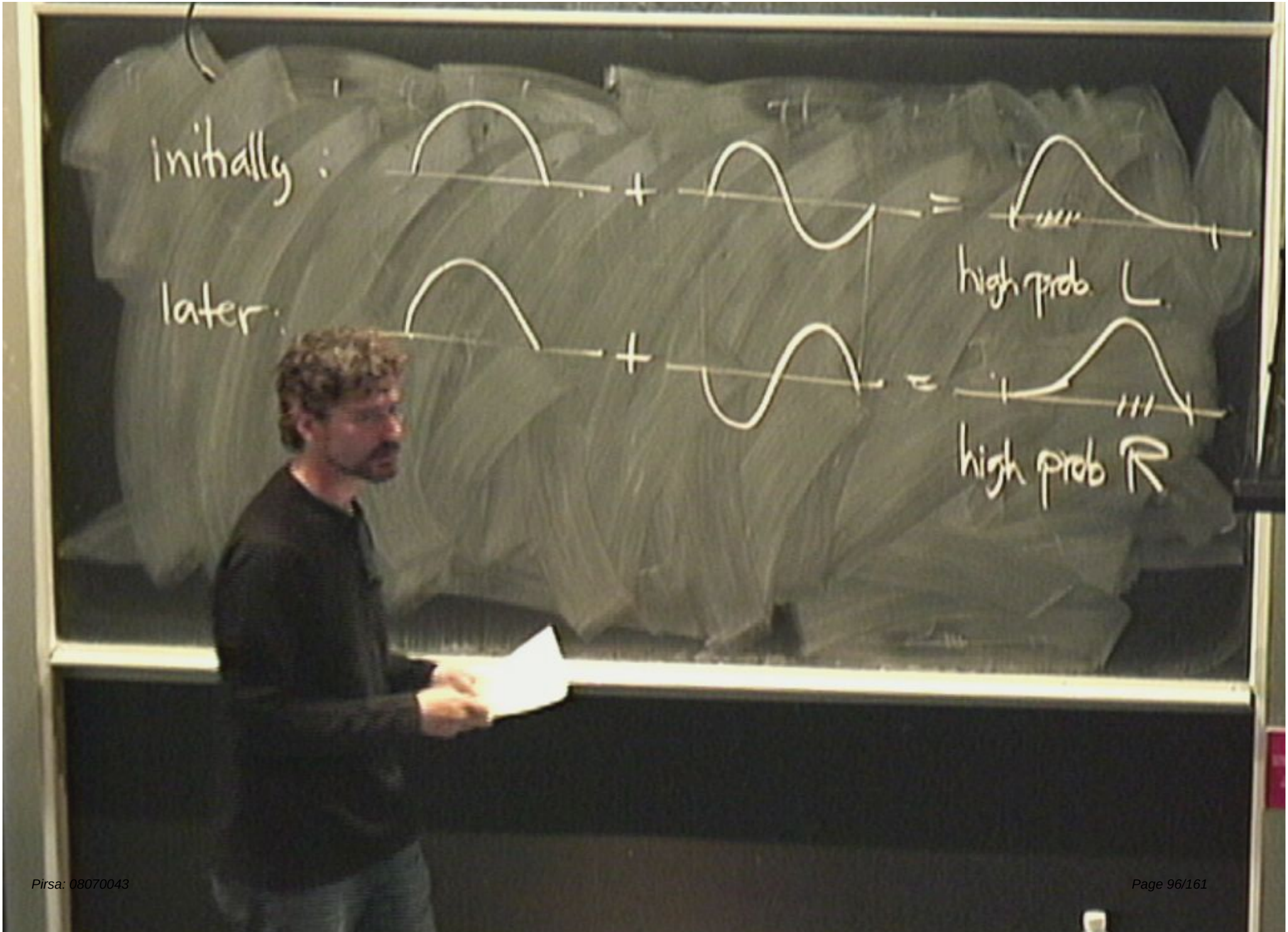
$$f_0 = \frac{E_0}{h}$$

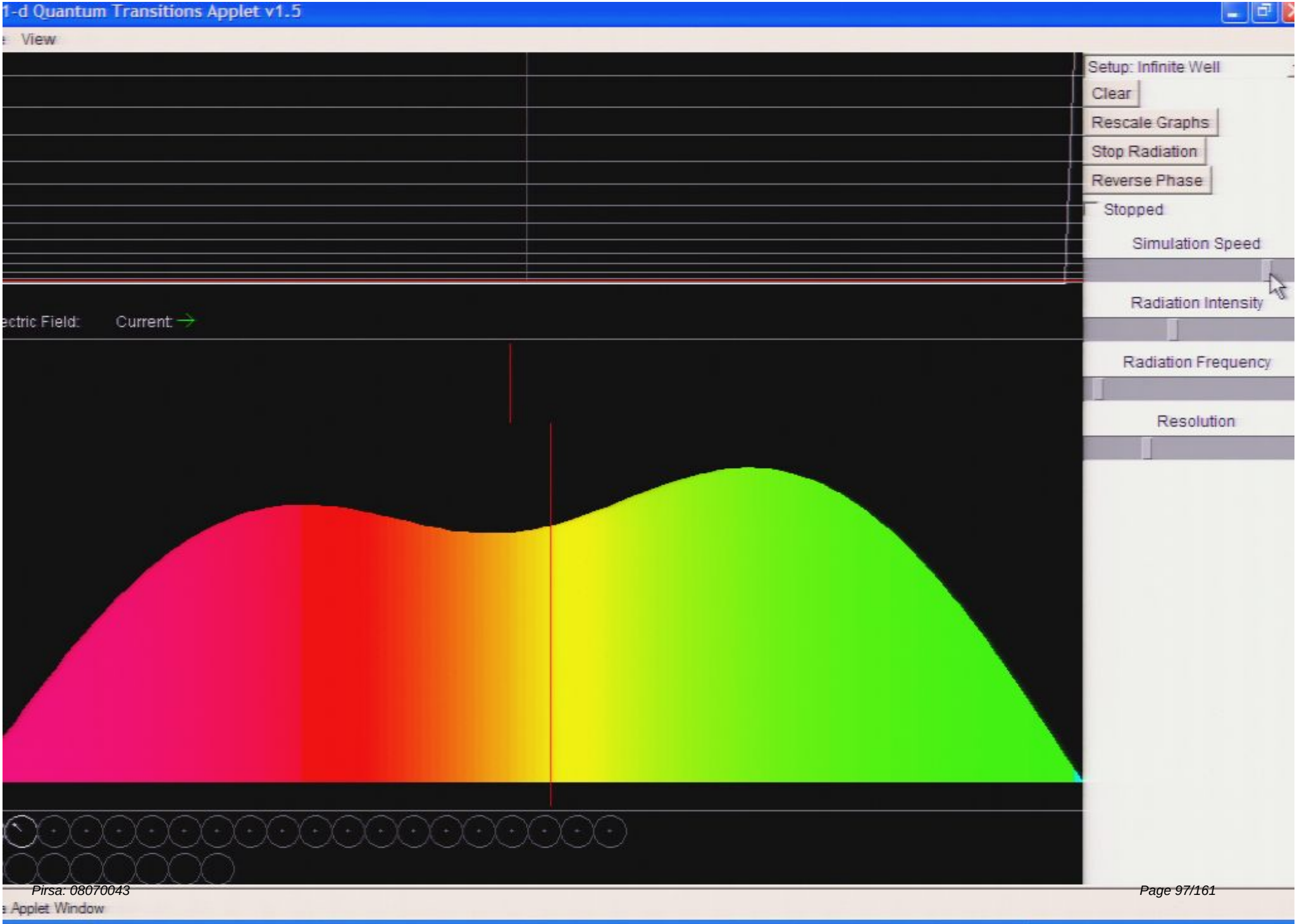

rotating at
$f_0 = \frac{E_0}{h}$
rotating at $f_1 = \frac{E_1}{h}$

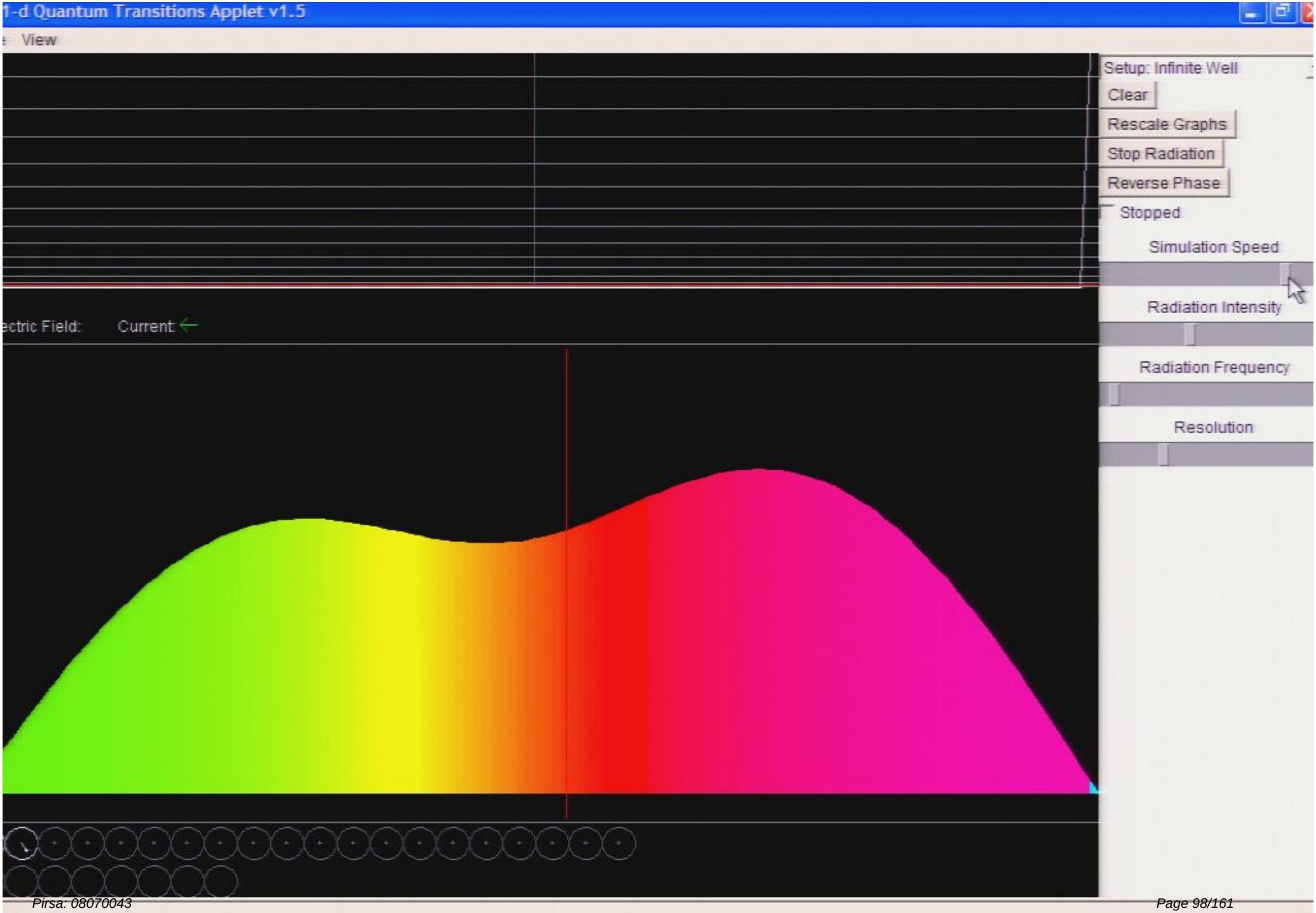

rotating at
$f_0 = \frac{E_0}{h}$
rotating at $f_1 = \frac{E_1}{h}$
Initially :


rotating at
$f_0 = \frac{E_0}{h}$
rotating at $f_1 = \frac{E_1}{h}$
initially :


Initially :
+
=
high prob.


initially :
high prob. L
later :
high prob R


1-d Quantum Transitions Applet v1.5
View
Setup: Infinite Well
Clear
Rescale Graphs
Stop Radiation
Reverse Phase
Stopped
Simulation Speed
Radiation Intensity
Radiation Frequency
Resolution
ectric Field:
Current:
Applet Window


1-d Quantum Transitions Applet v1.5
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Setup: Infinite Well
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Rescale Graphs
Stop Radiation
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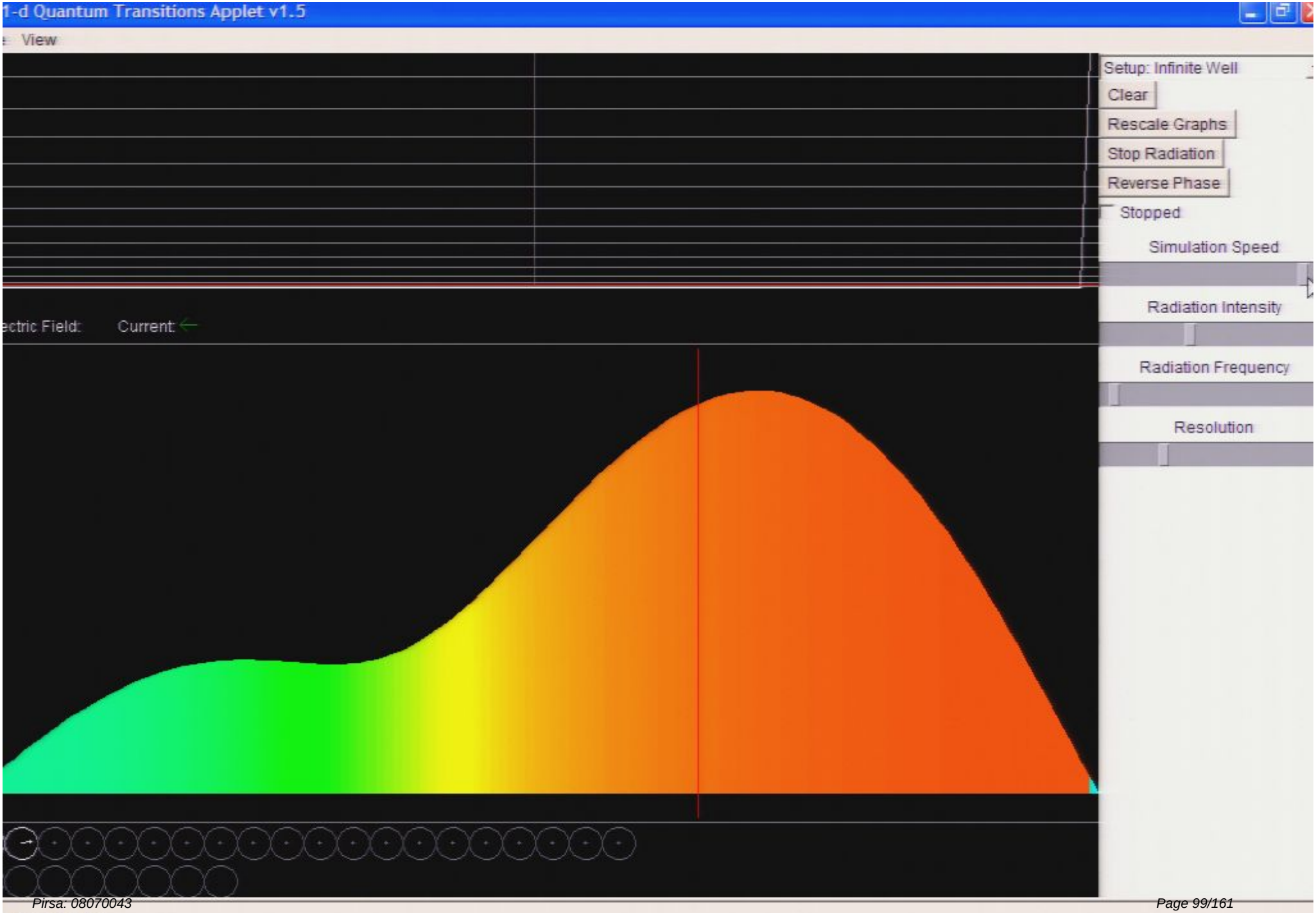
Simulation Speed
Radiation Intensity
Radiation Frequency
Resolution
ectric Field:
Current:
Applet Window


1-d Quantum Transitions Applet v1.5
View
Setup: Infinite Well
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Rescale Graphs
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Reverse Phase
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Simulation Speed
Radiation Intensity
Radiation Frequency
Resolution
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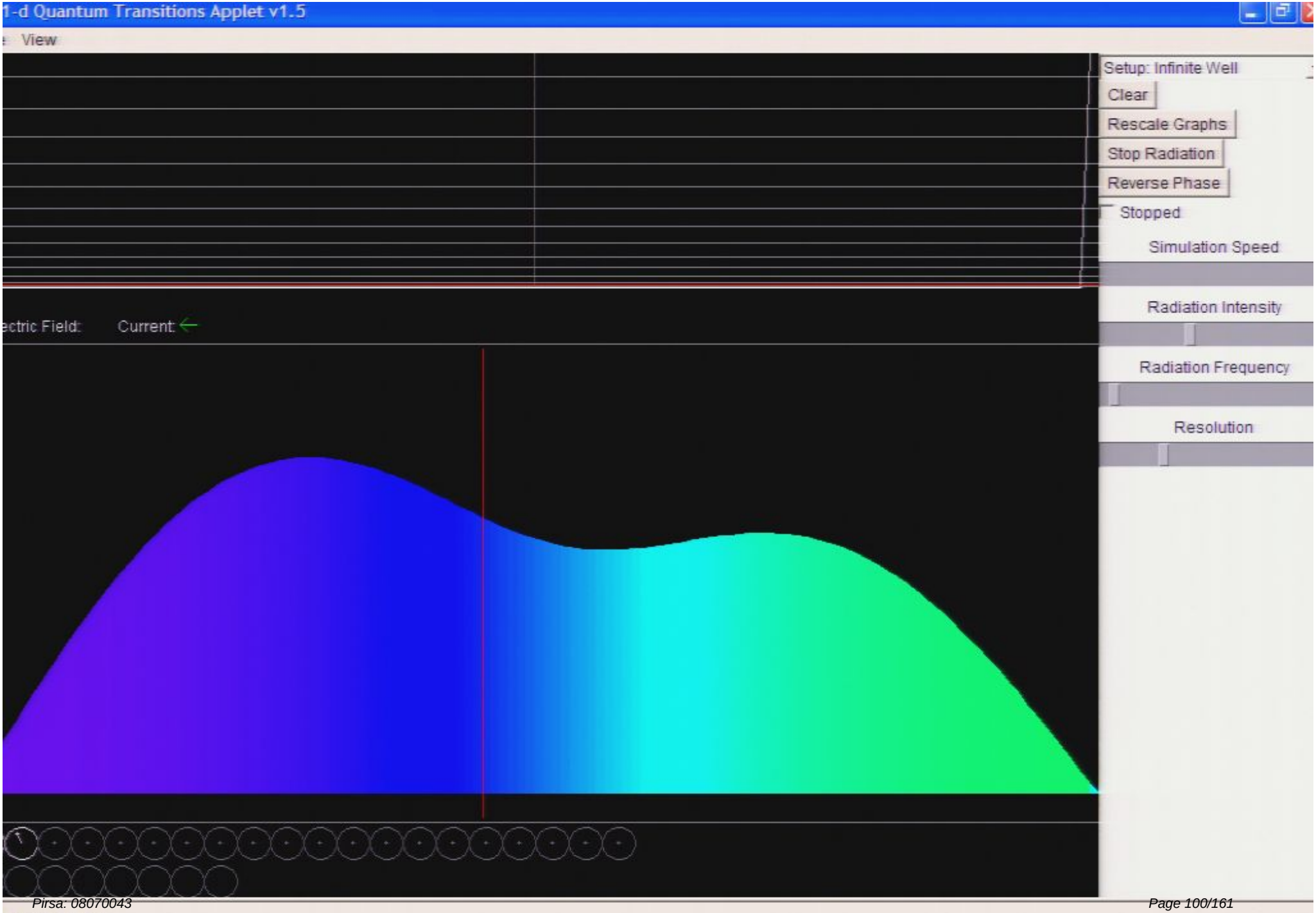
Current:
Applet Window


1-d Quantum Transitions Applet v1.5
View
Setup: Infinite Well
Clear
Rescale Graphs
Stop Radiation
Reverse Phase
Stopped
Simulation Speed
Radiation Intensity
Radiation Frequency
Resolution
ectric Field:
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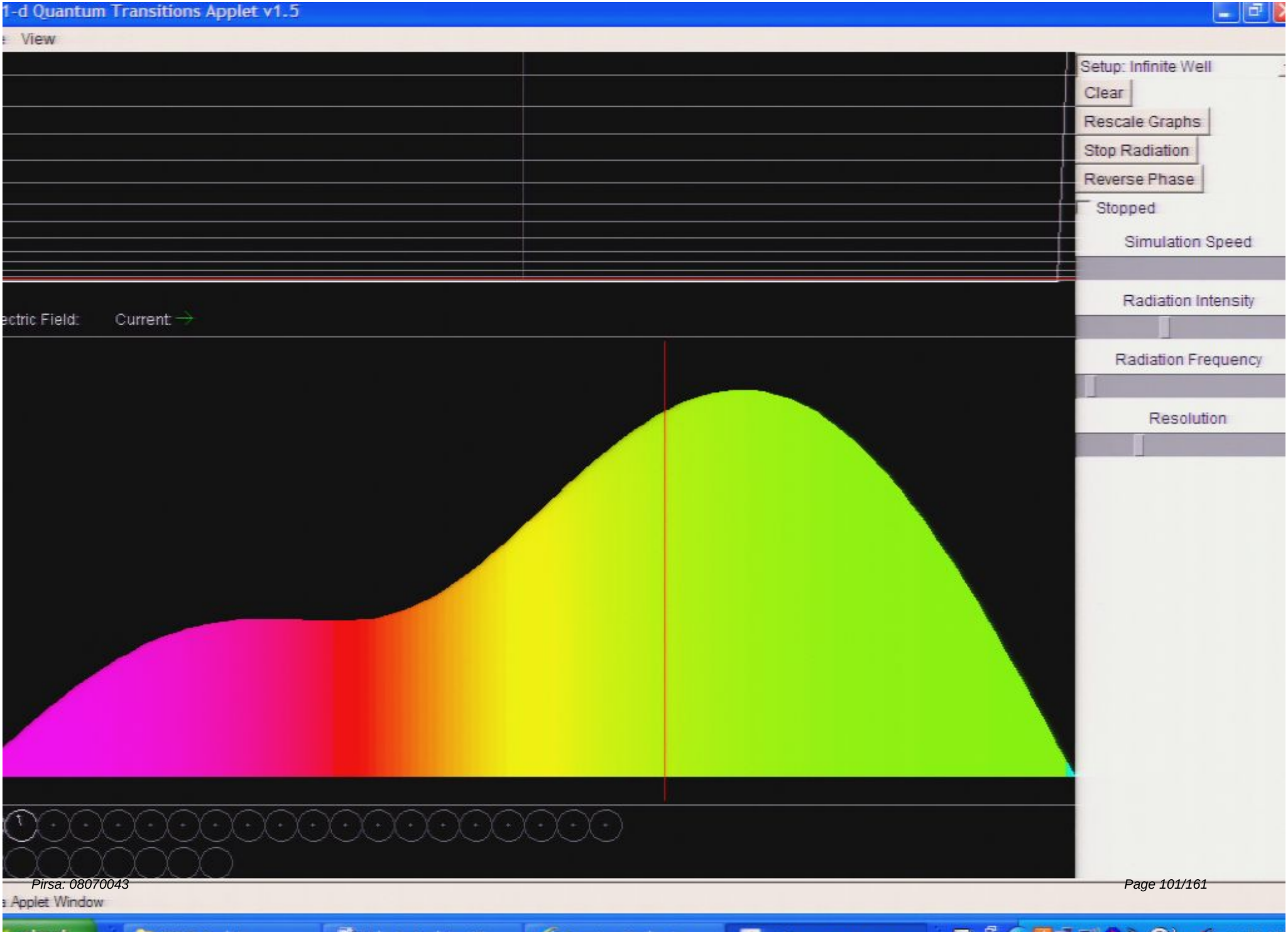
Applet Window


1-d Quantum Transitions Applet v1.5
View
Setup: Infinite Well
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Rescale Graphs
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Stopped
Simulation Speed
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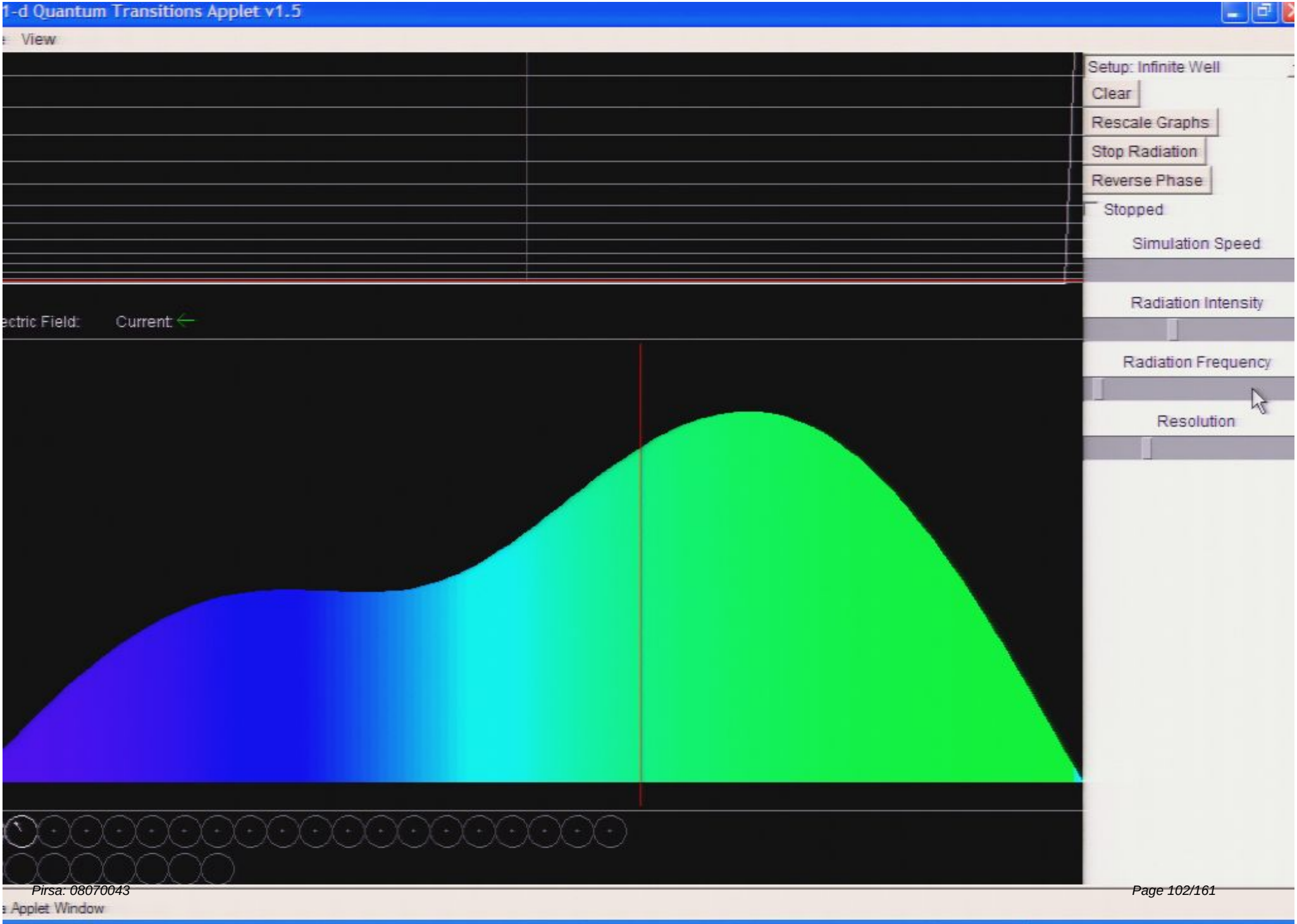
1-d Quantum Transitions Applet v1.5
View
Setup: Infinite Well
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Rescale Graphs
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Reverse Phase
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Simulation Speed
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Radiation Frequency
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ectric Field:
Current:
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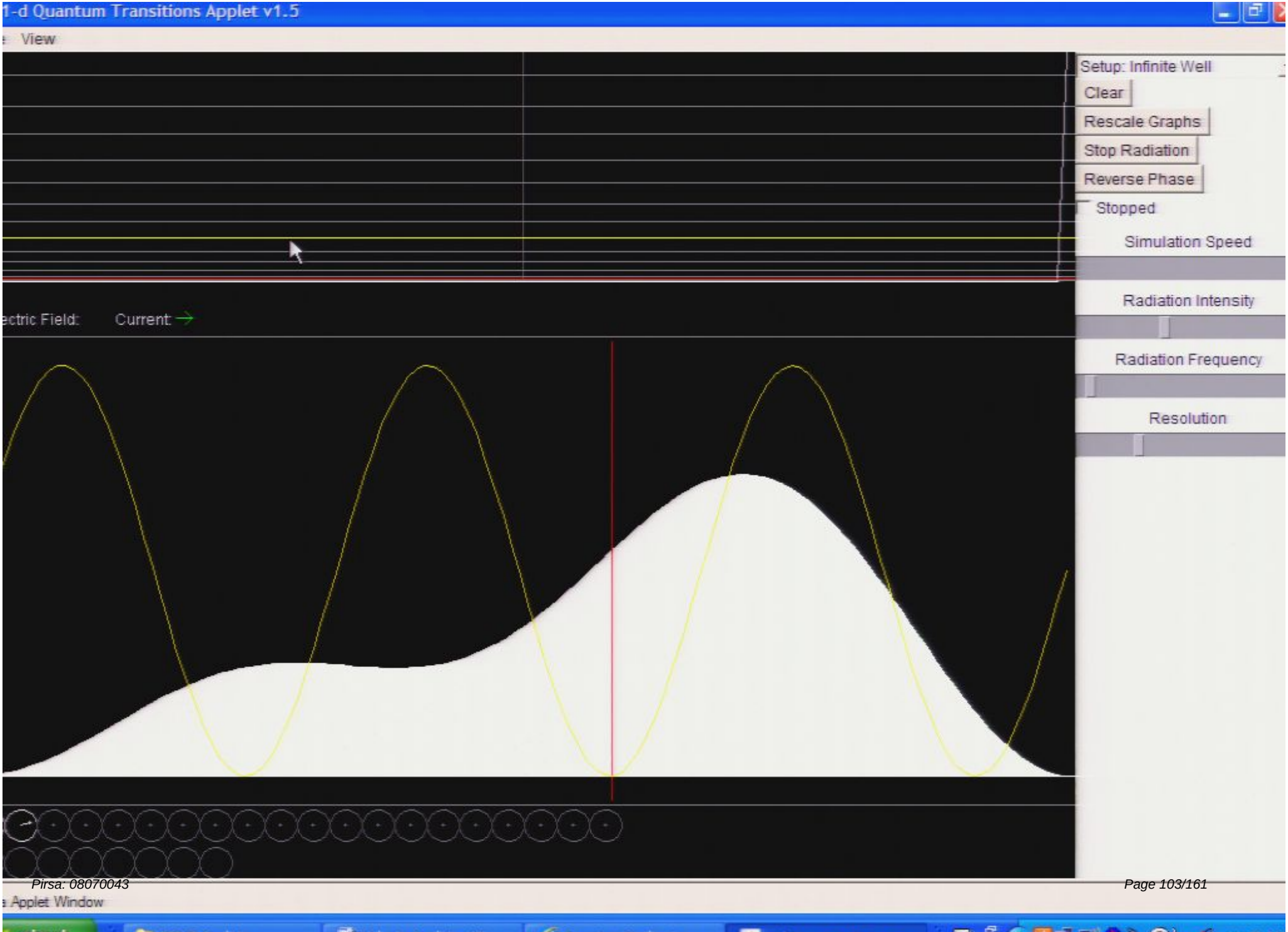
1-d Quantum Transitions Applet v1.5
View
Setup: Infinite Well
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Rescale Graphs
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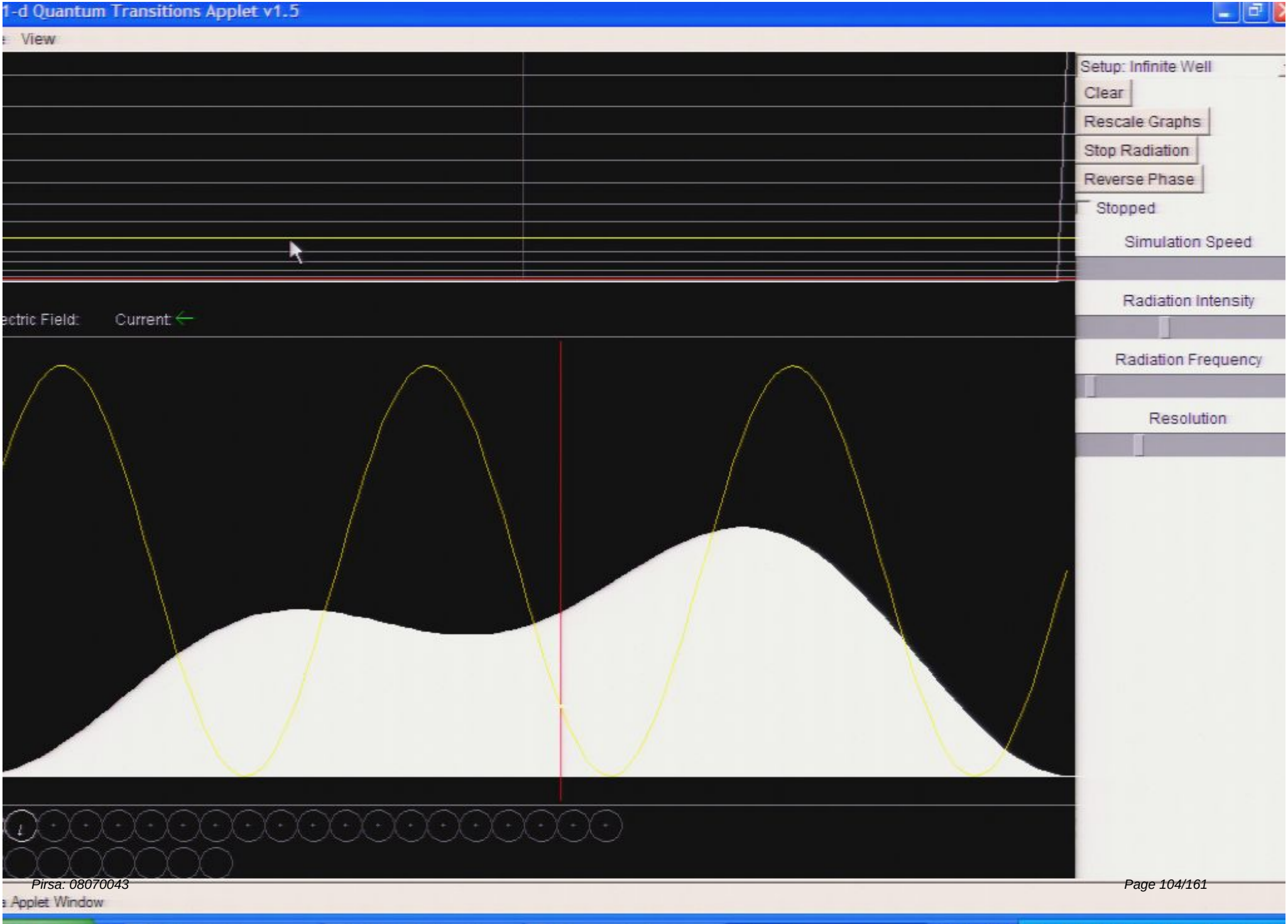
1-d Quantum Transitions Applet v1.5
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Rescale Graphs
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Reverse Phase
Stopped
Simulation Speed
Radiation Intensity
Radiation Frequency
Resolution
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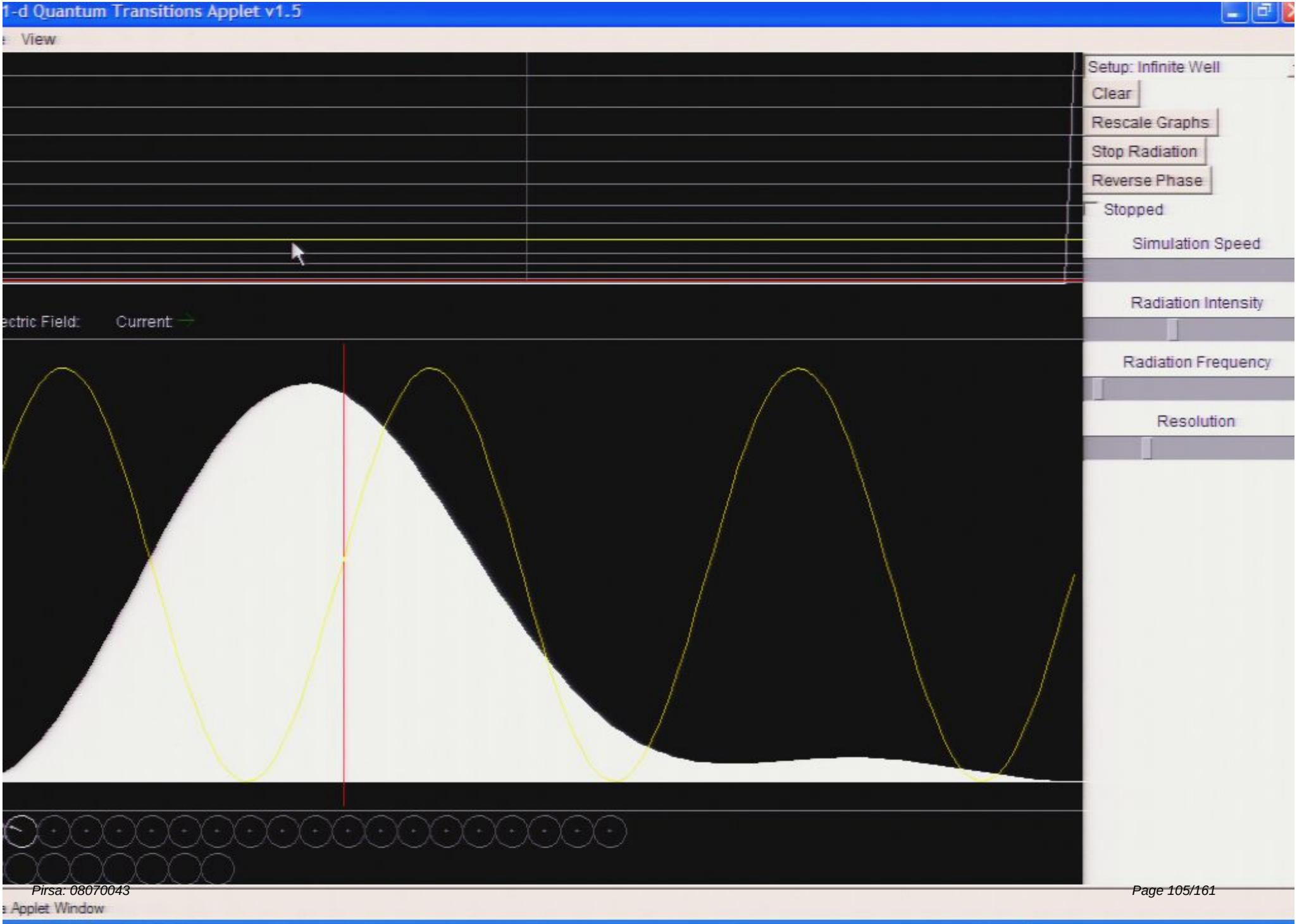
1-d Quantum Transitions Applet v1.5
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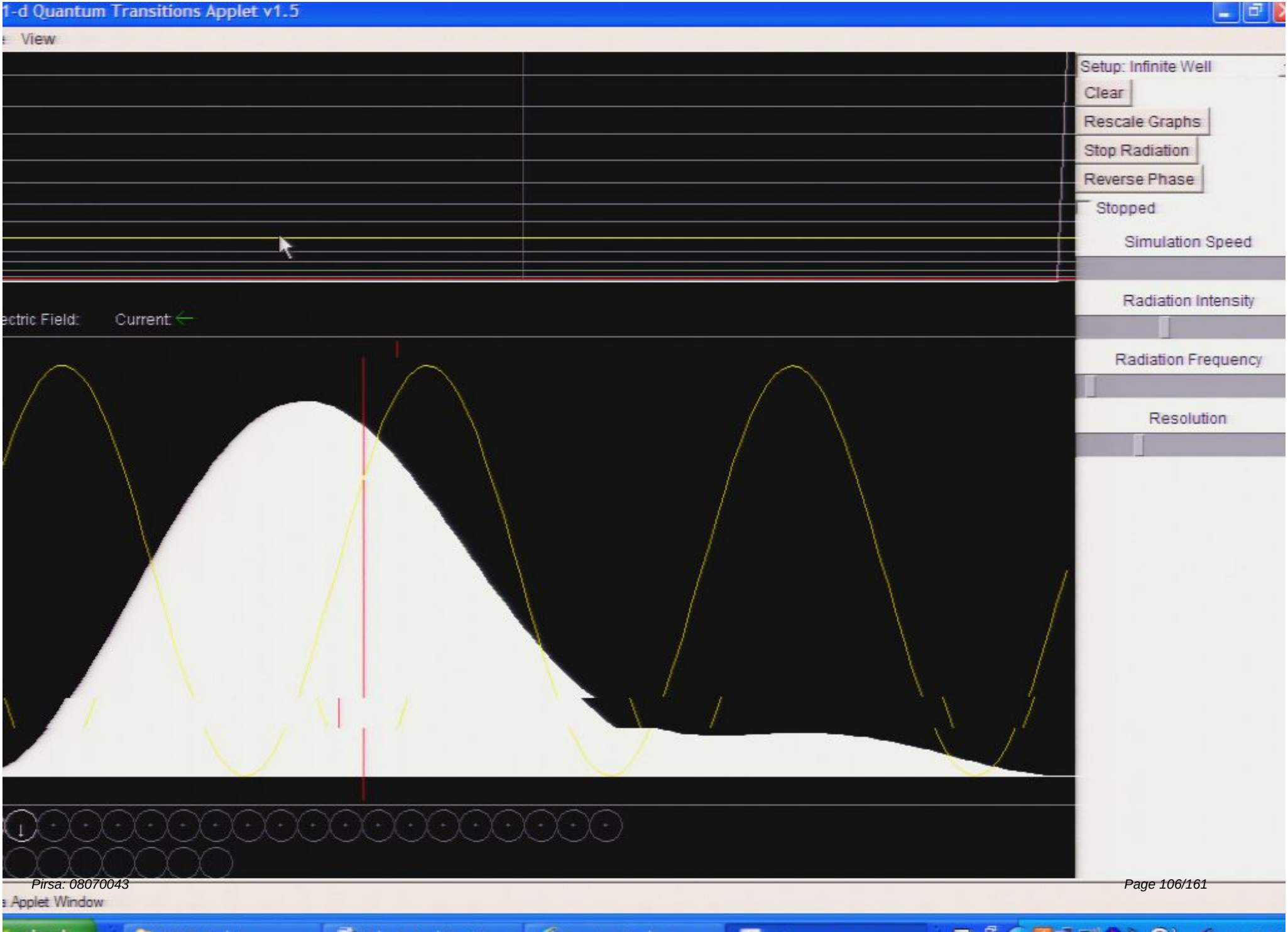
1-d Quantum Transitions Applet v1.5
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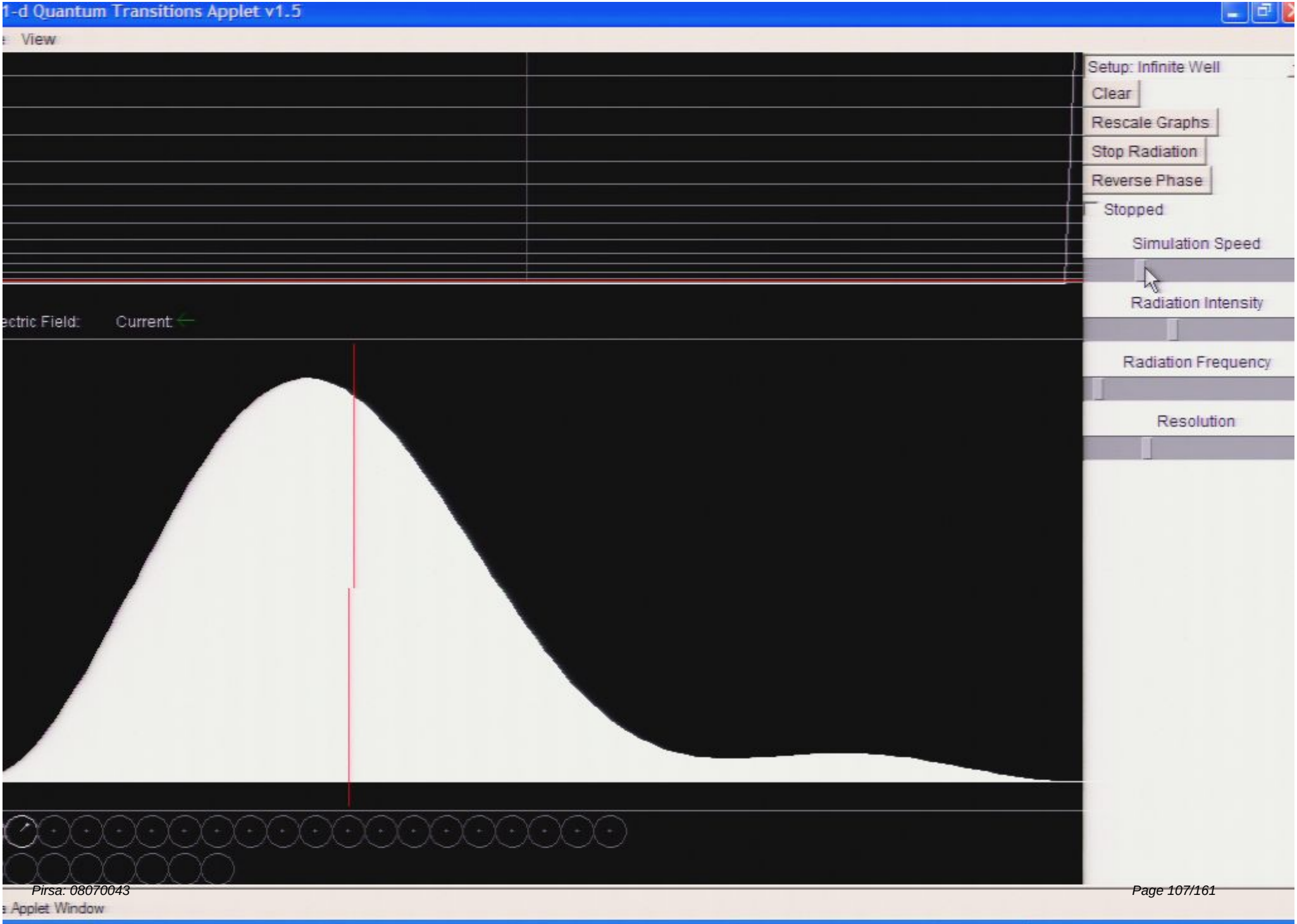
1-d Quantum Transitions Applet v1.5
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Simulation Speed
Radiation Intensity
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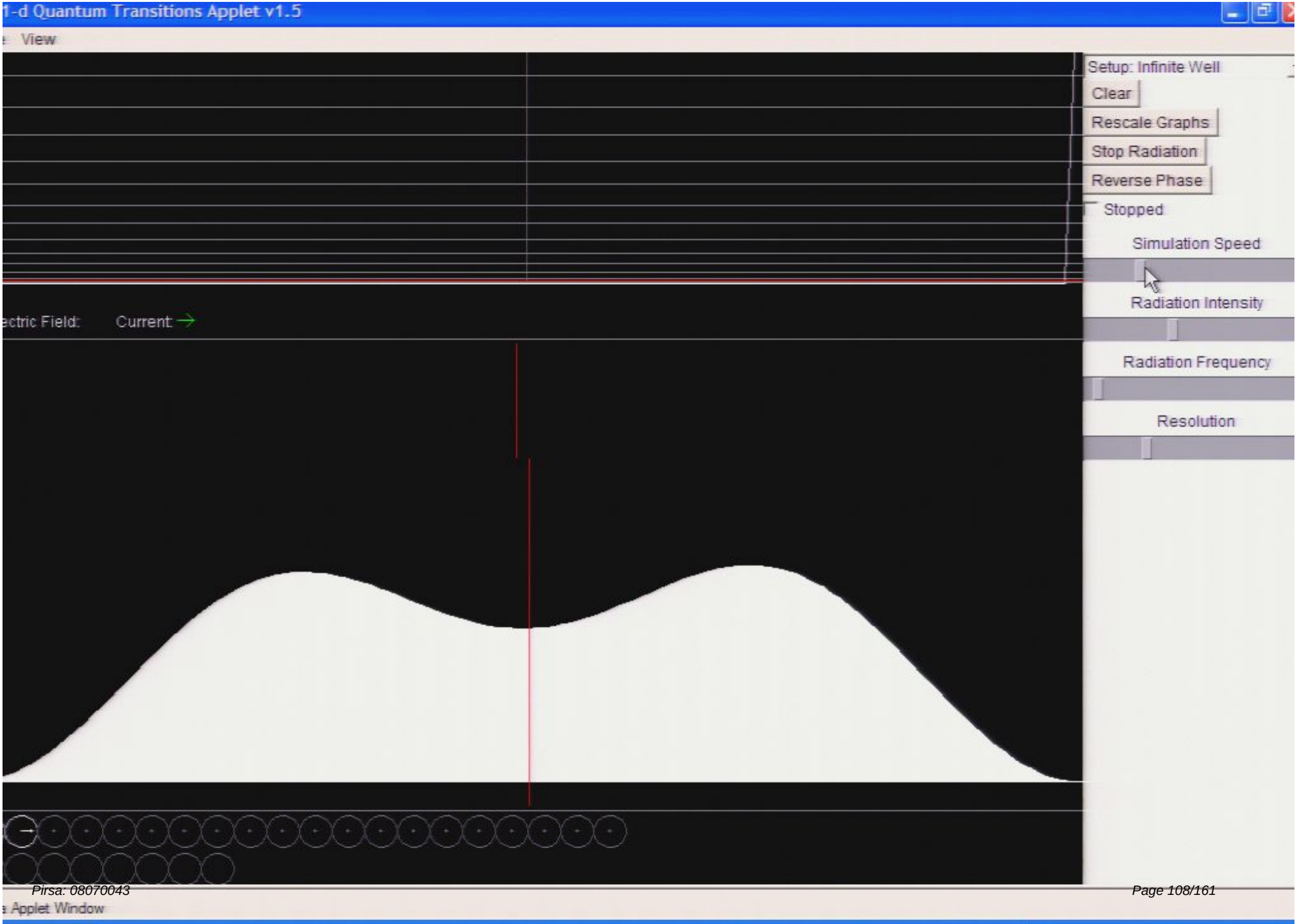
Applet Window


1-d Quantum Transitions Applet v1.5
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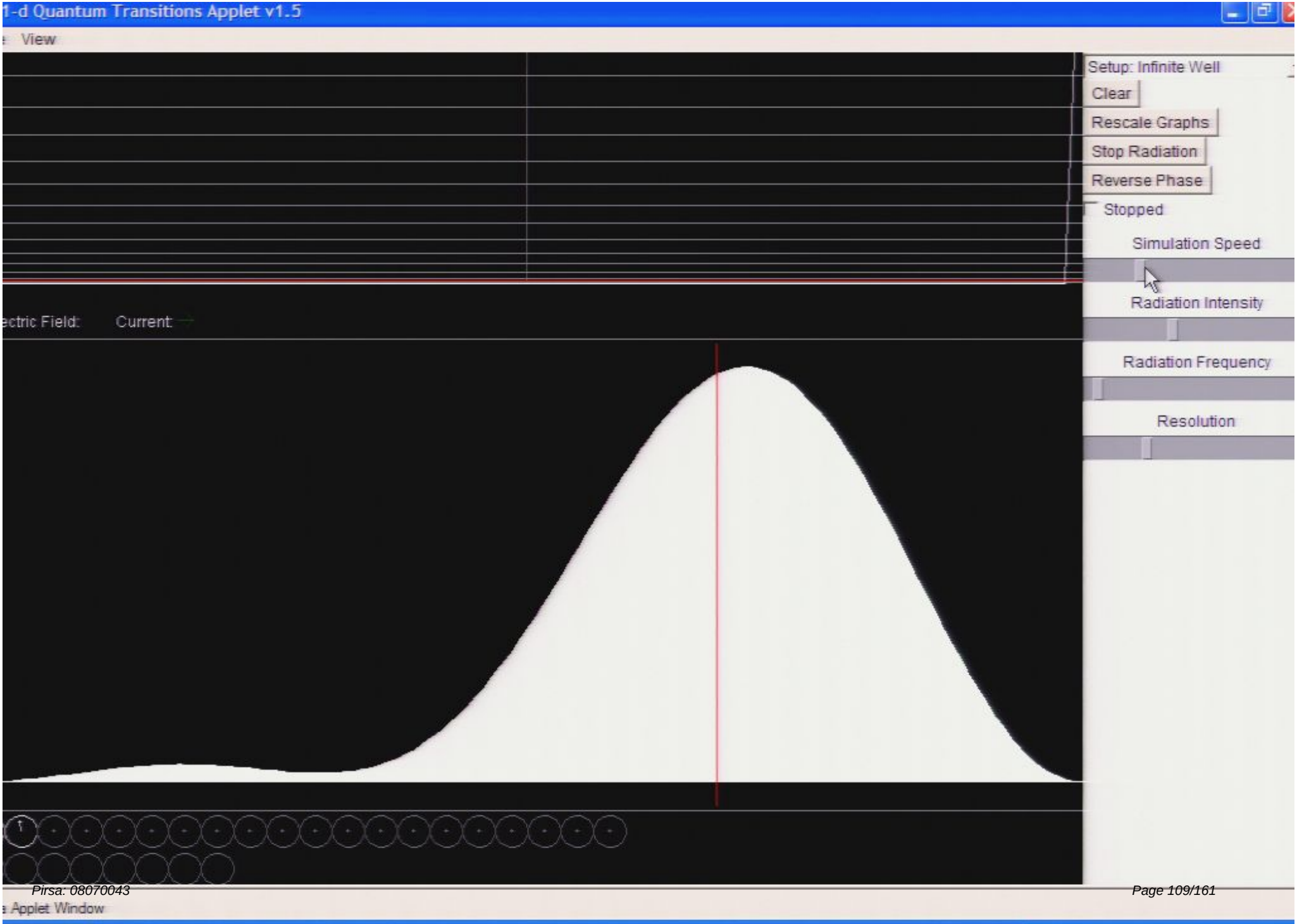
1-d Quantum Transitions Applet v1.5
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Simulation Speed
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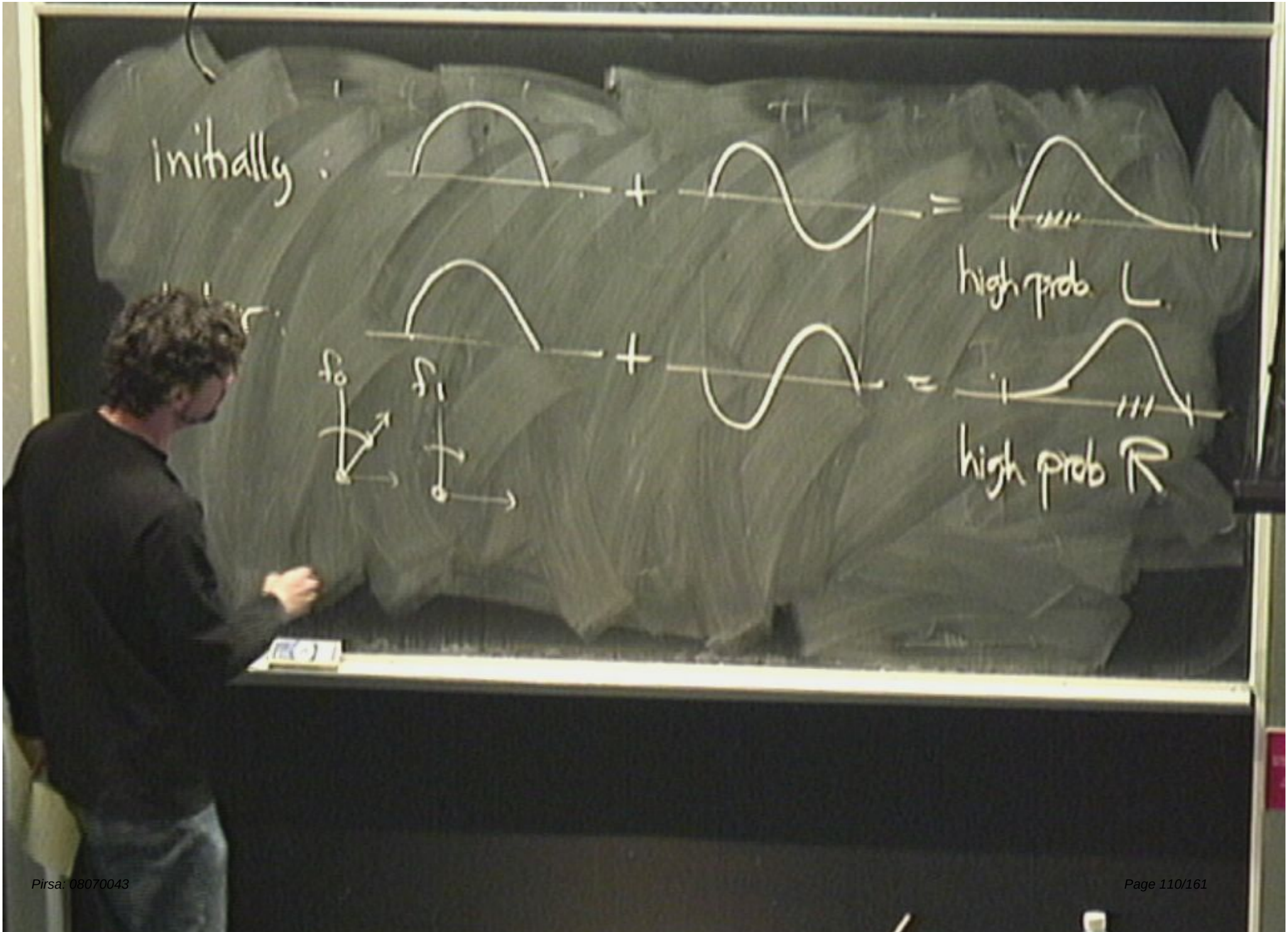
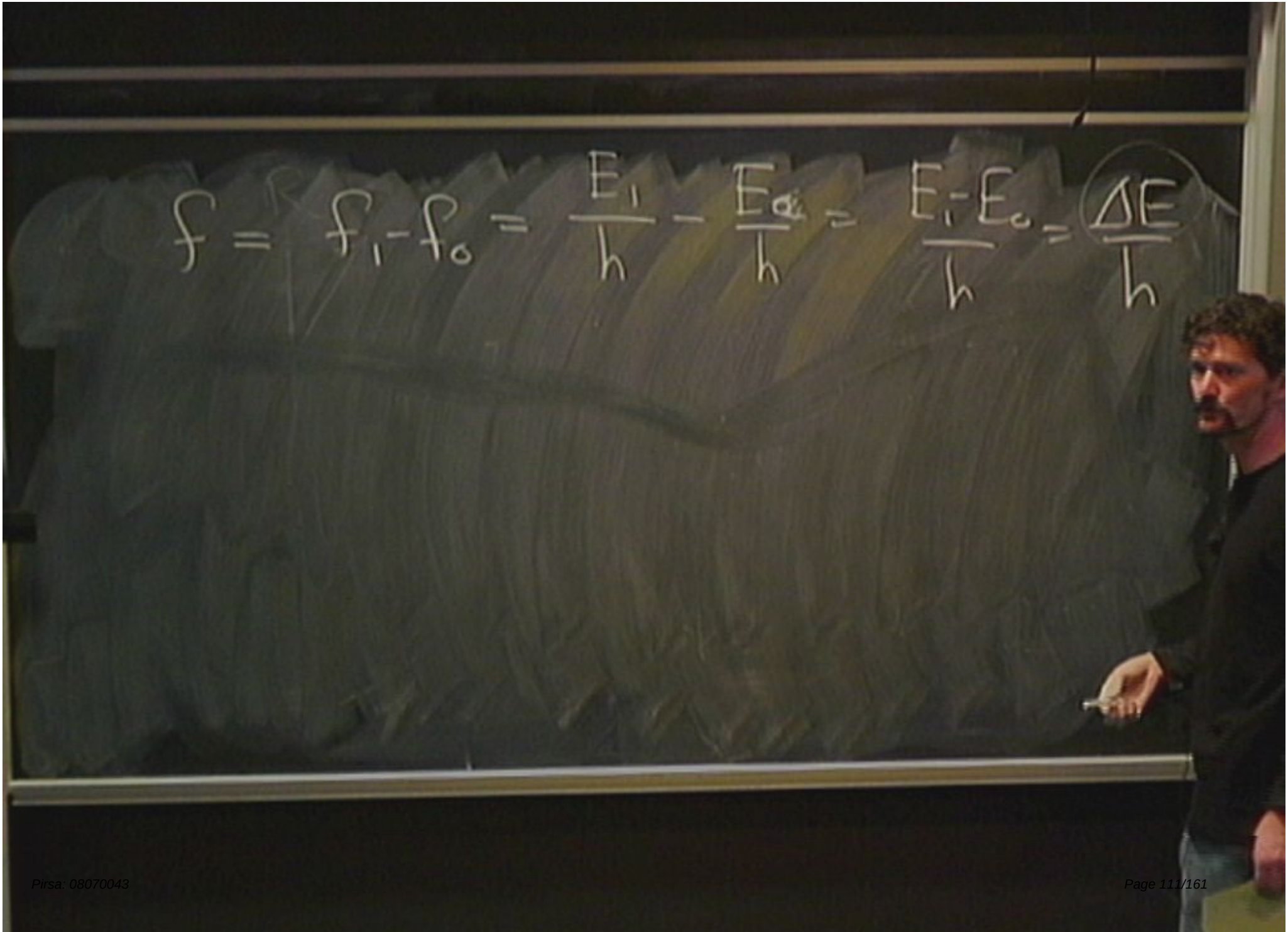
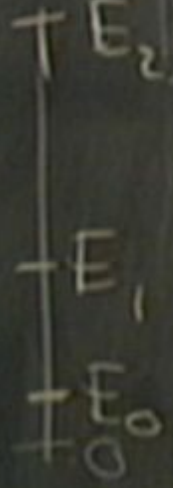
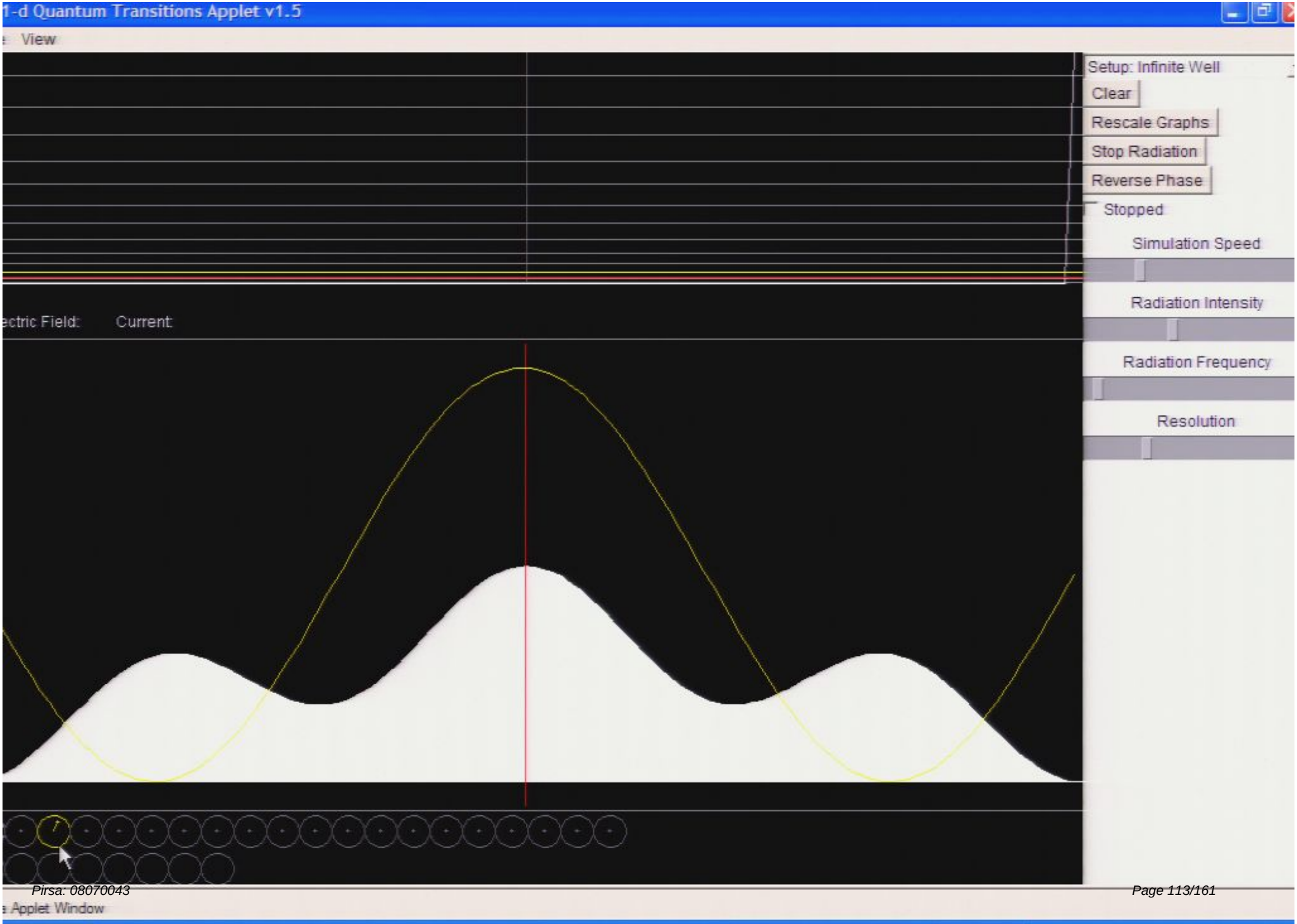
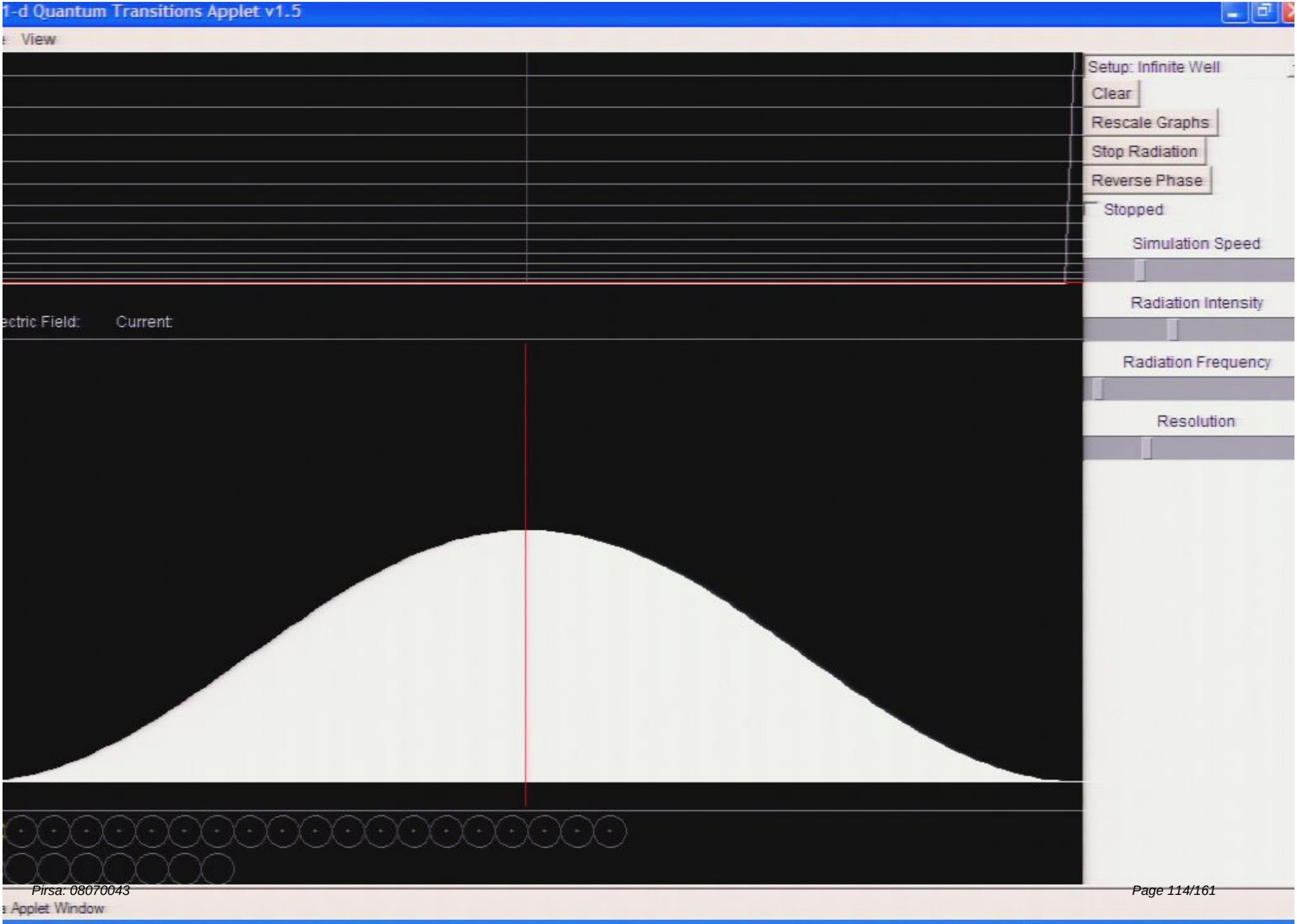

Initially :
high prob L
high prob R


$f = f_1 - f_0 = \frac{E_1}{h} - \frac{E_0}{h} = \frac{E_1 - E_0}{h} = \frac{\Delta E}{h}$

$$f = f_1 - f_0 = \frac{E_1}{h} - \frac{E_0}{h} = \frac{E_1 - E_0}{h} = \frac{\Delta E}{h}$$




1-d Quantum Transitions Applet v1.5
View
Setup: Infinite Well
Clear
Rescale Graphs
Stop Radiation
Reverse Phase
Stopped
Simulation Speed
Radiation Intensity
Radiation Frequency
Resolution
ectric Field:
Current:
Applet Window


1-d Quantum Transitions Applet v1.5
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Reverse Phase
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Simulation Speed
Radiation Intensity
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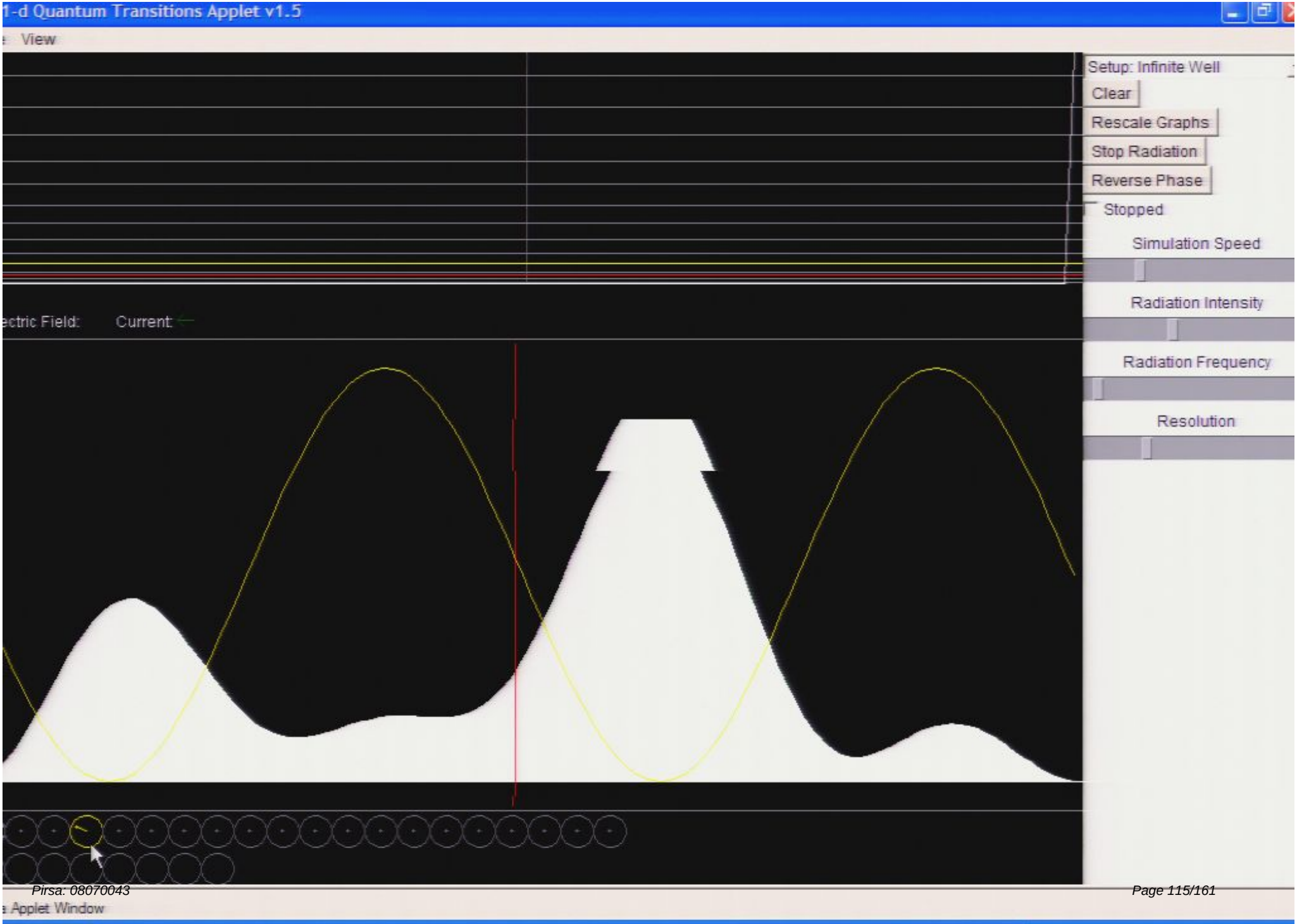
1-d Quantum Transitions Applet v1.5
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Reverse Phase
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Simulation Speed
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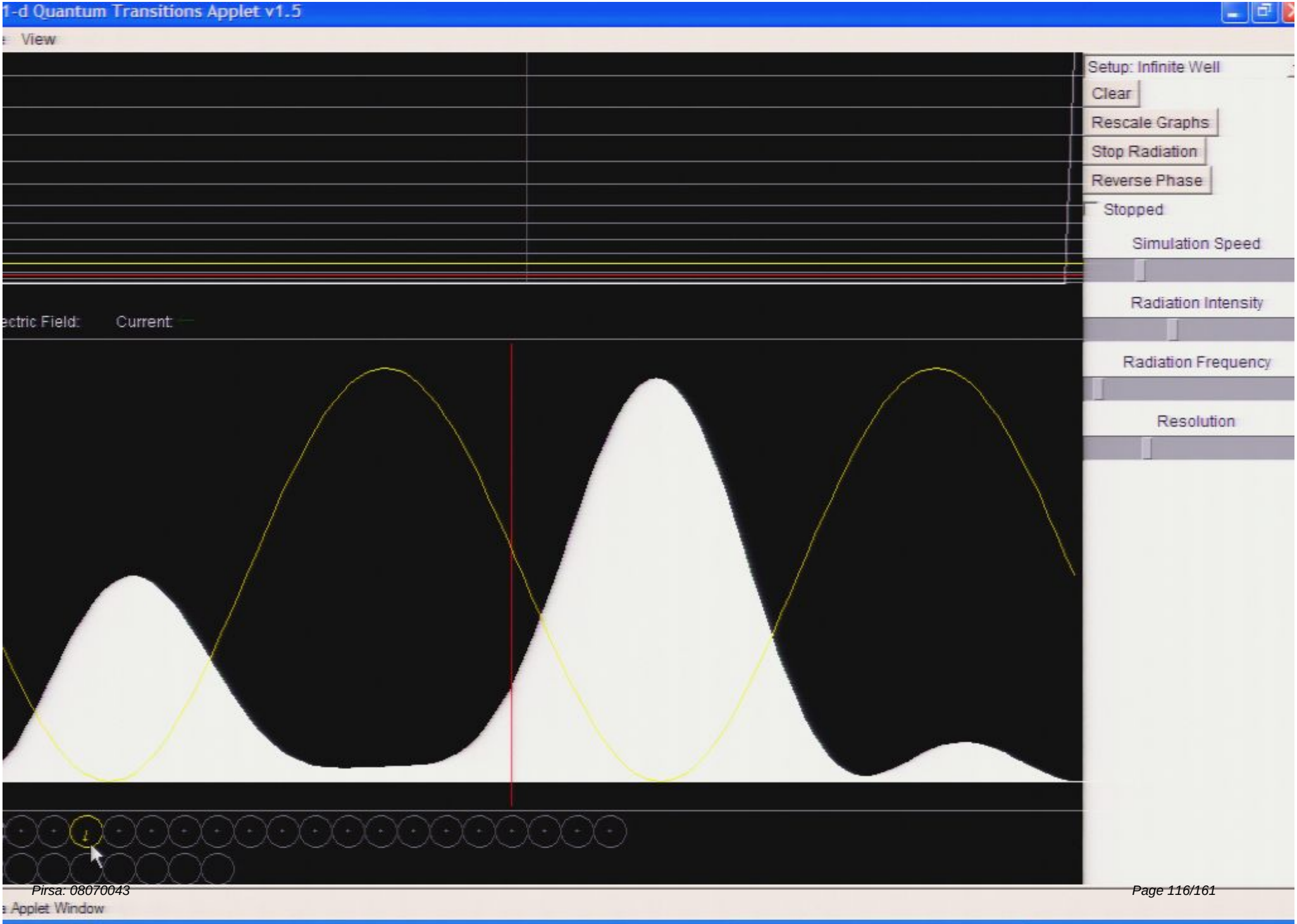
1-d Quantum Transitions Applet v1.5
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Rescale Graphs
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Reverse Phase
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Simulation Speed
Radiation Intensity
Radiation Frequency
Resolution
ectric Field:
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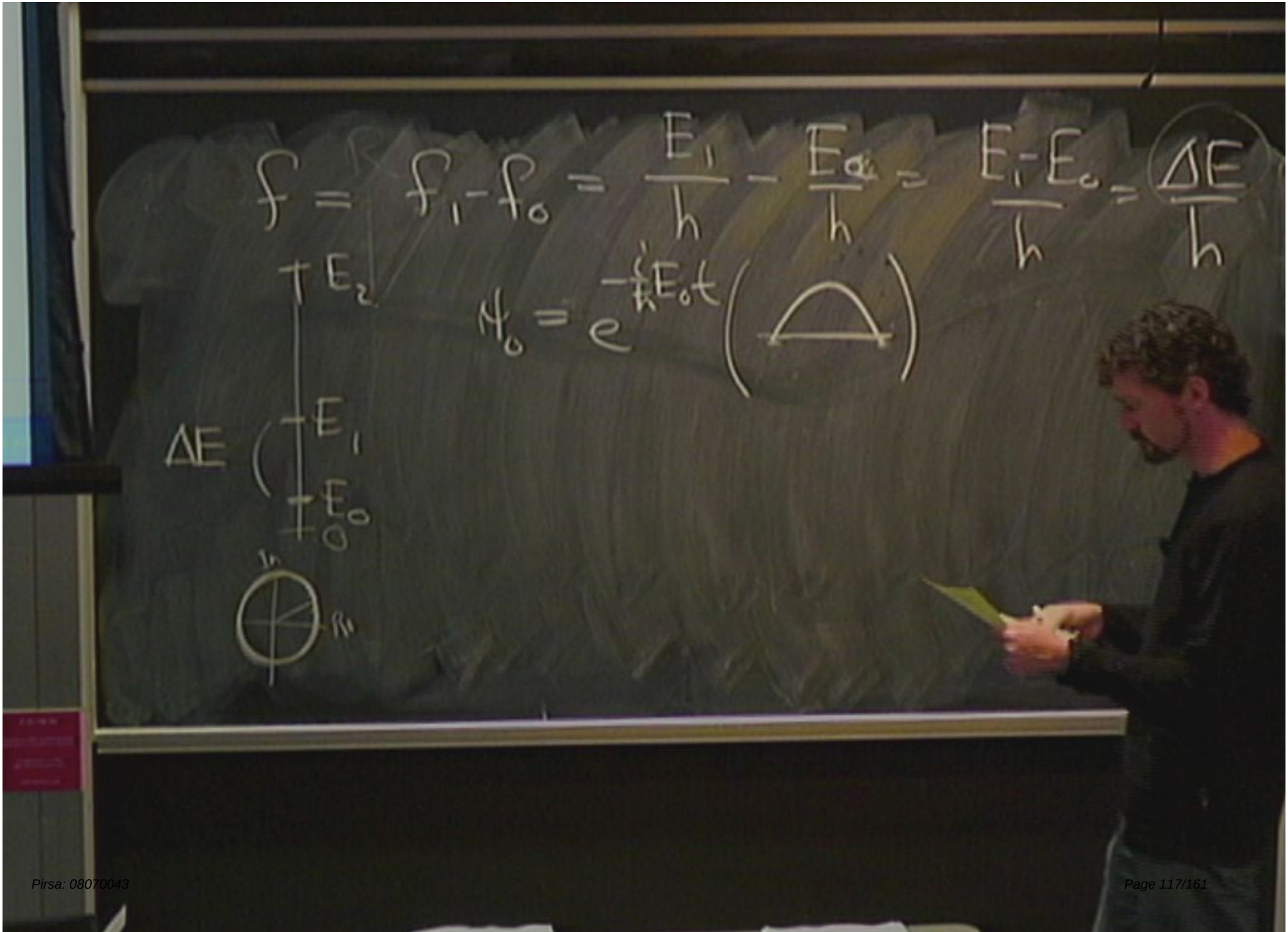
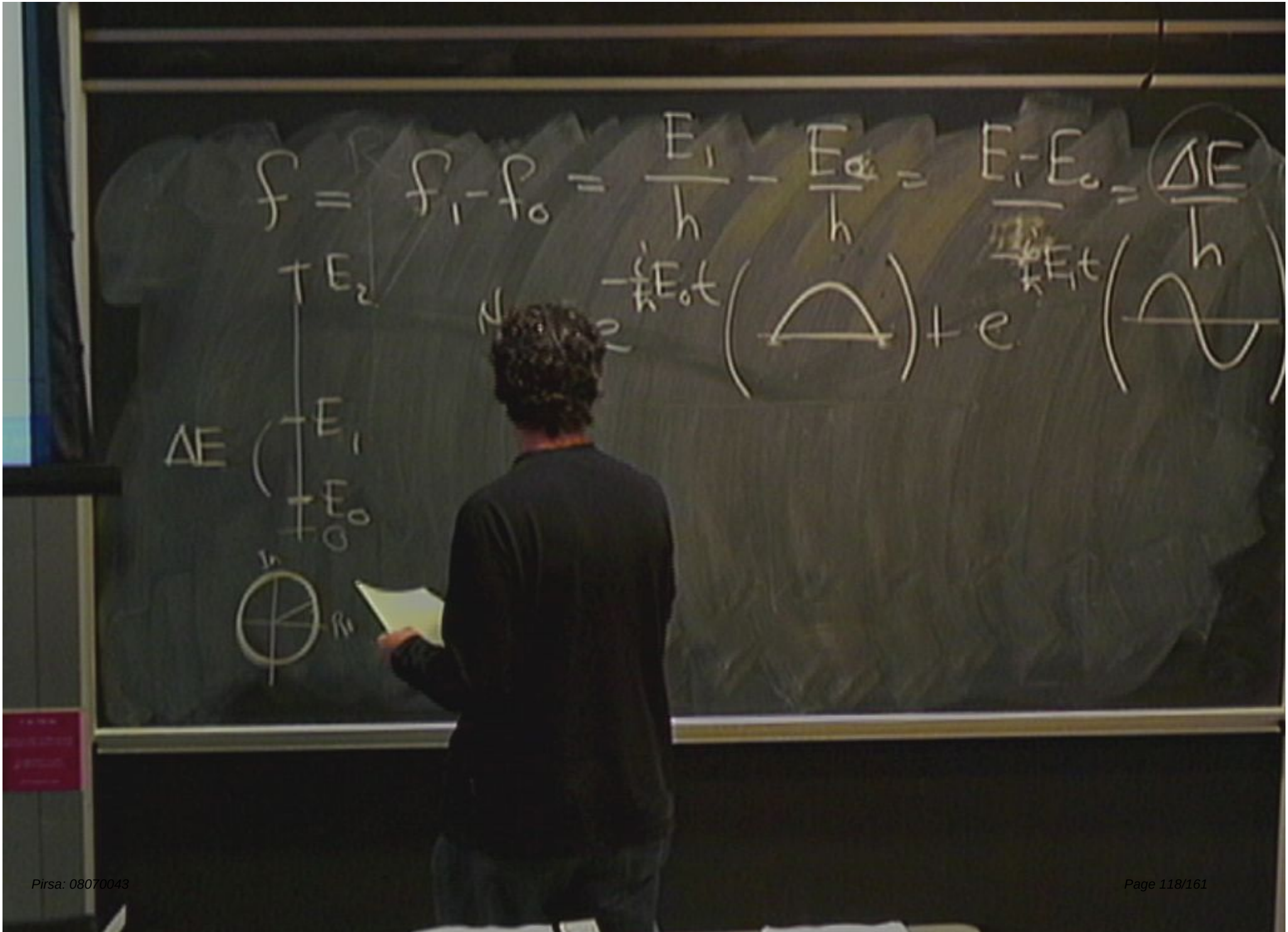
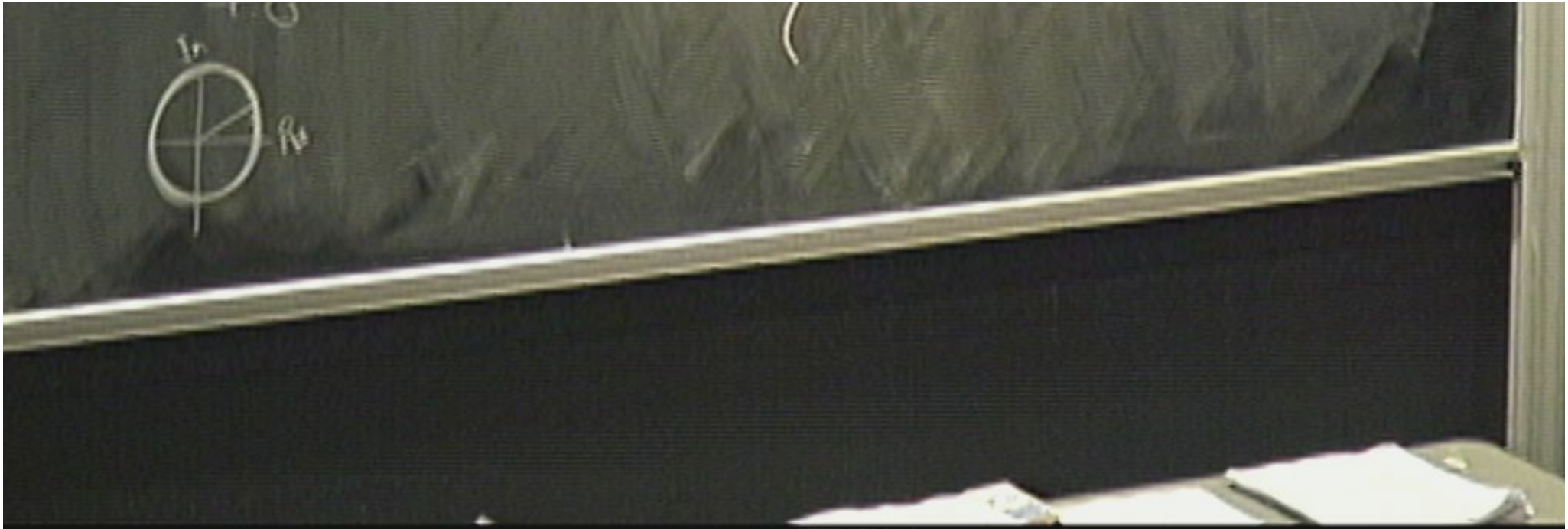
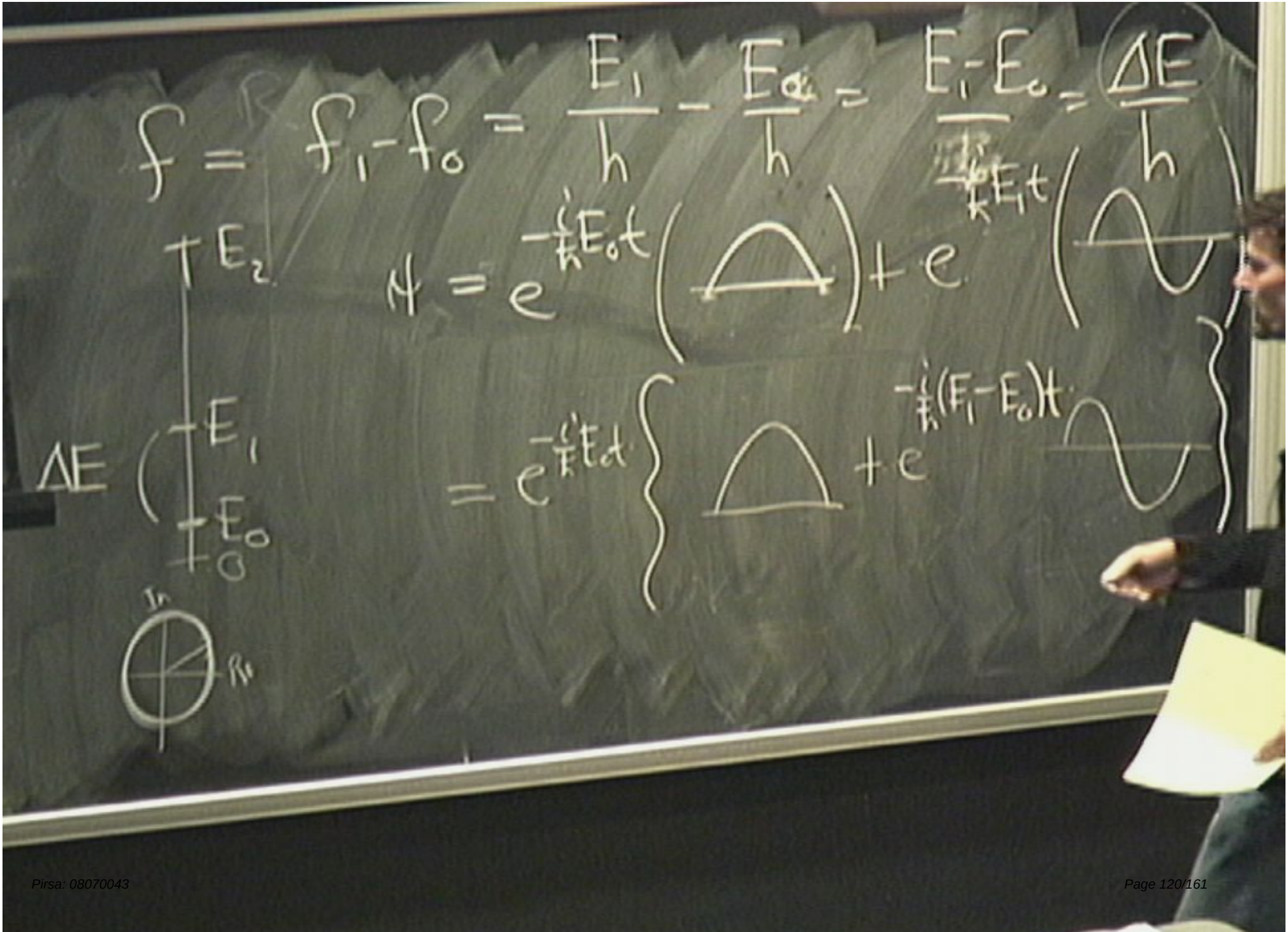

$f = f_1 - f_0 = \frac{E_1}{h} - \frac{E_0}{h} = \frac{E_1 - E_0}{h} = \frac{\Delta E}{h}$
$N_0 = e^{-\frac{1}{\tau} E_0 t}$
E_2
ΔE
E_1
E_0
0
h
R

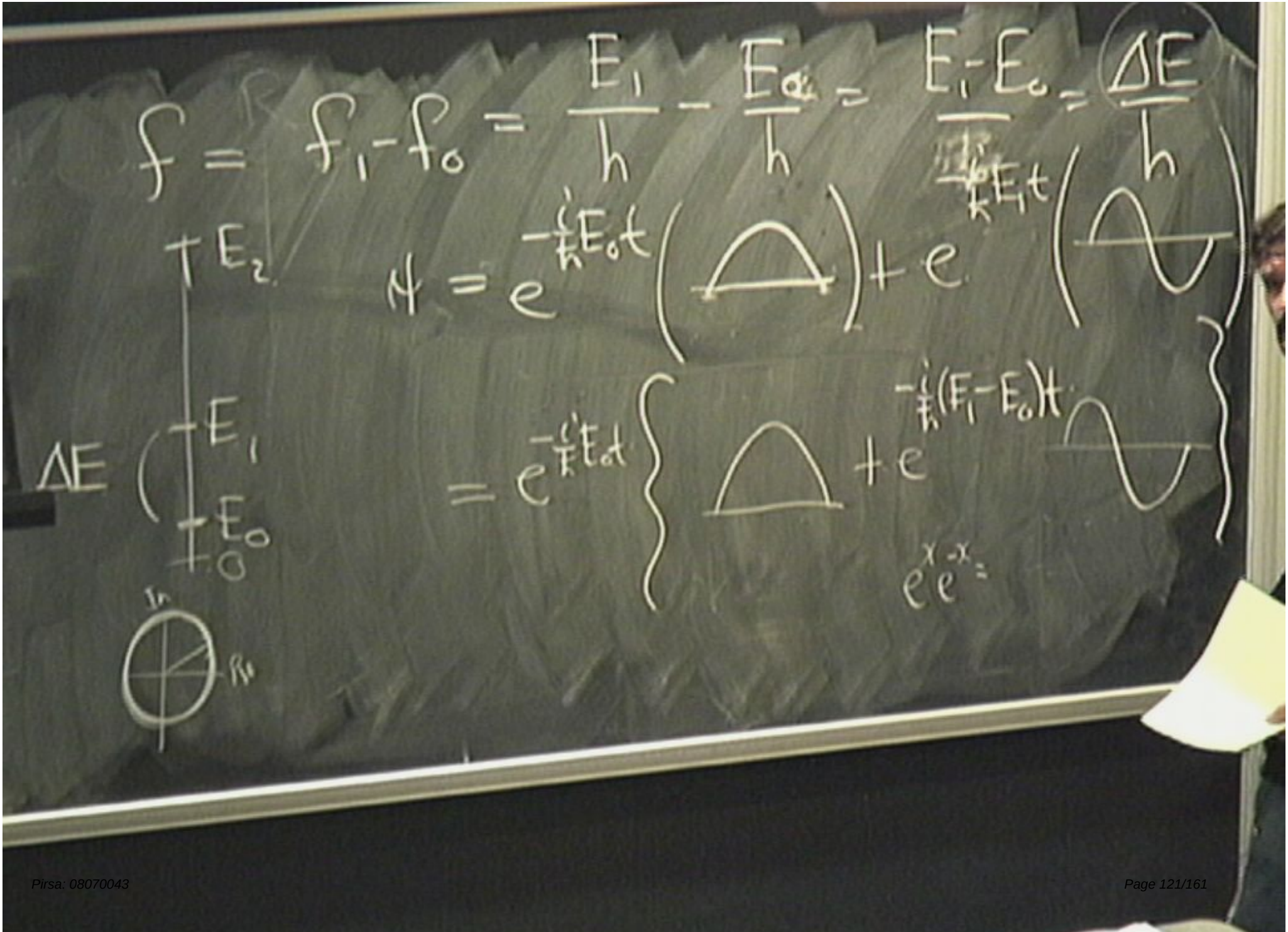

$\nu = \nu_1 - \nu_0 = \frac{E_1}{h} - \frac{E_0}{h} = \frac{E_1 - E_0}{h} = \frac{\Delta E}{h}$
E_2
E_1
E_0
ΔE

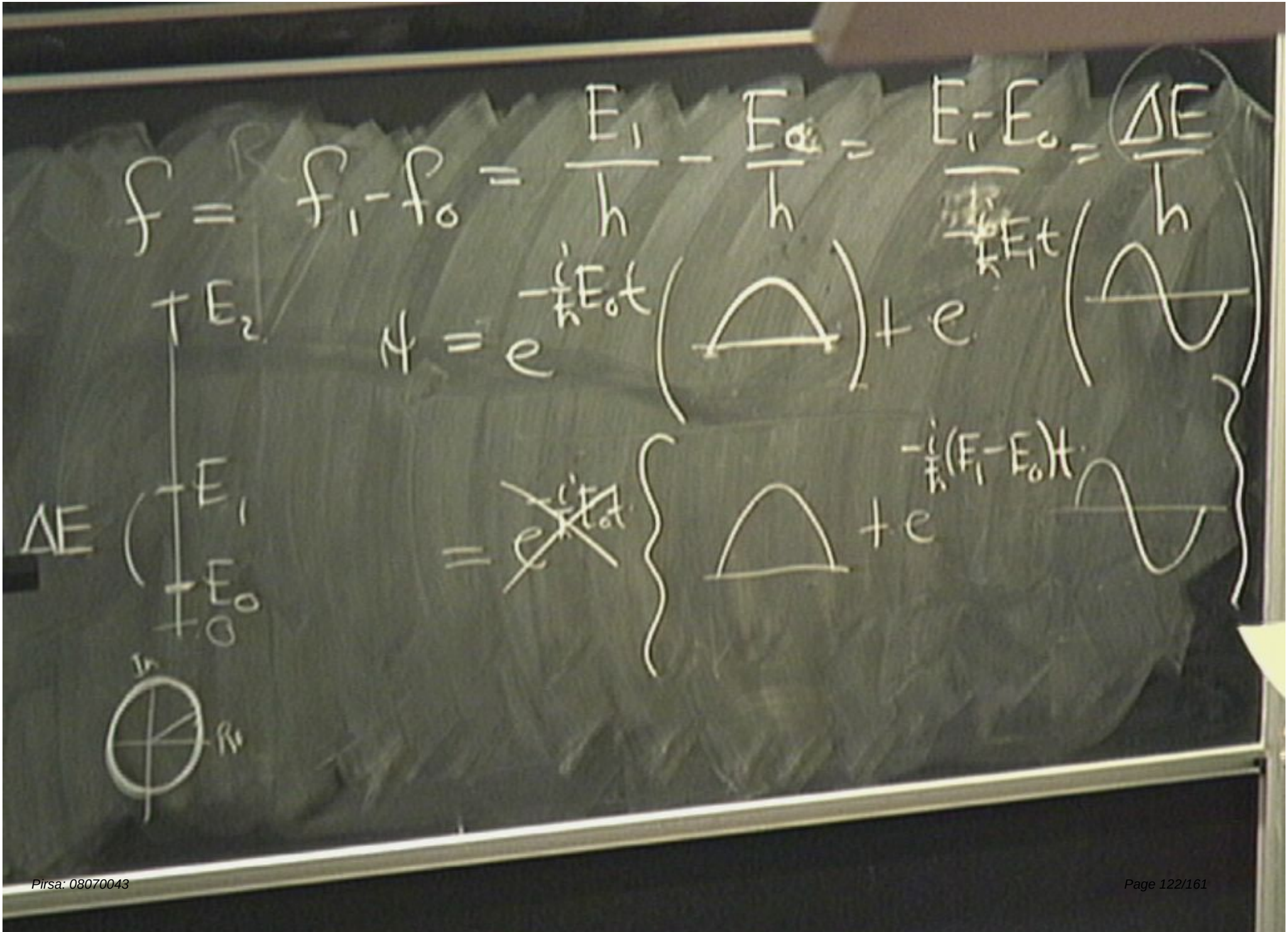


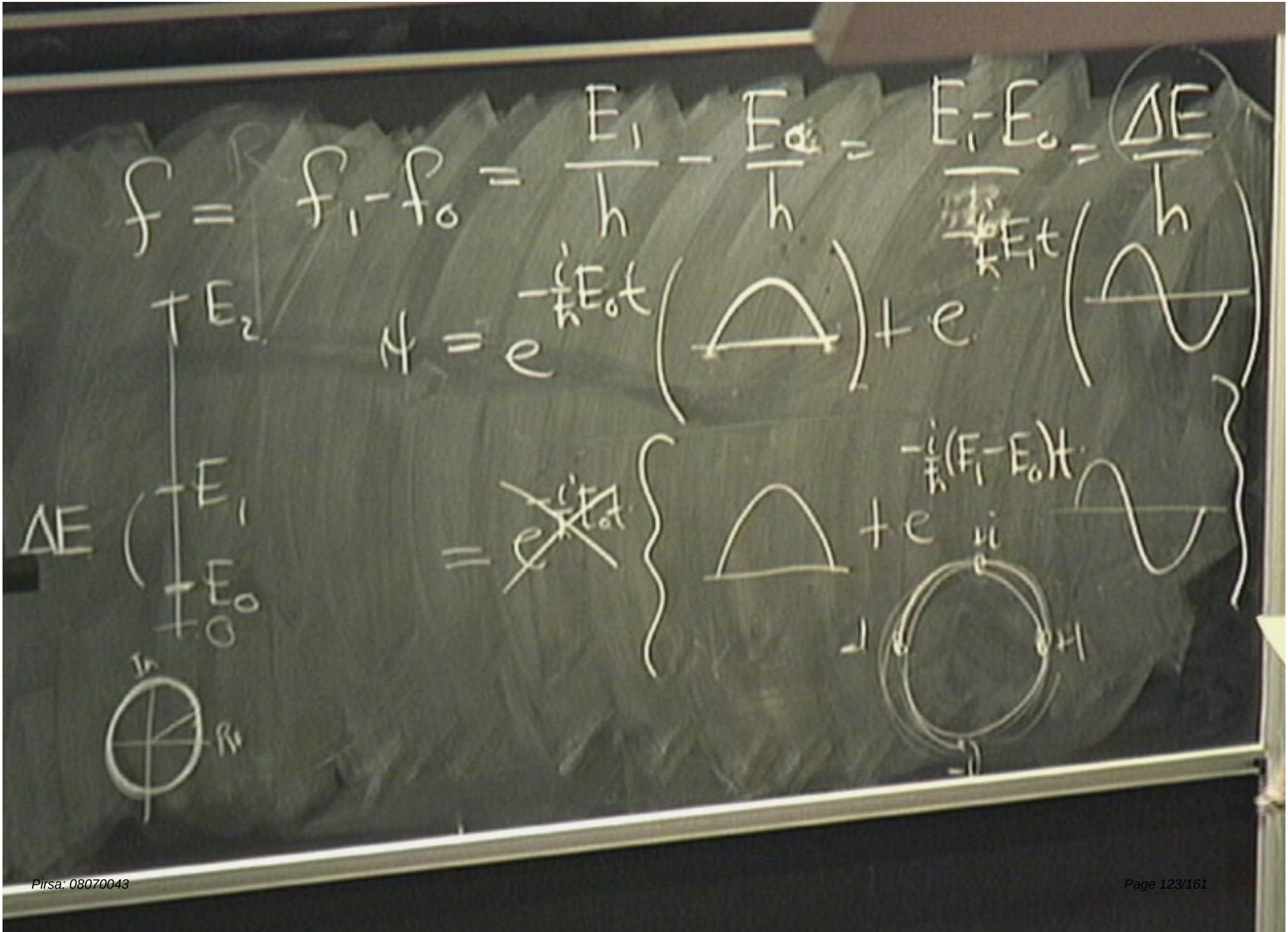
$$f = f_1 - f_0 = \frac{E_1}{h} - \frac{E_0}{h} = \frac{E_1 - E_0}{h} = \frac{\Delta E}{h}$$

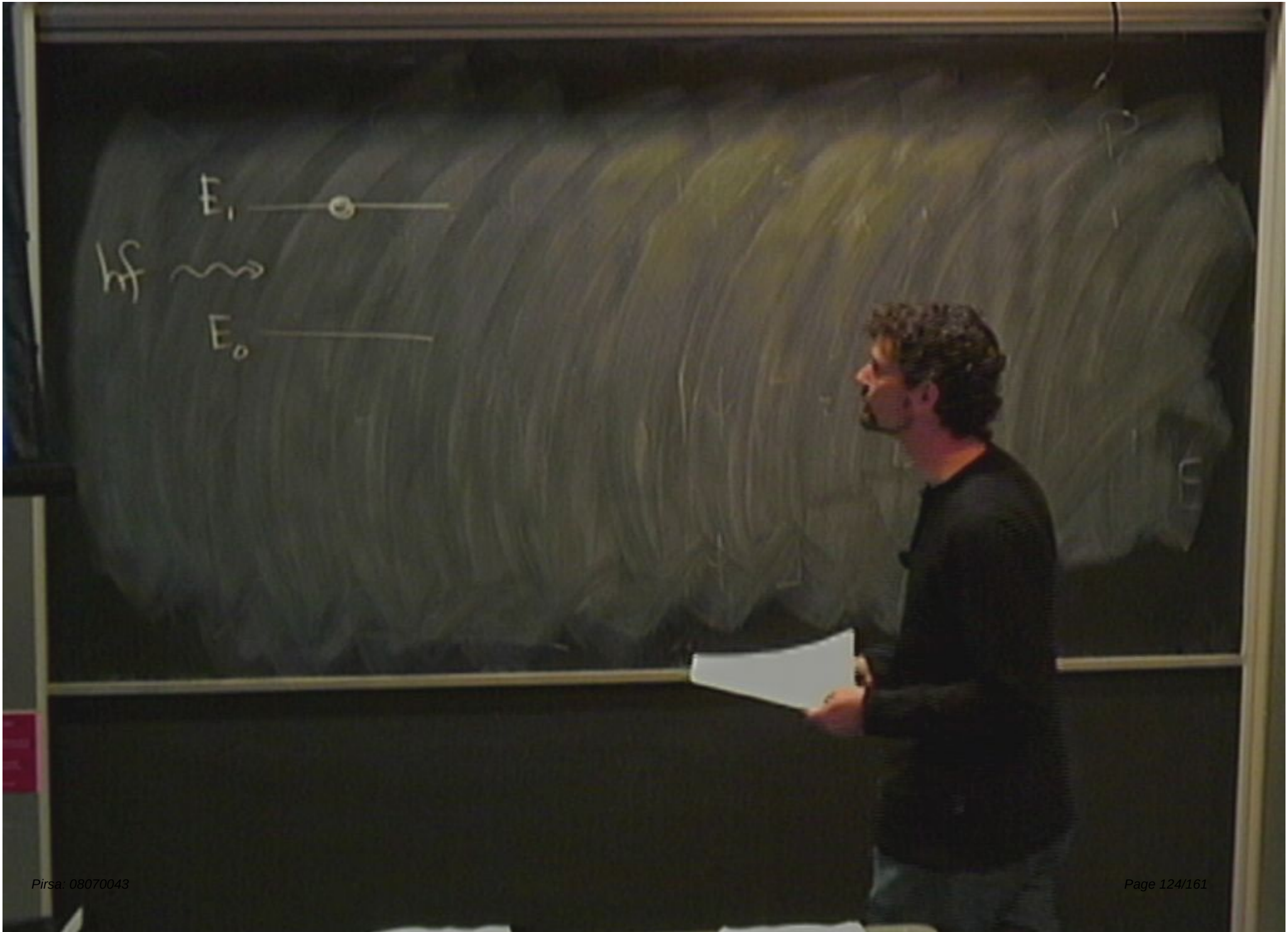
$$\psi = e^{-\frac{i}{\hbar}E_0 t}\left(\text{⌒}\right) + e^{-\frac{i}{\hbar}E_1 t}\left(\text{∩}\right)$$

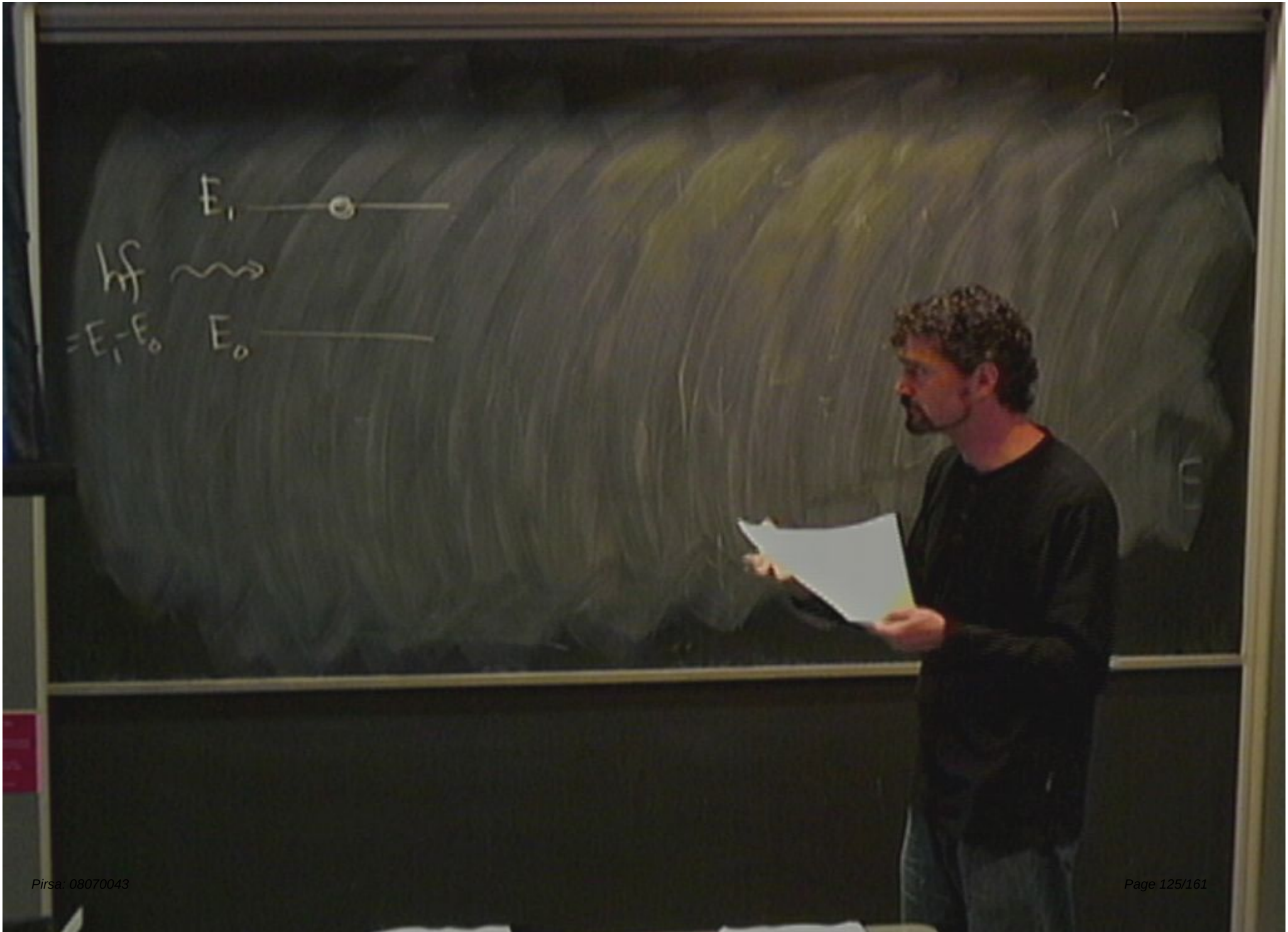

$f = f_1 - f_0 = \frac{E_1}{h} - \frac{E_0}{h} = \frac{E_1 - E_0}{h} = \frac{\Delta E}{h}$
E_2
E_1
E_0
ΔE
$N = e^{-\frac{i}{\hbar}E_0 t}$
$+ e^{-\frac{i}{\hbar}E_1 t}$
$= e^{-\frac{i}{\hbar}E_0 t}$
$+ e^{-\frac{i}{\hbar}(E_1 - E_0)t}$

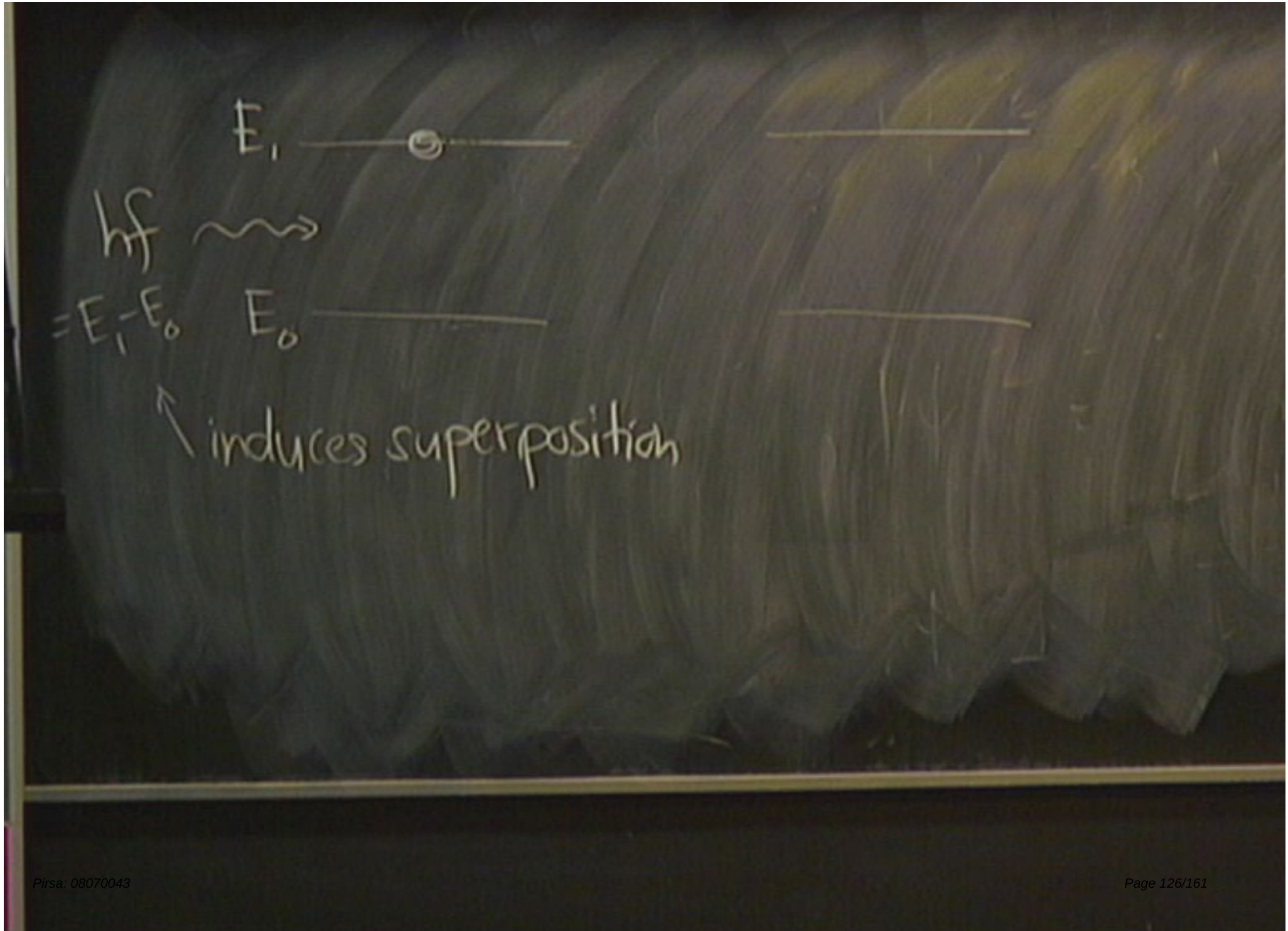

$f = f_1 - f_0 = \frac{E_1}{h} - \frac{E_0}{h} = \frac{E_1 - E_0}{h} = \frac{\Delta E}{h}$
E_2
$N = e^{-\frac{i}{\hbar}E_0 t}$
$+ e^{-\frac{i}{\hbar}E_1 t}$
ΔE
E_1
E_0
0
$= e^{-\frac{i}{\hbar}E_0 t}$
$+ e^{-\frac{i}{\hbar}(E_1 - E_0)t}$
$e^x e^{-x} =$

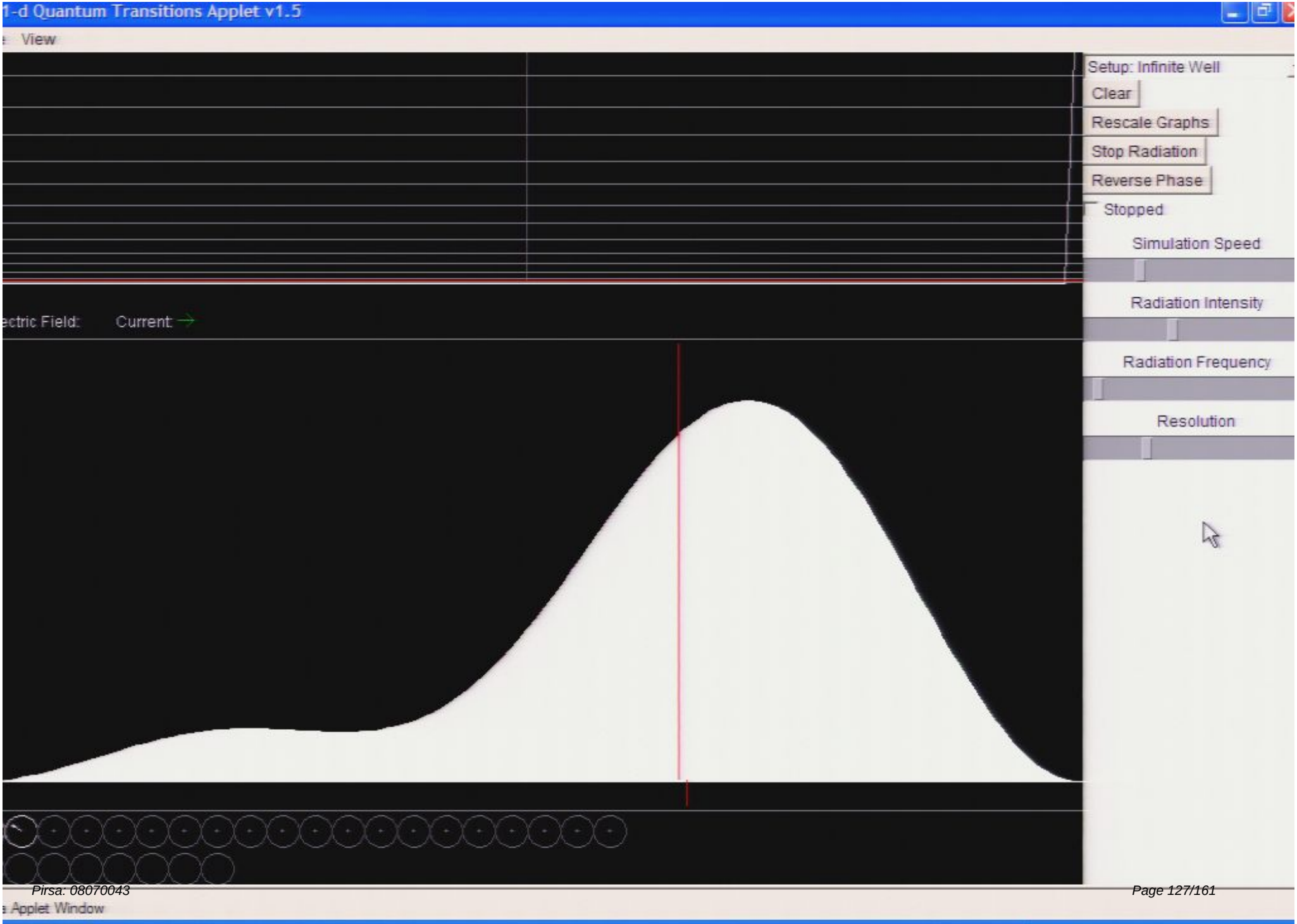

$f = f_1 - f_0 = \frac{E_1}{h} - \frac{E_0}{h} = \frac{E_1 - E_0}{h} = \frac{\Delta E}{h}$
E_2
E_1
E_0
ΔE
$N = e^{-\frac{i}{\hbar}E_0 t}$
$+ e^{-\frac{i}{\hbar}E_1 t}$
$= e^{-\frac{i}{\hbar}E_0 t}\left\{ + e^{-\frac{i}{\hbar}(E_1 - E_0)t} \right.$

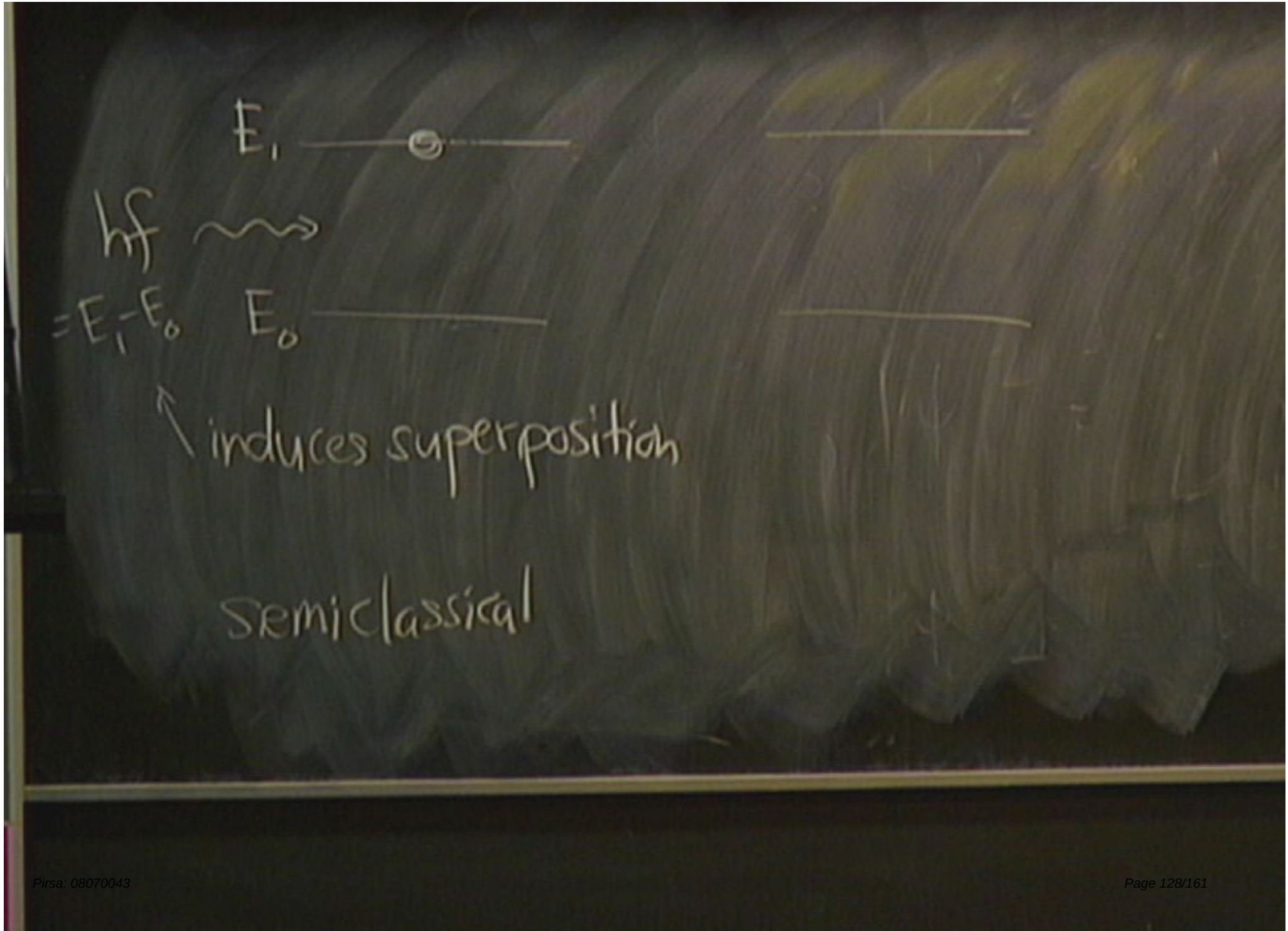

$f = f_1 - f_0 = \frac{E_1}{h} - \frac{E_0}{h} = \frac{E_1 - E_0}{h} = \frac{\Delta E}{h}$
E_2
E_1
E_0
ΔE

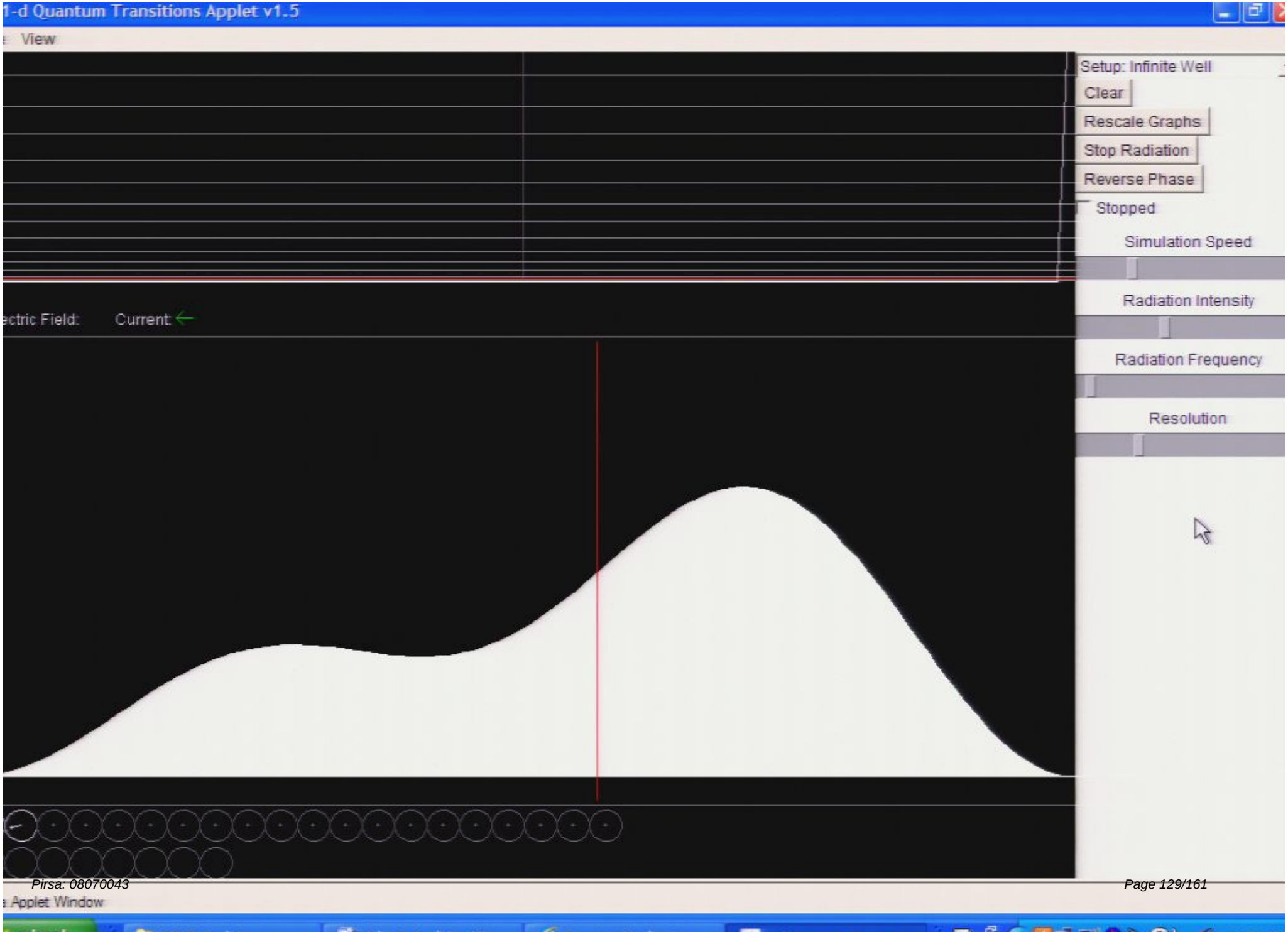

E1
hf
E0


E1
hf
=E1-E0
E0


E_1
hf
$= E_1 - E_0$
E_0
induces superposition


1-d Quantum Transitions Applet v1.5
View
Setup: Infinite Well
Clear
Rescale Graphs
Stop Radiation
Reverse Phase
Stopped
Simulation Speed
Radiation Intensity
Radiation Frequency
Resolution
ectric Field:
Current:
Applet Window


E_1
hf
$= E_1 - E_0$
E_0
induces superposition
semiclassical


1-d Quantum Transitions Applet v1.5
View
Setup: Infinite Well
Clear
Rescale Graphs
Stop Radiation
Reverse Phase
Stopped
Simulation Speed
Radiation Intensity
Radiation Frequency
Resolution
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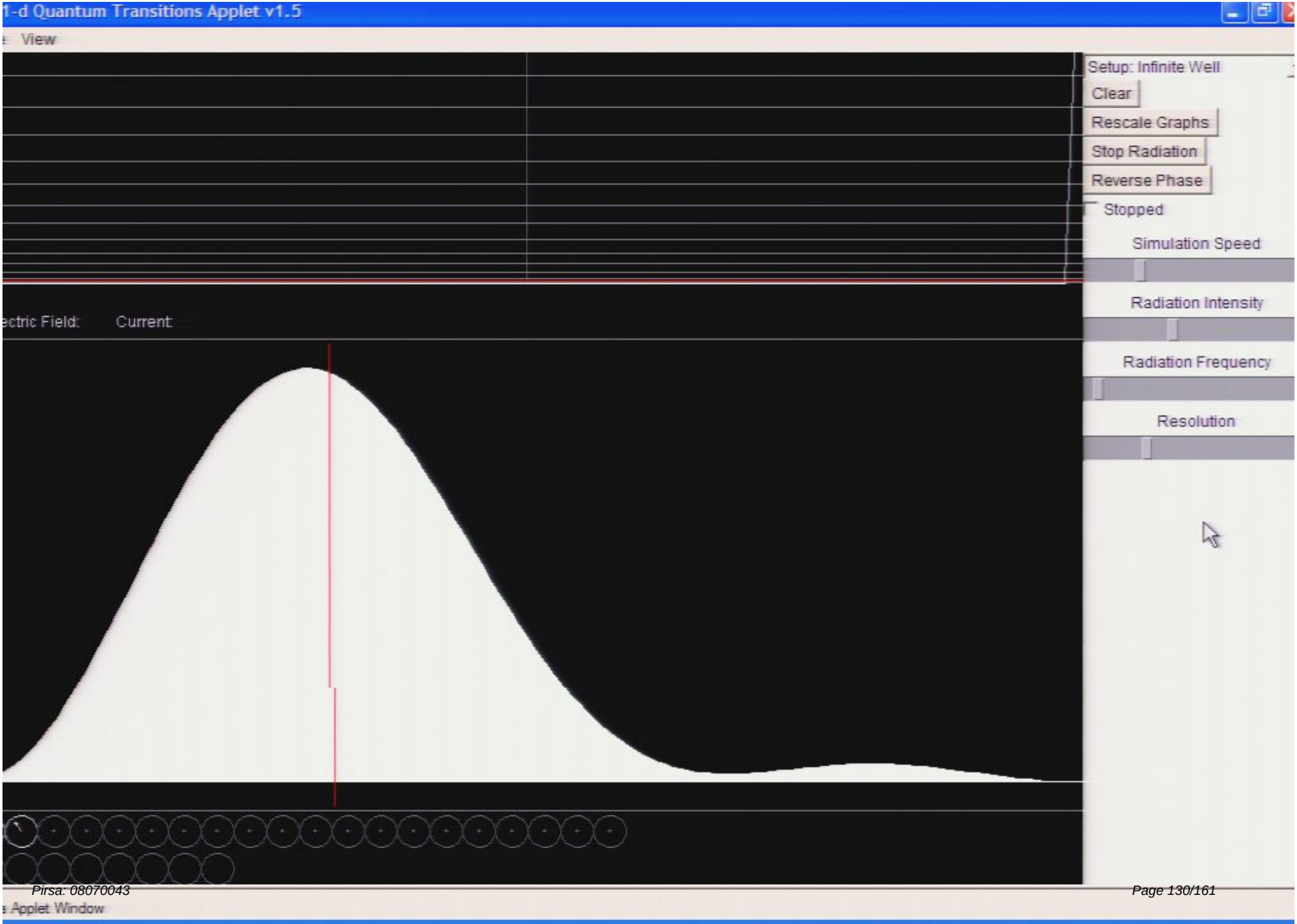
Current:
Applet Window


1-d Quantum Transitions Applet v1.5
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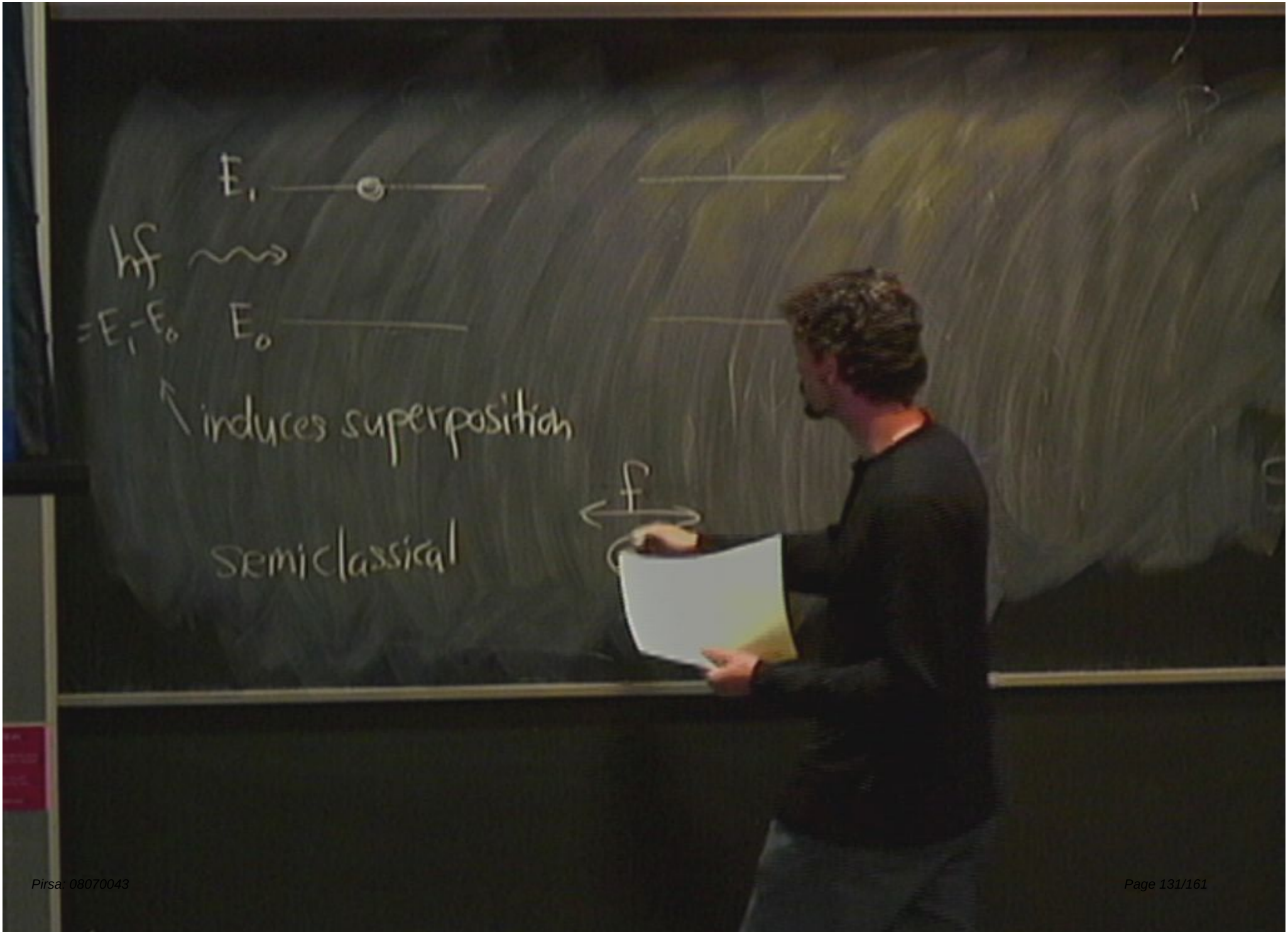
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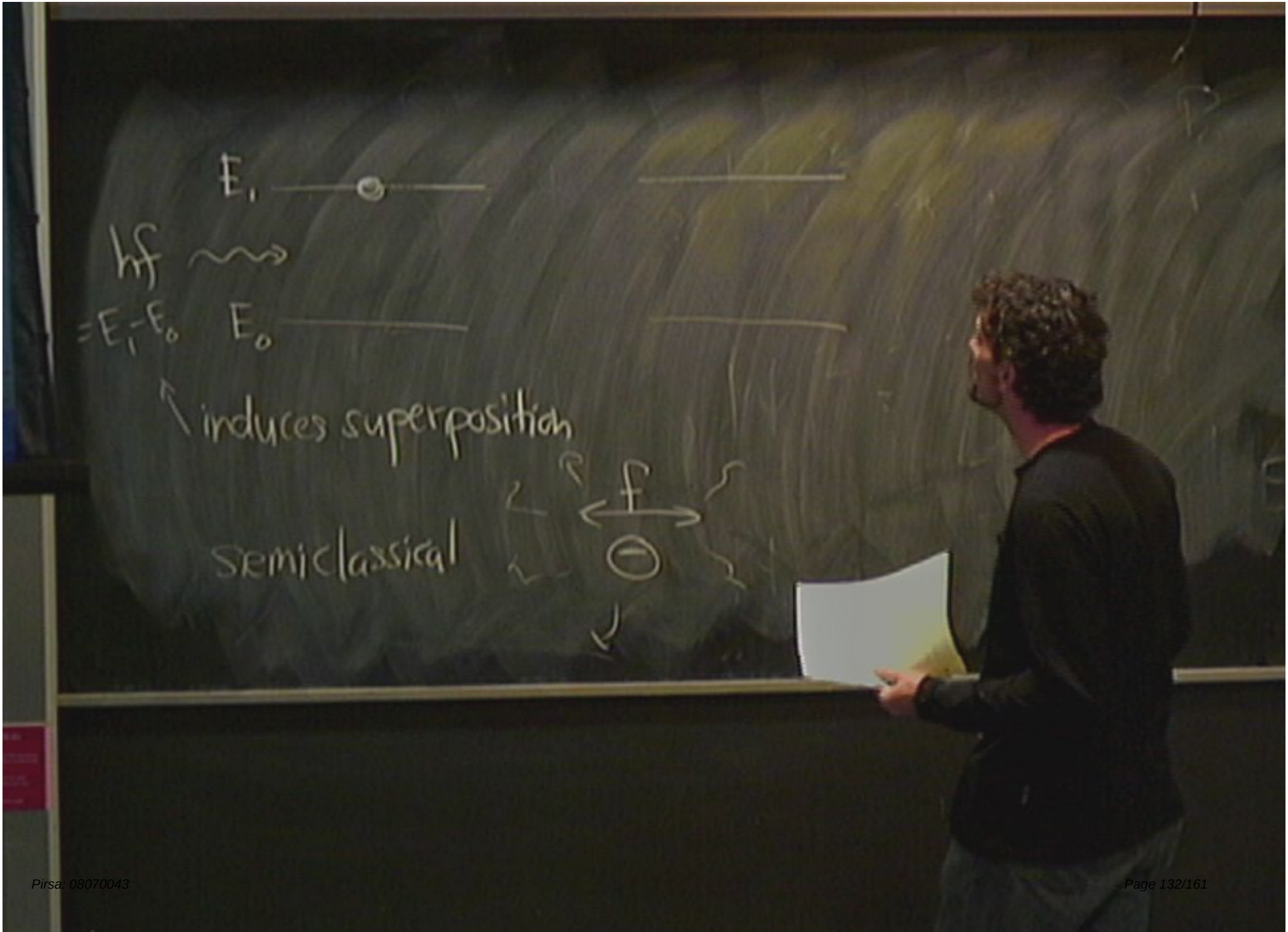
$=E_1-E_0$
E_0
induces superposition
f
semiclassical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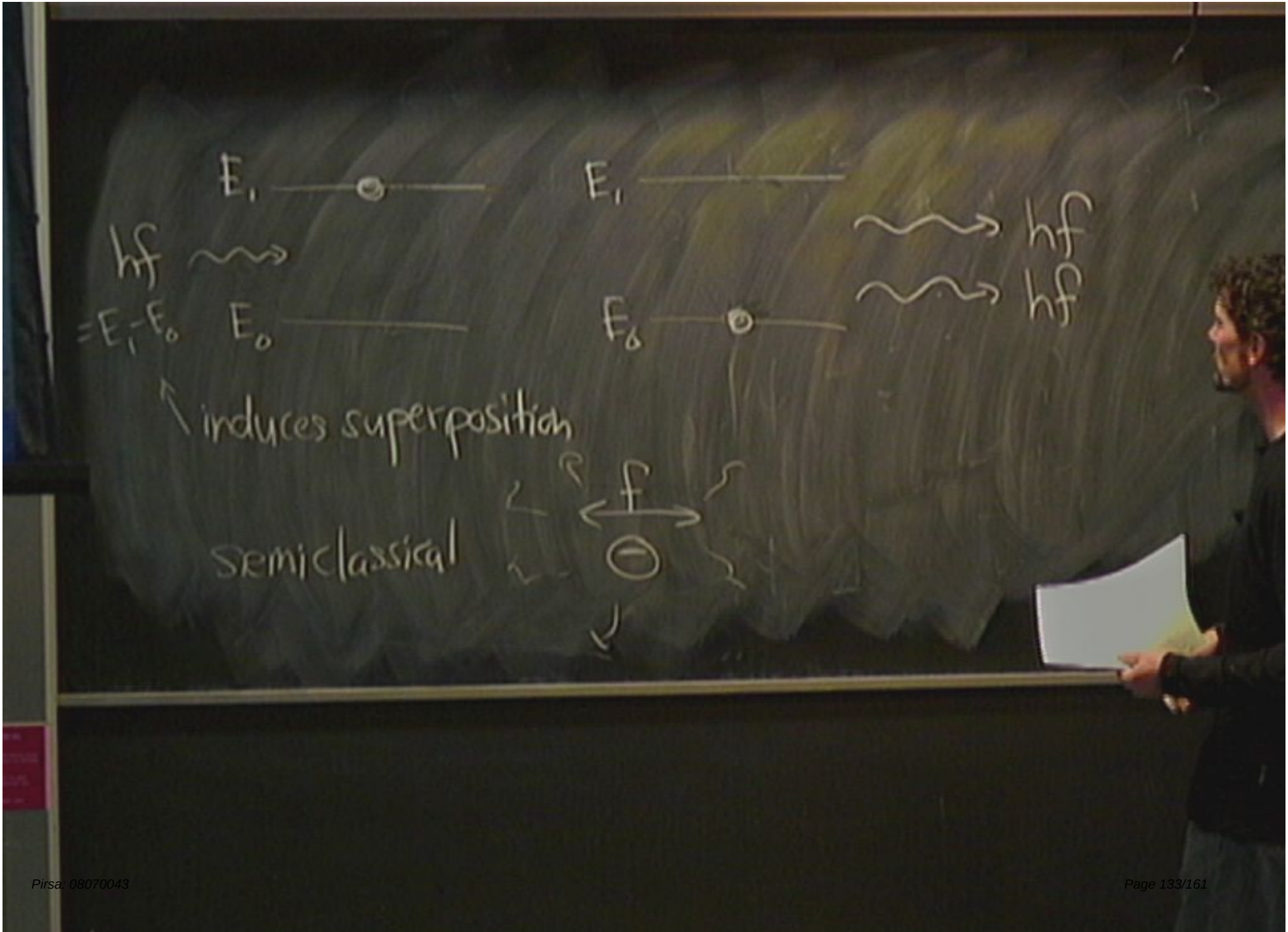
$= E_1 - E_0$
E_0
induces superposition
f
semiclassical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E_0
induces superposition
f
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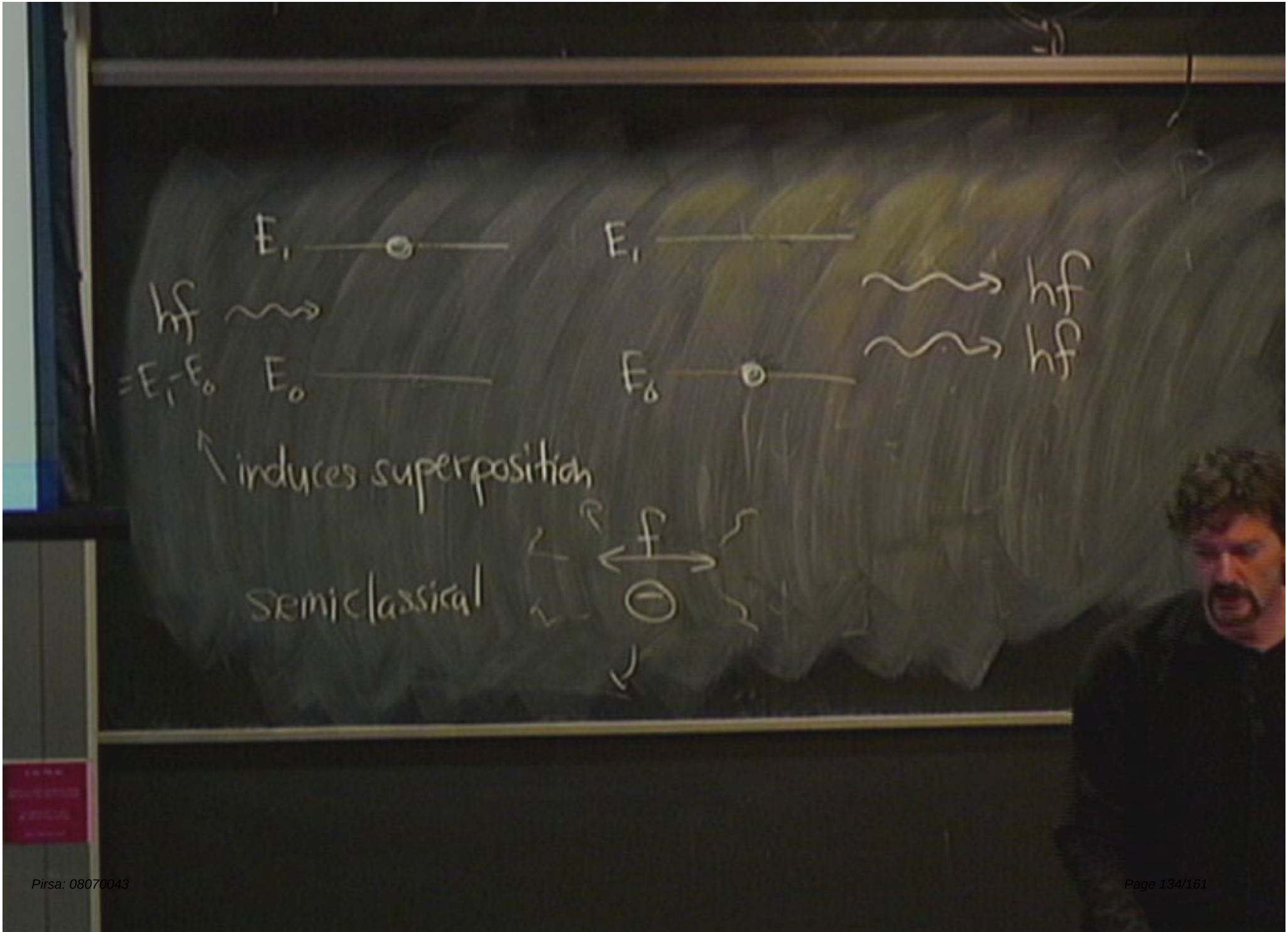
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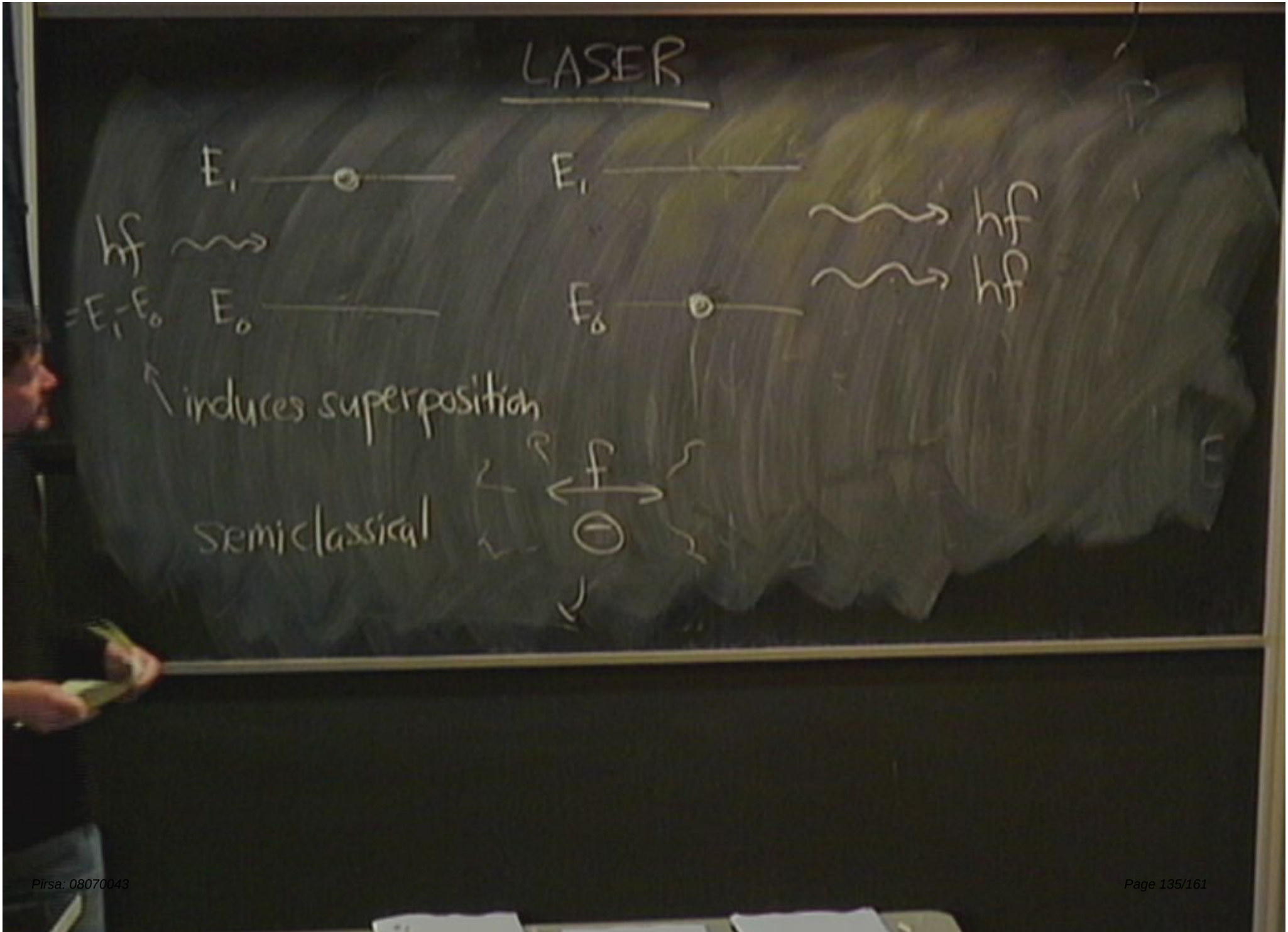
LASER
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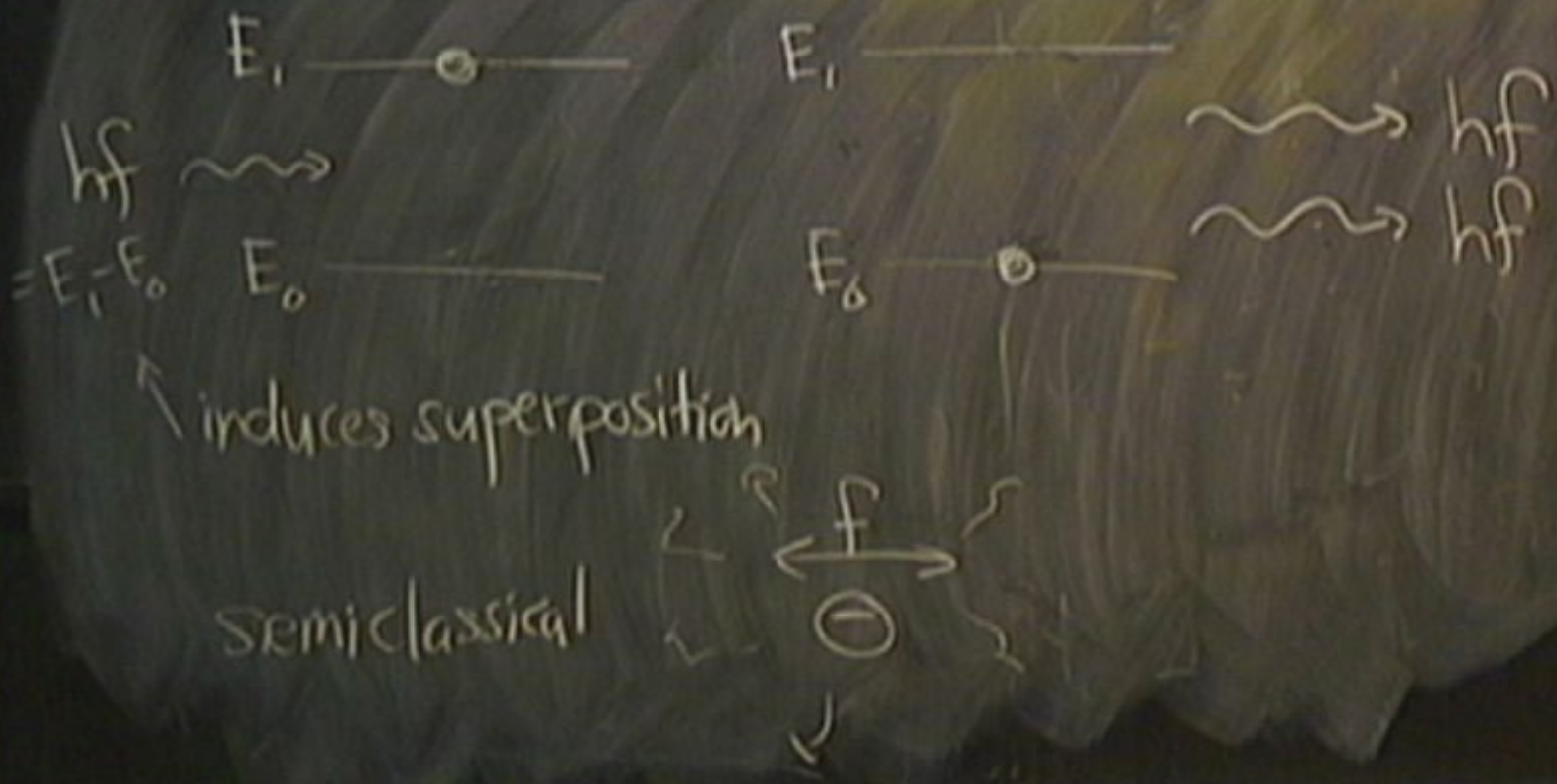
hf
$=E_1-E_0$
E_0
E_0
induces superposition
f
semiclassical

LASER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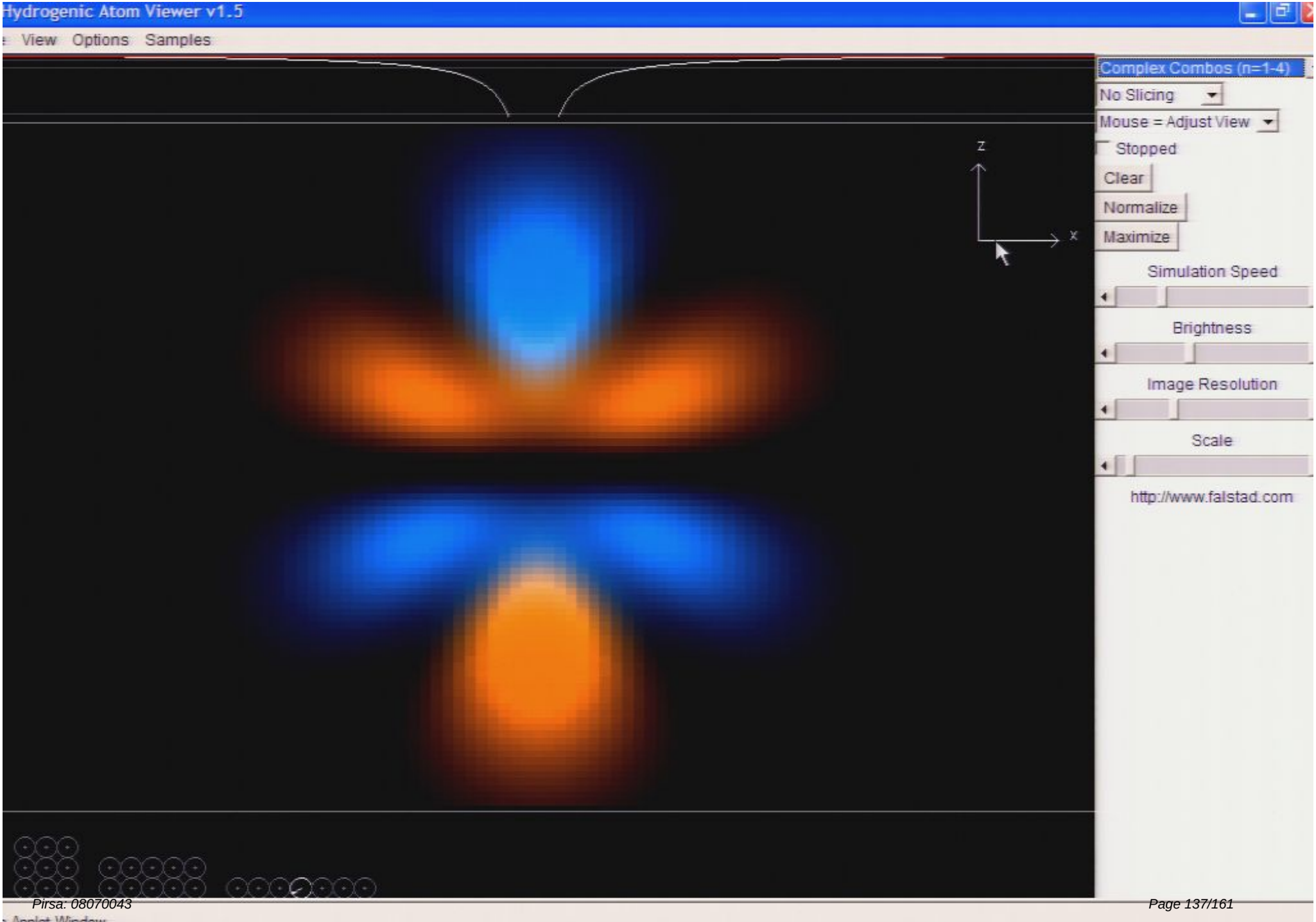
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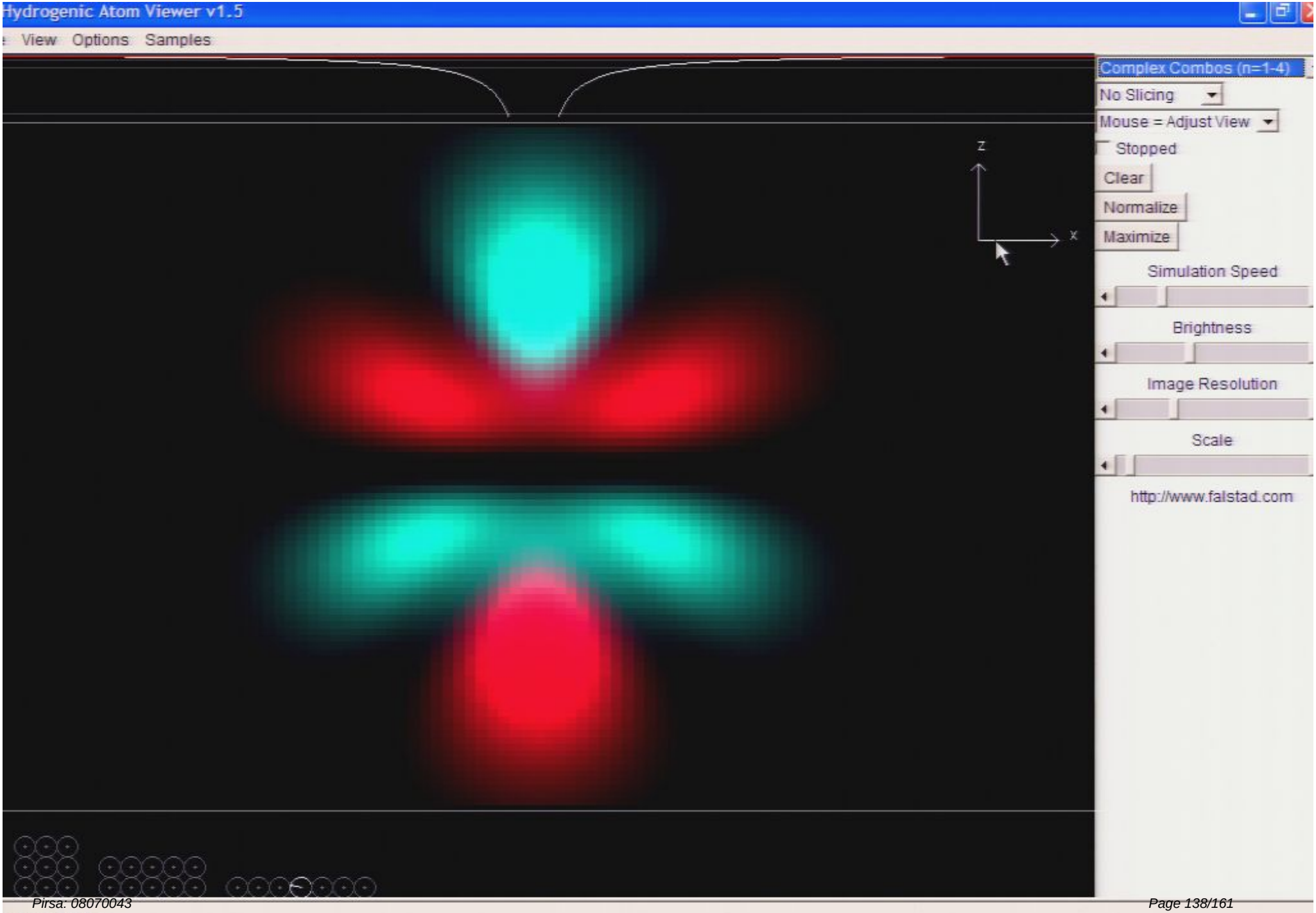
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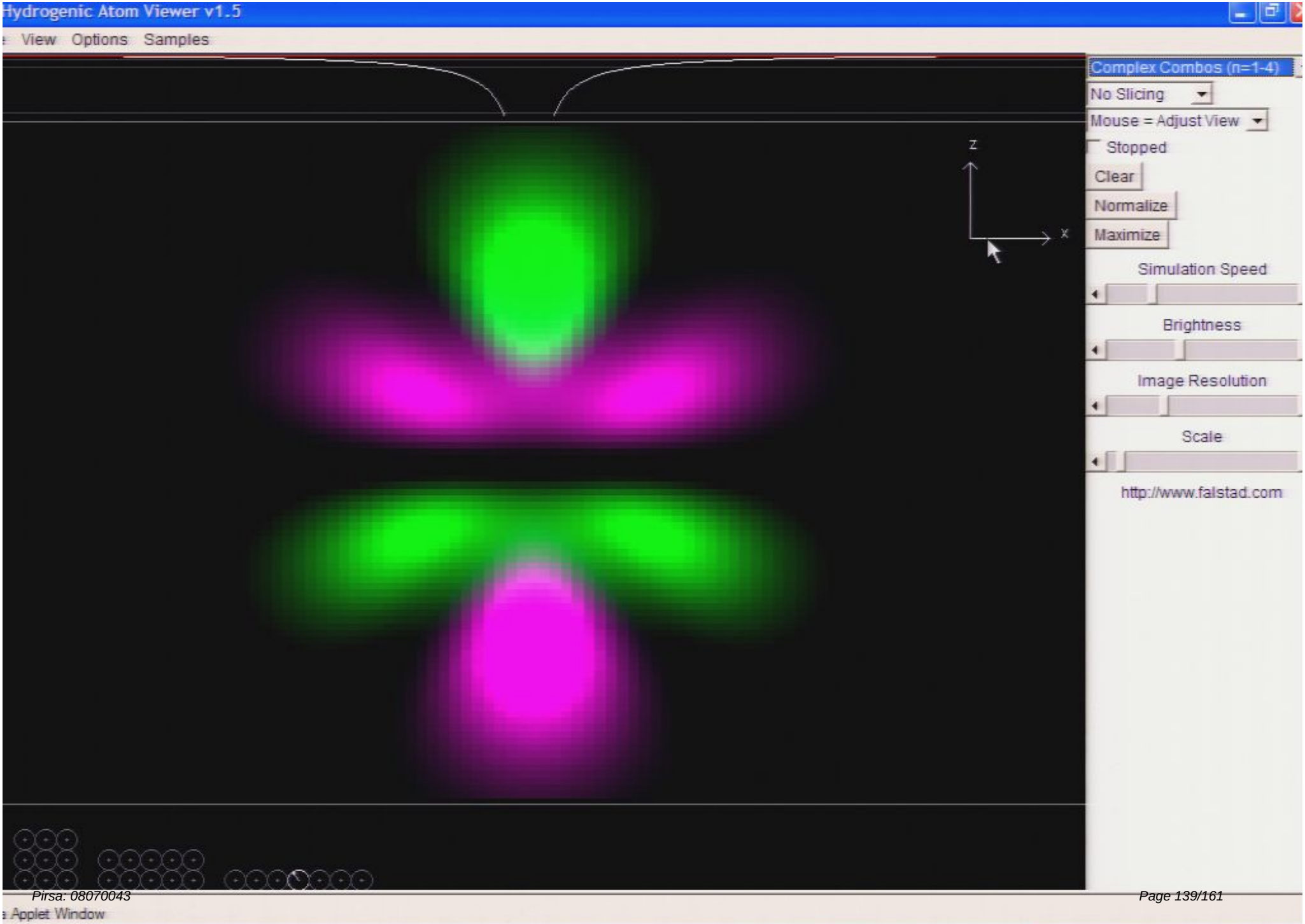
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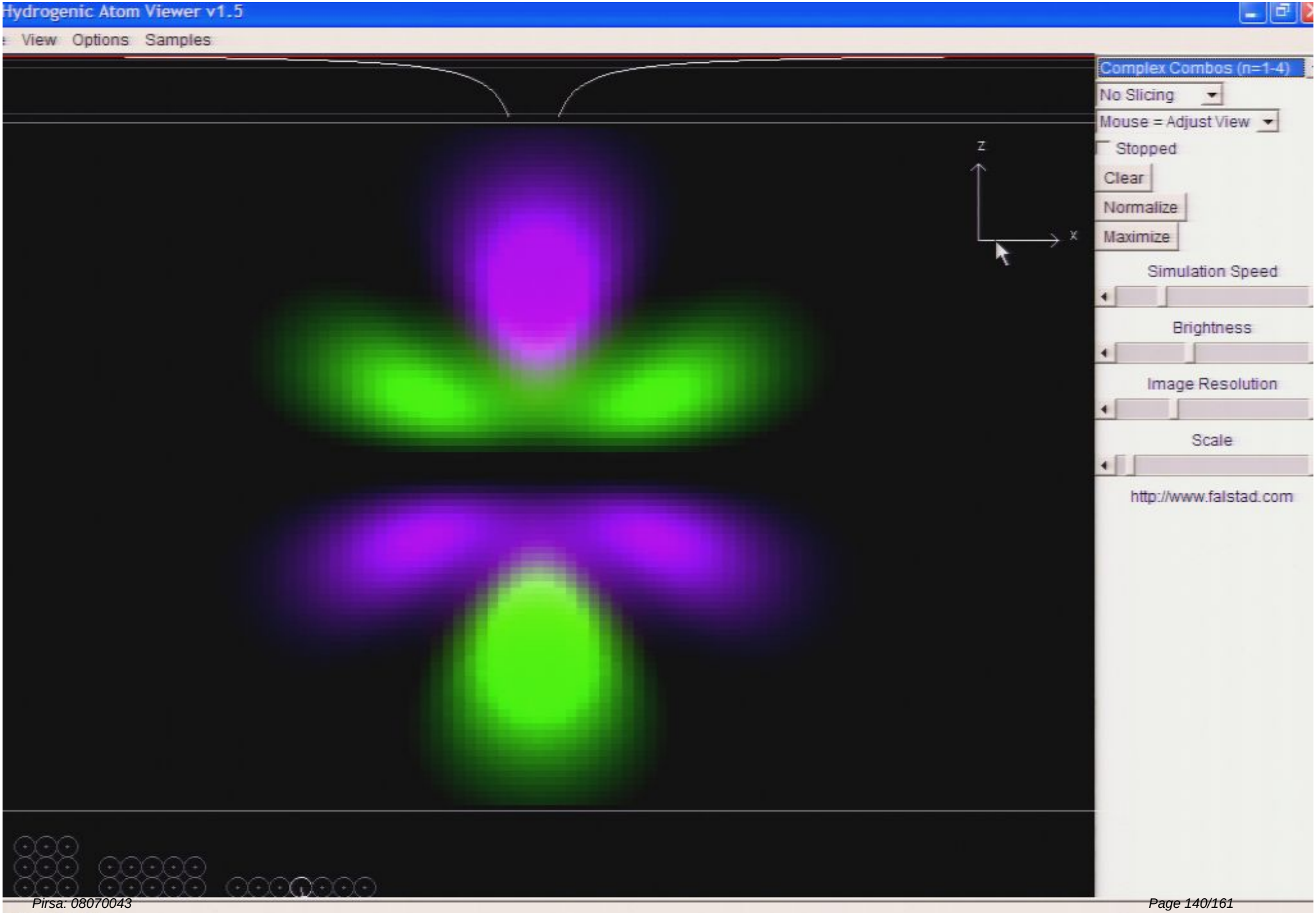

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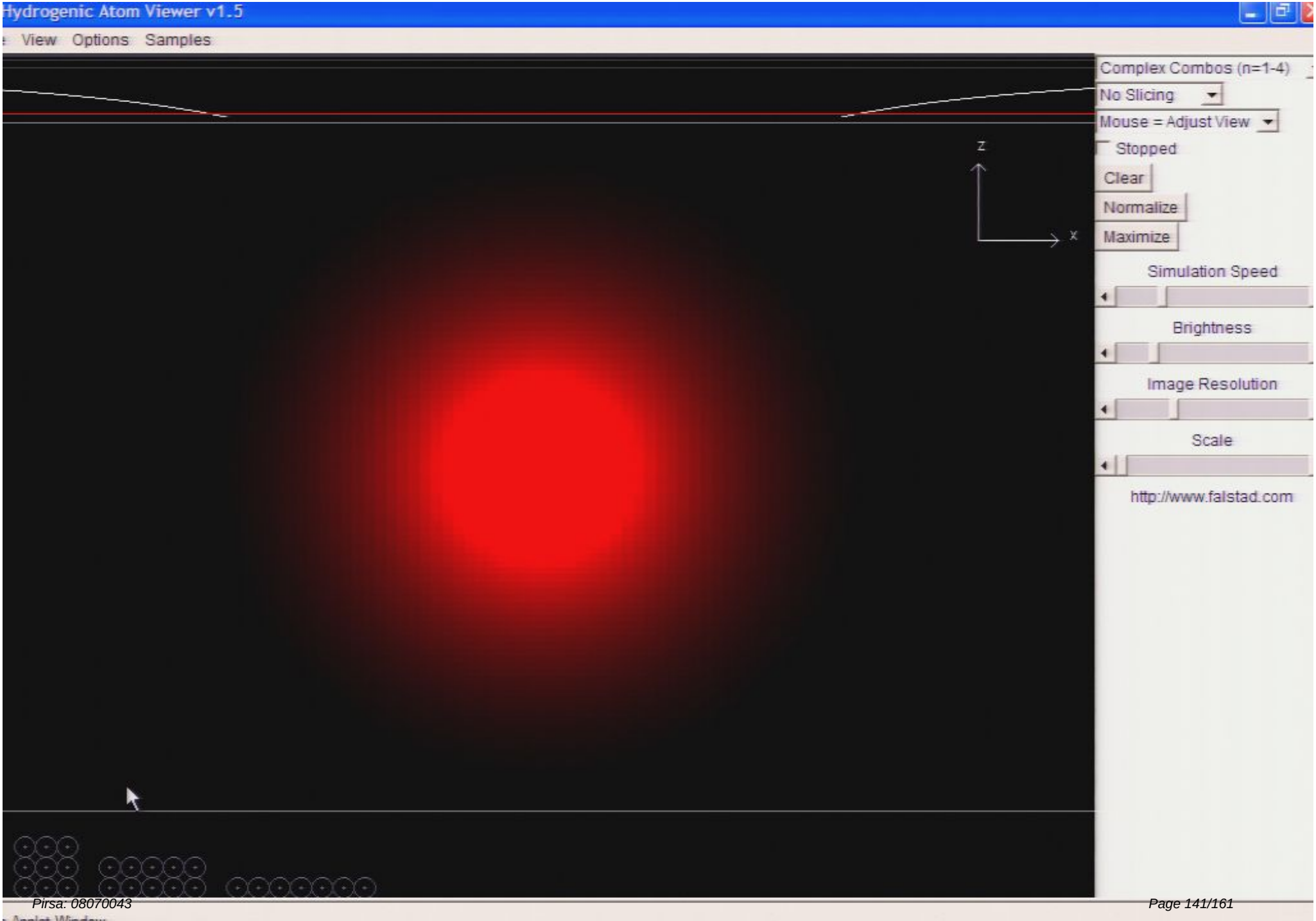
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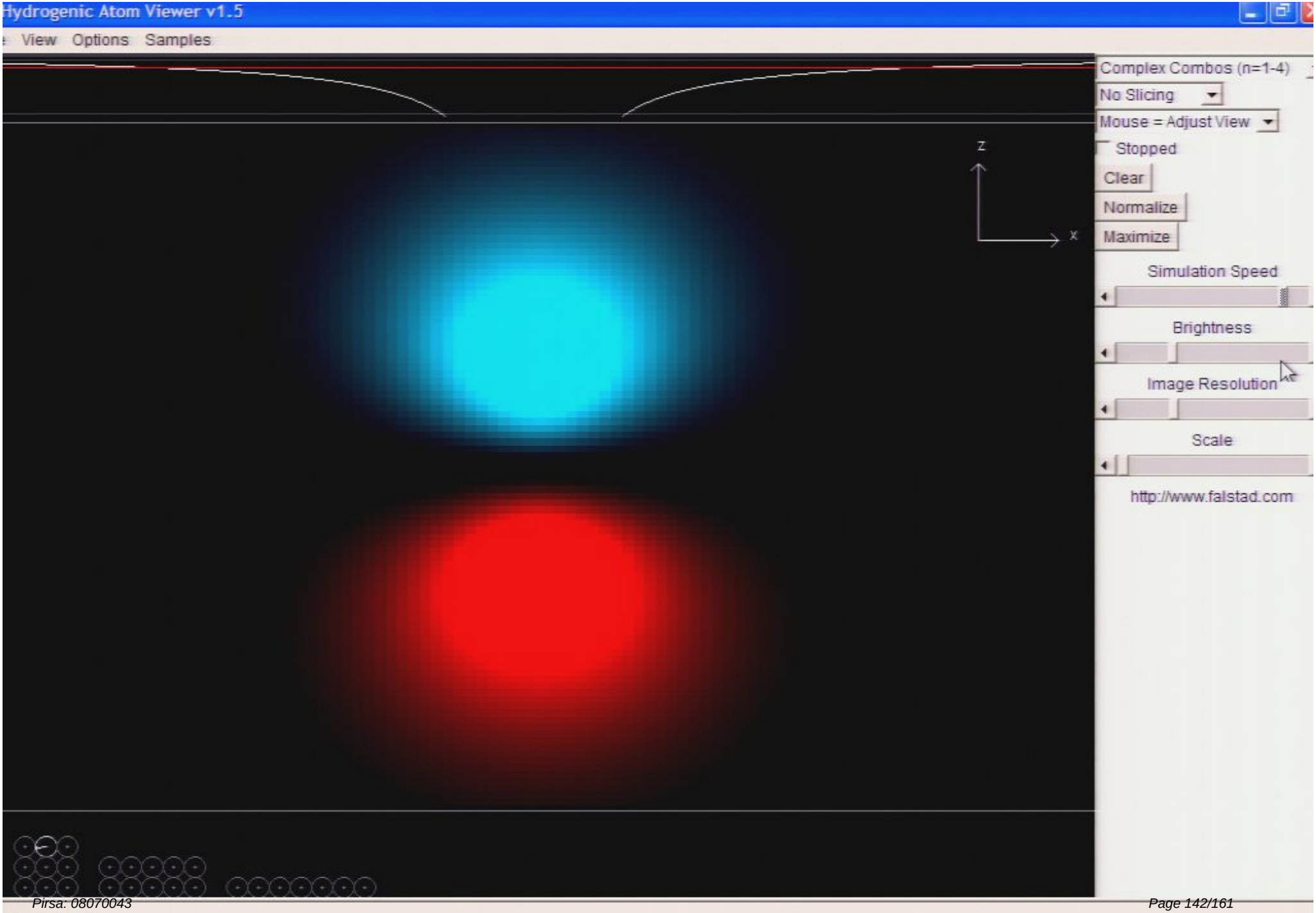
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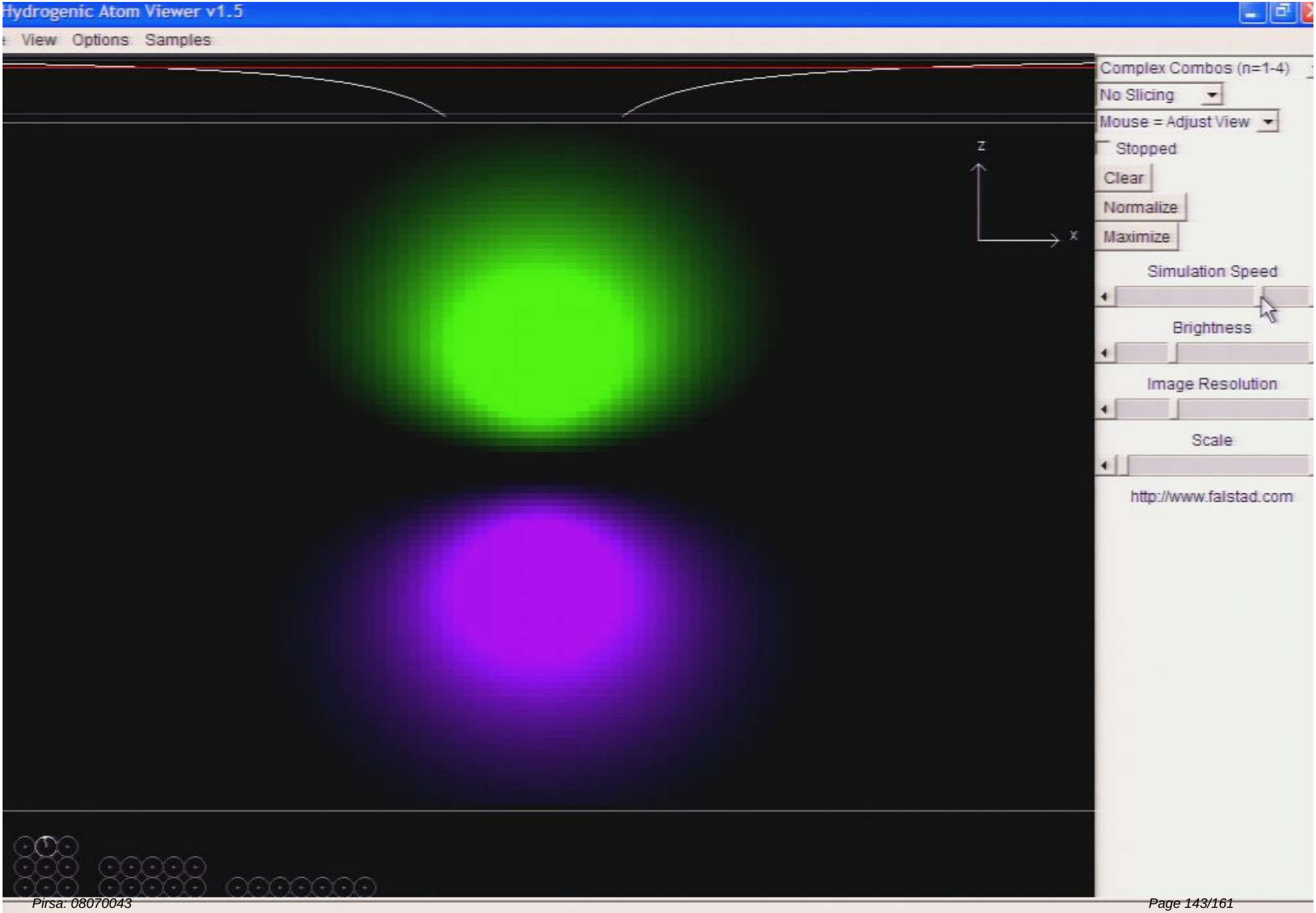
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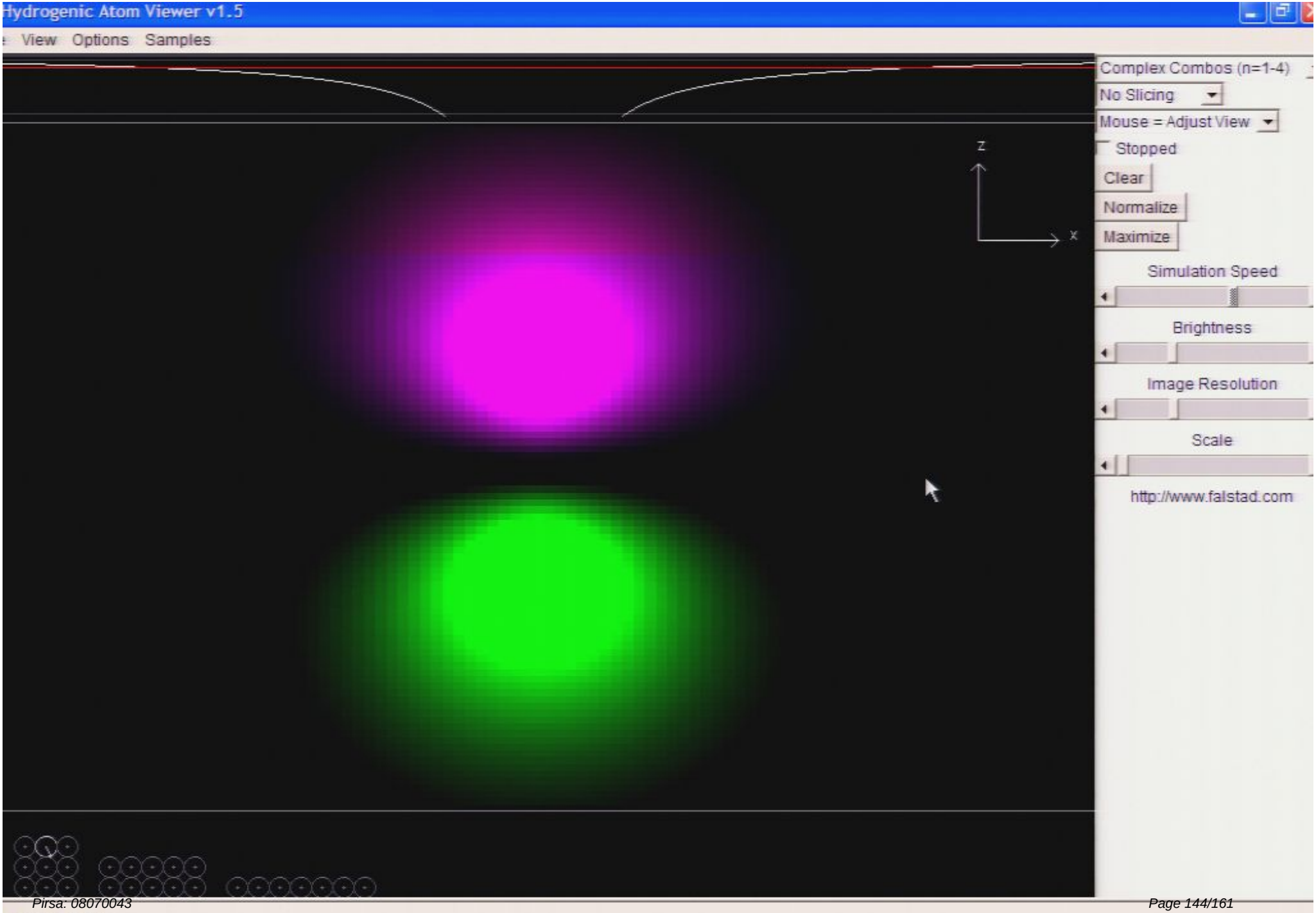
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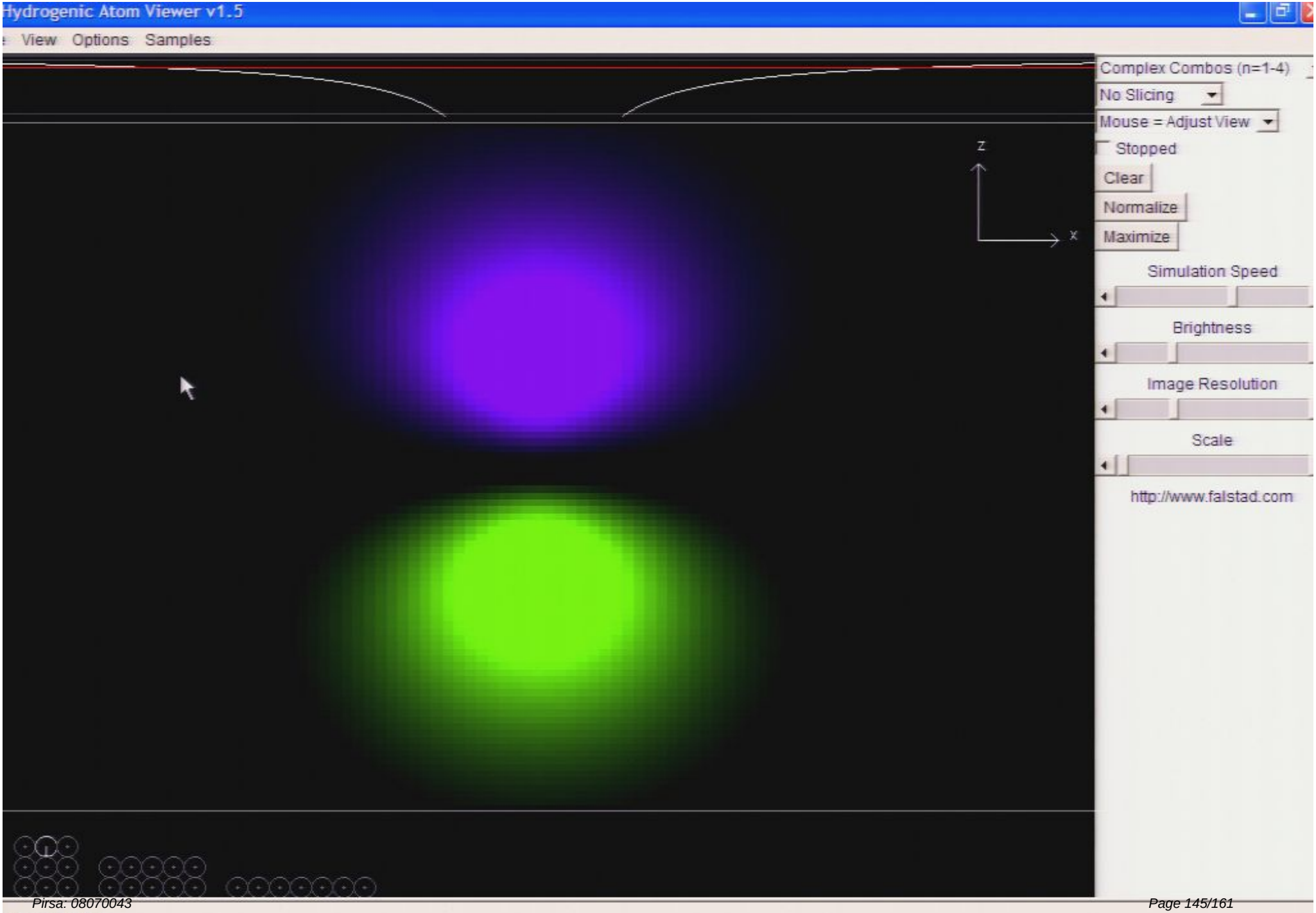
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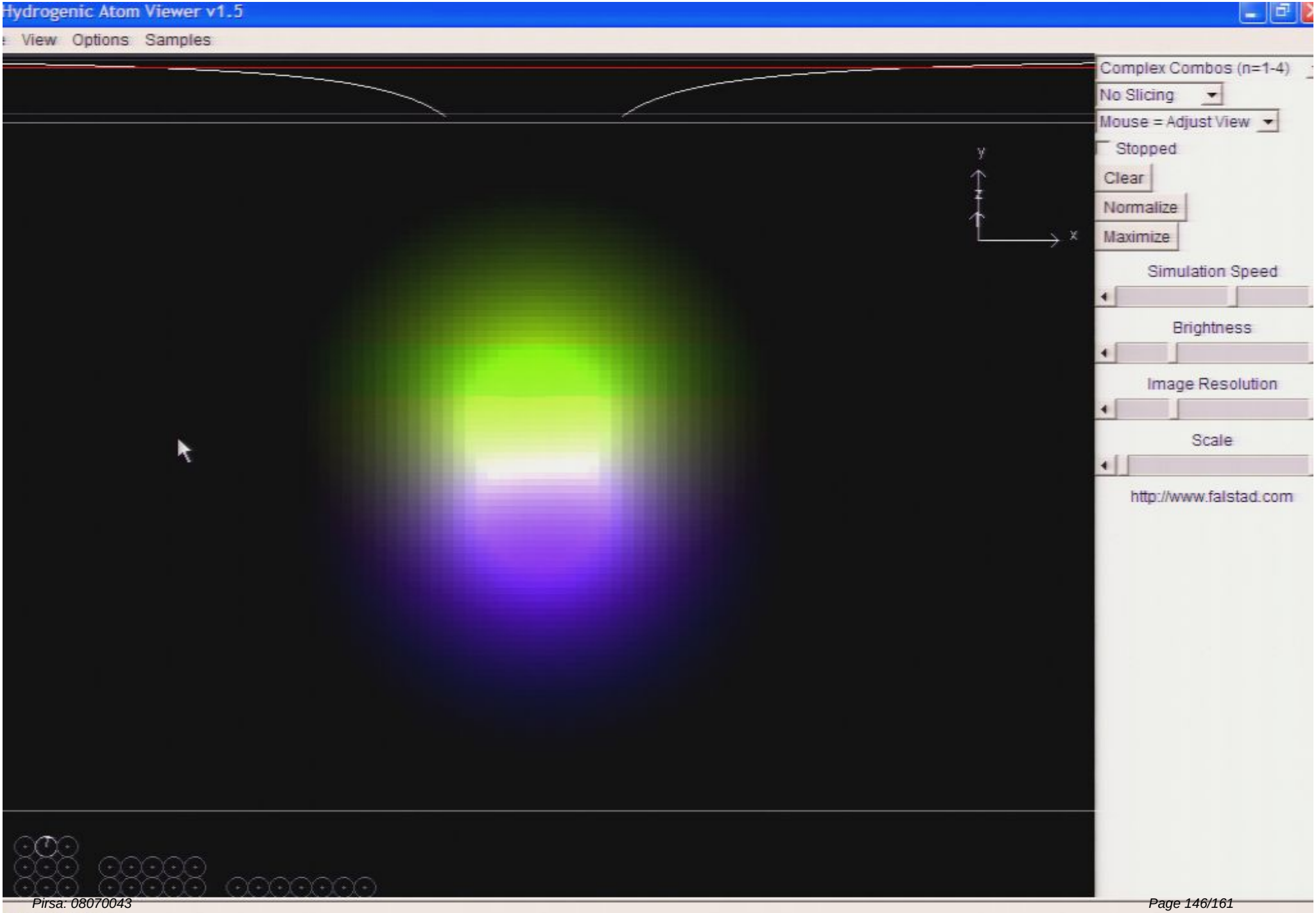
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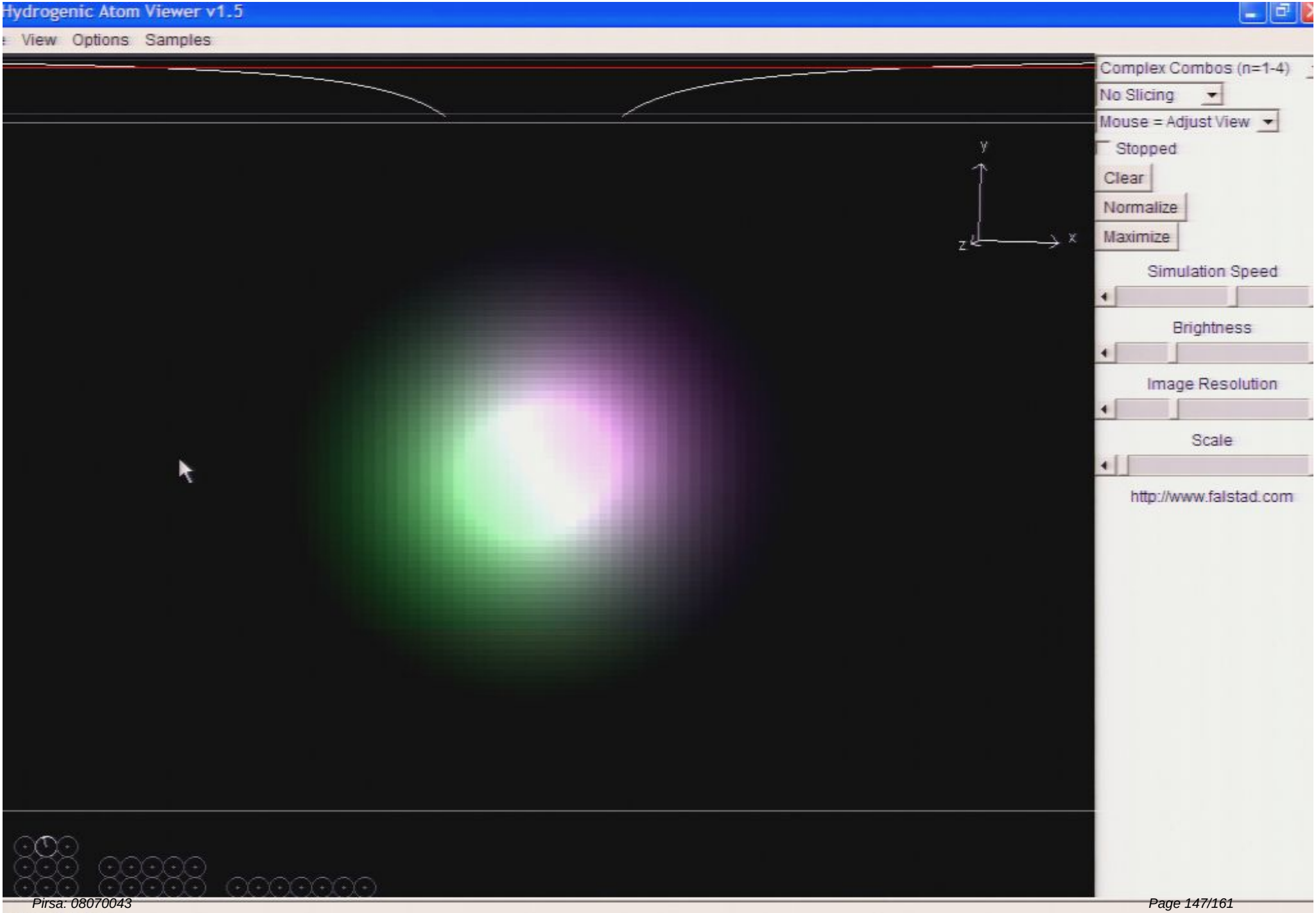
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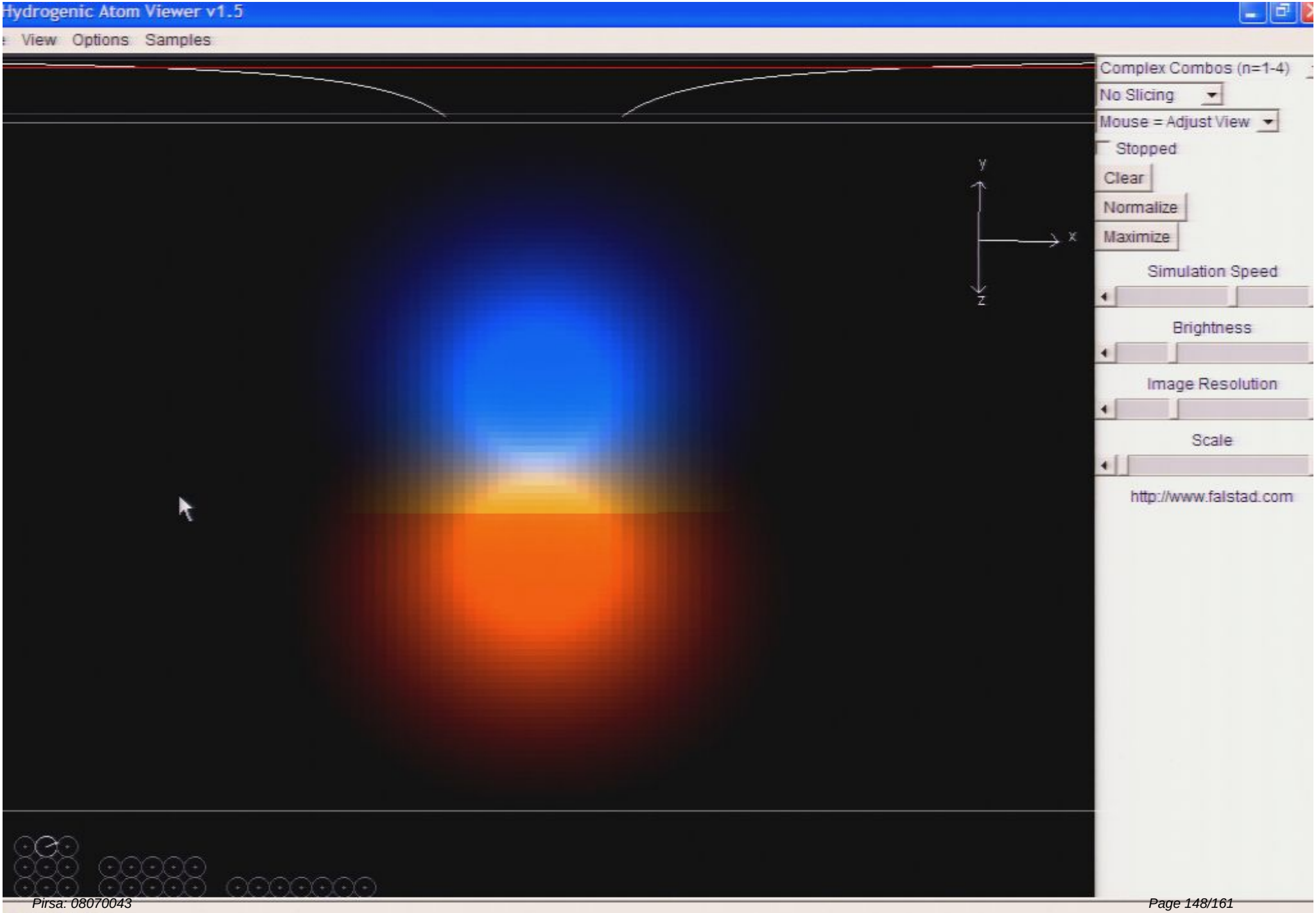
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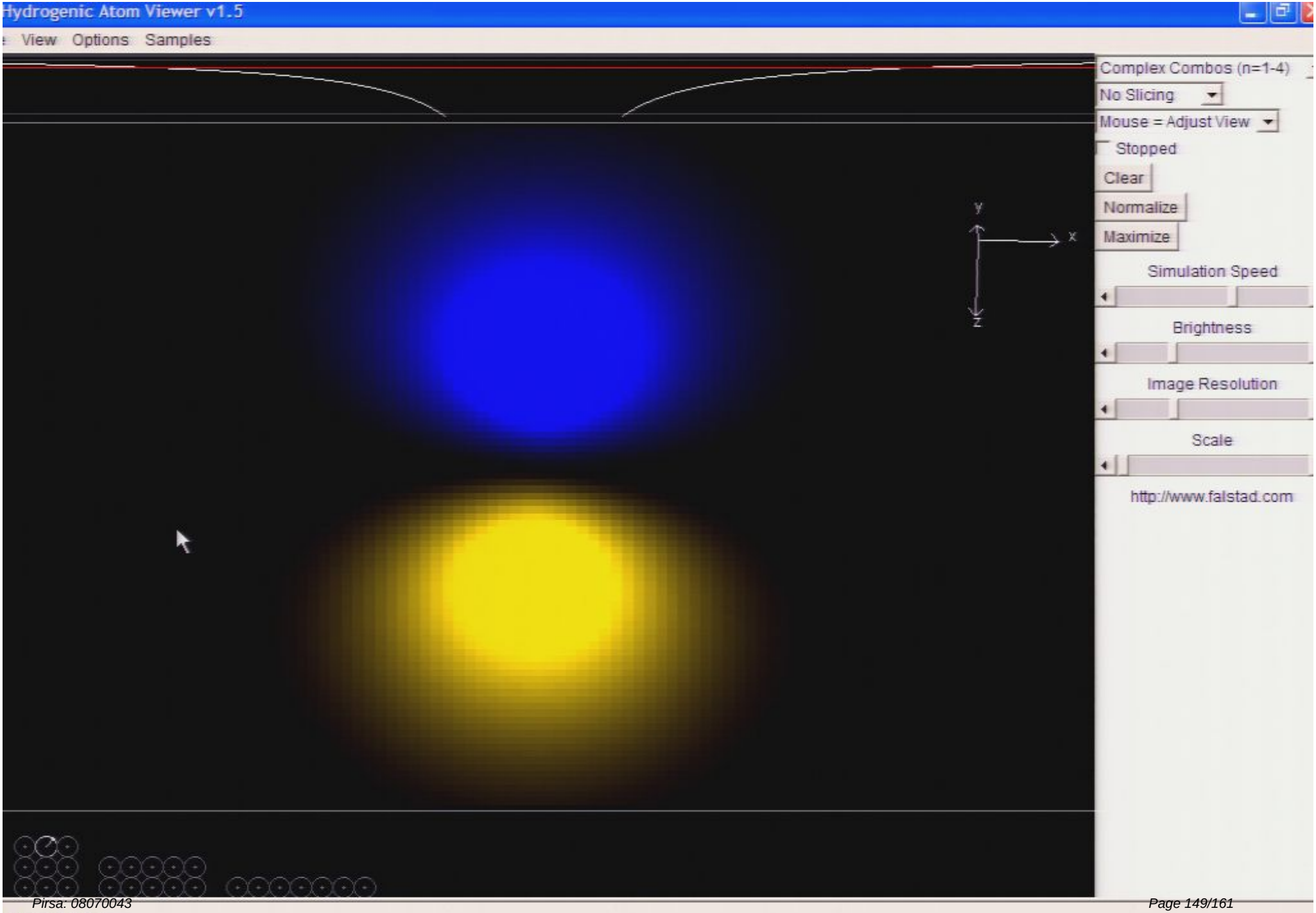

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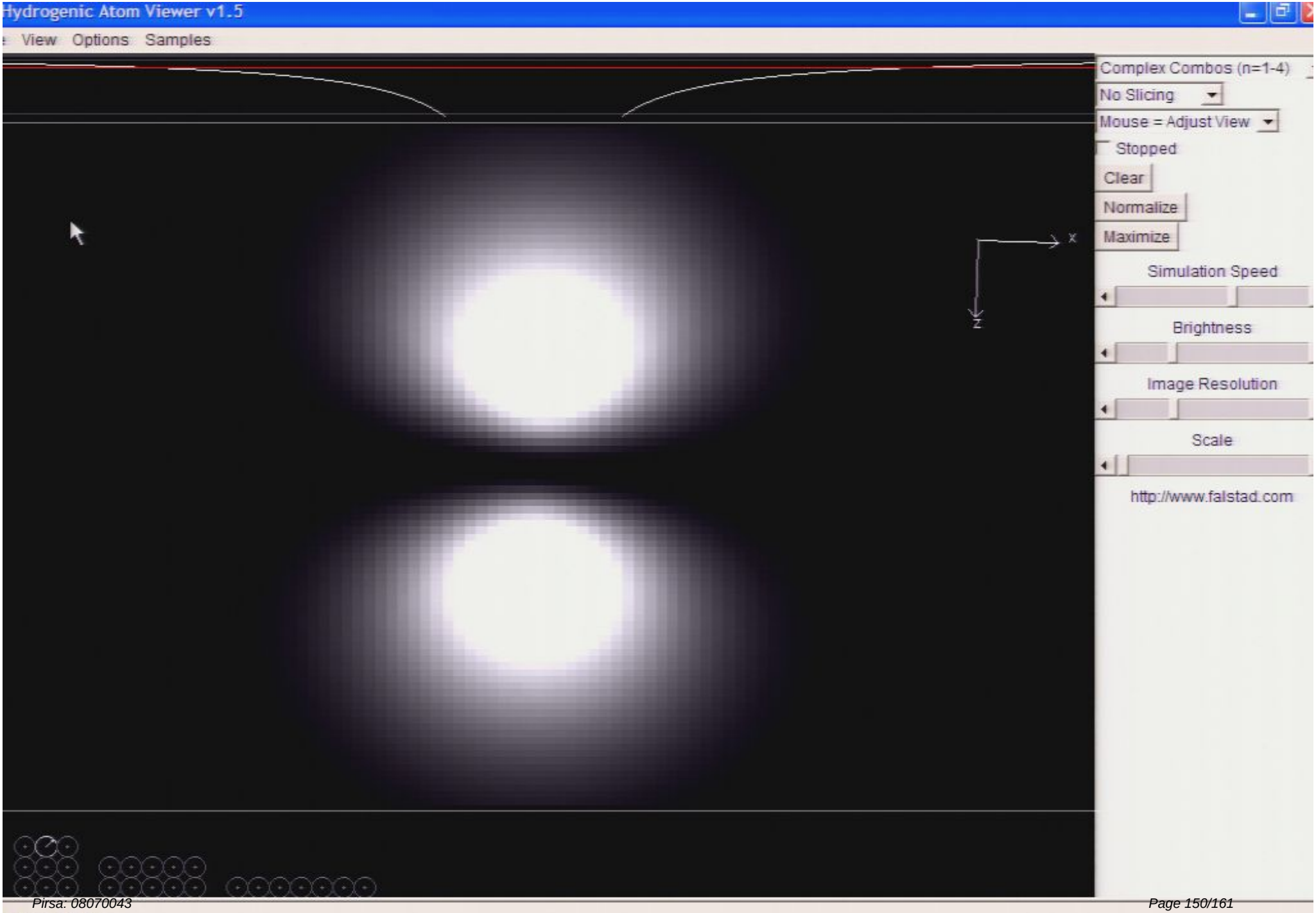
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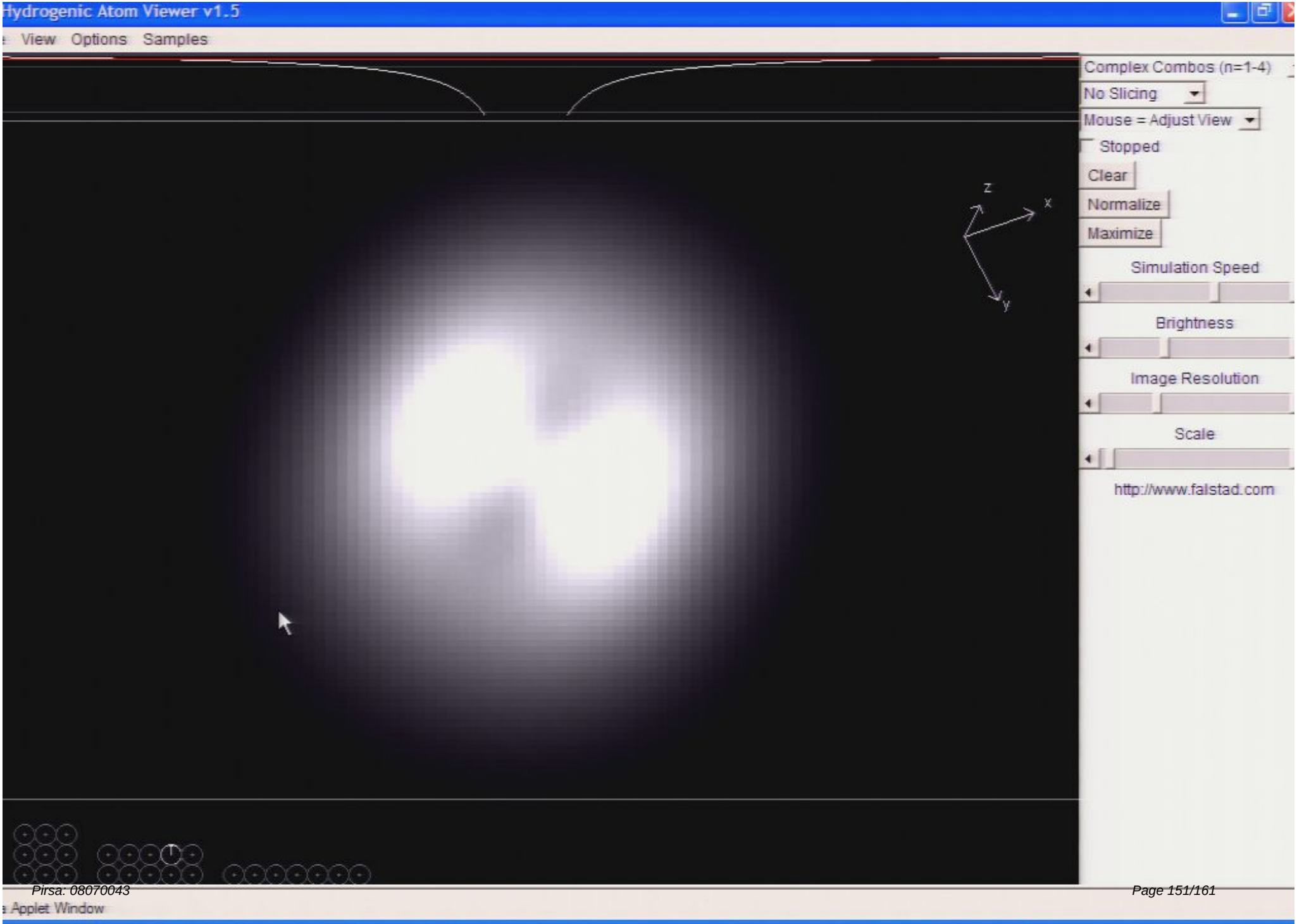
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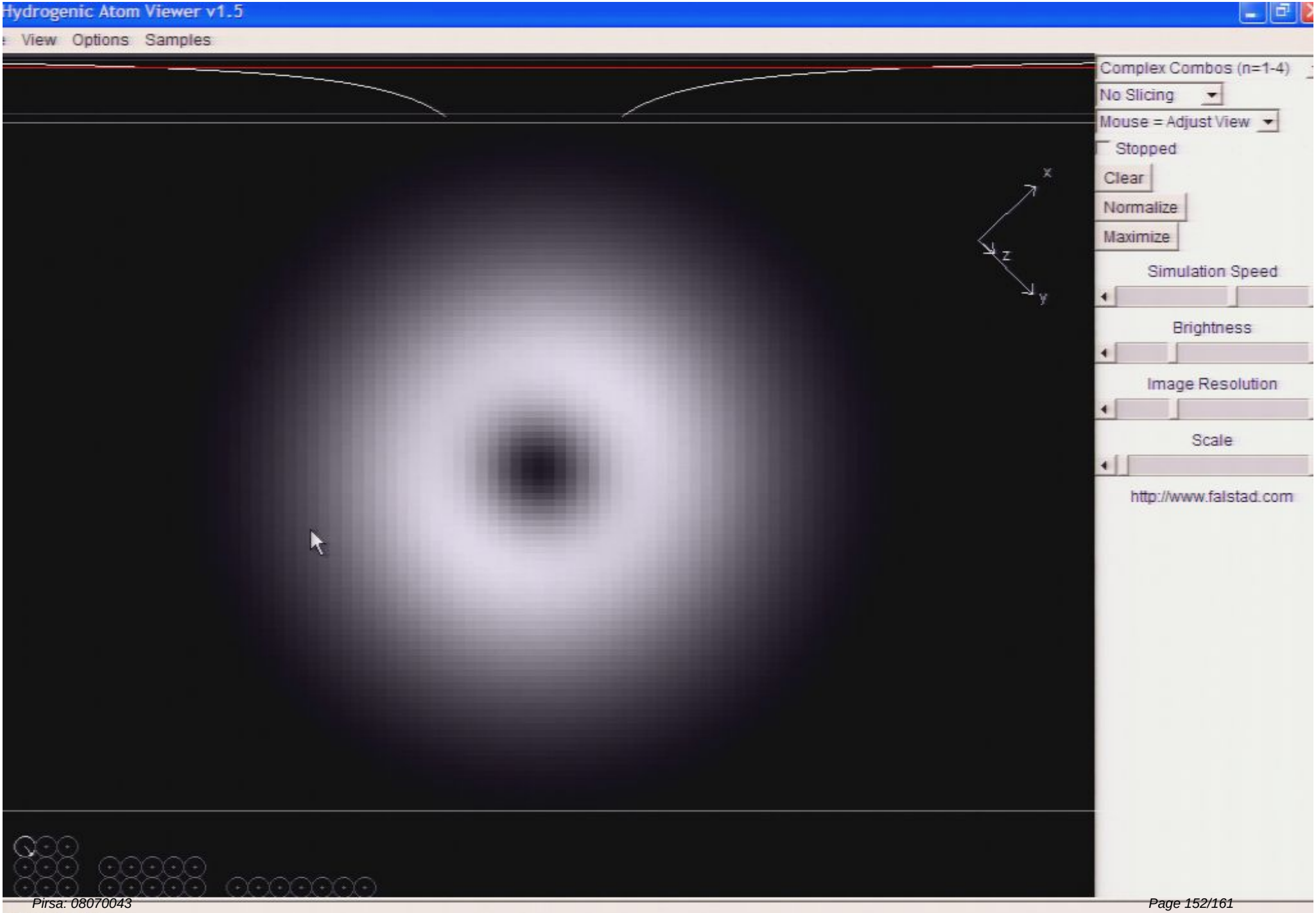
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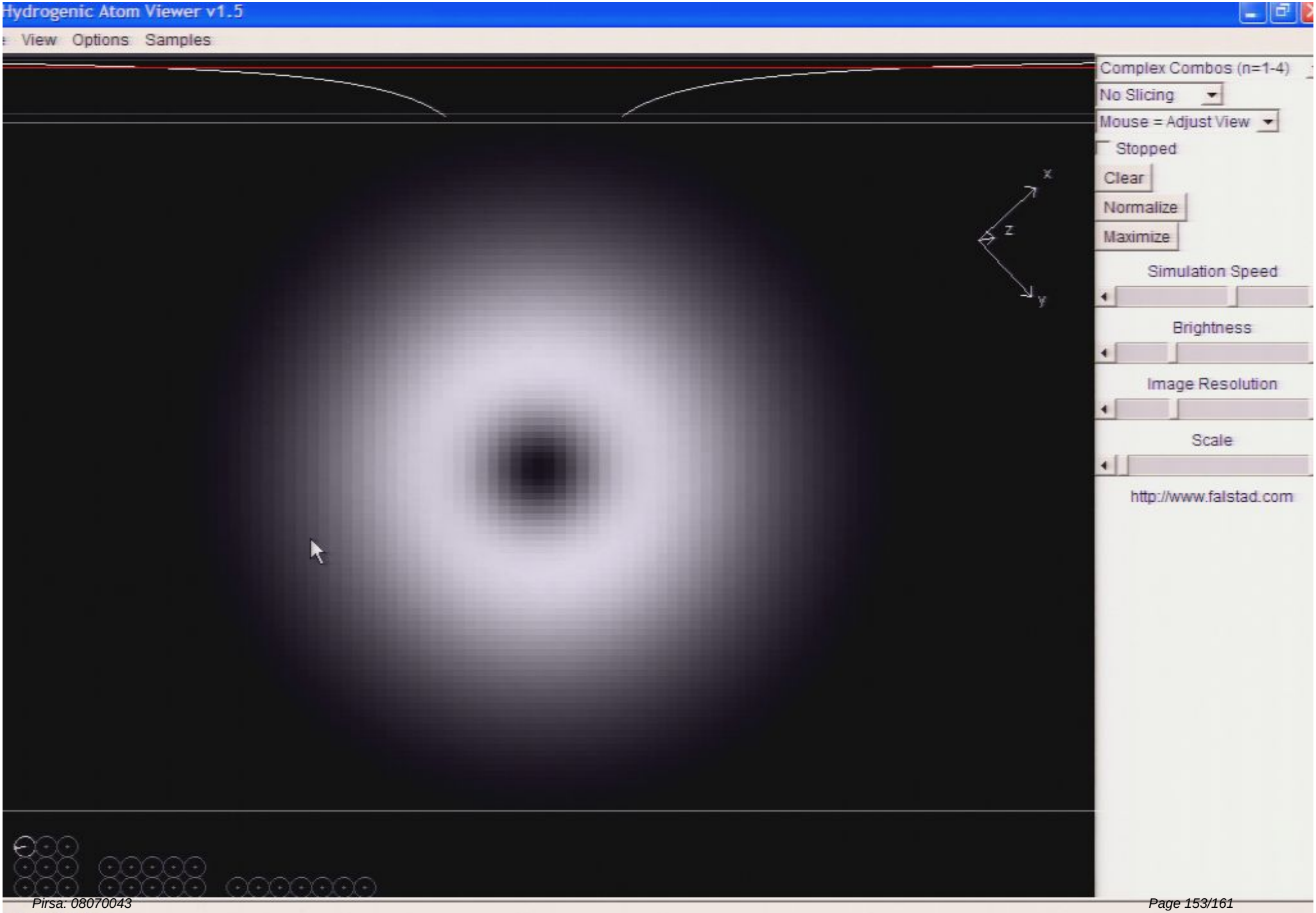
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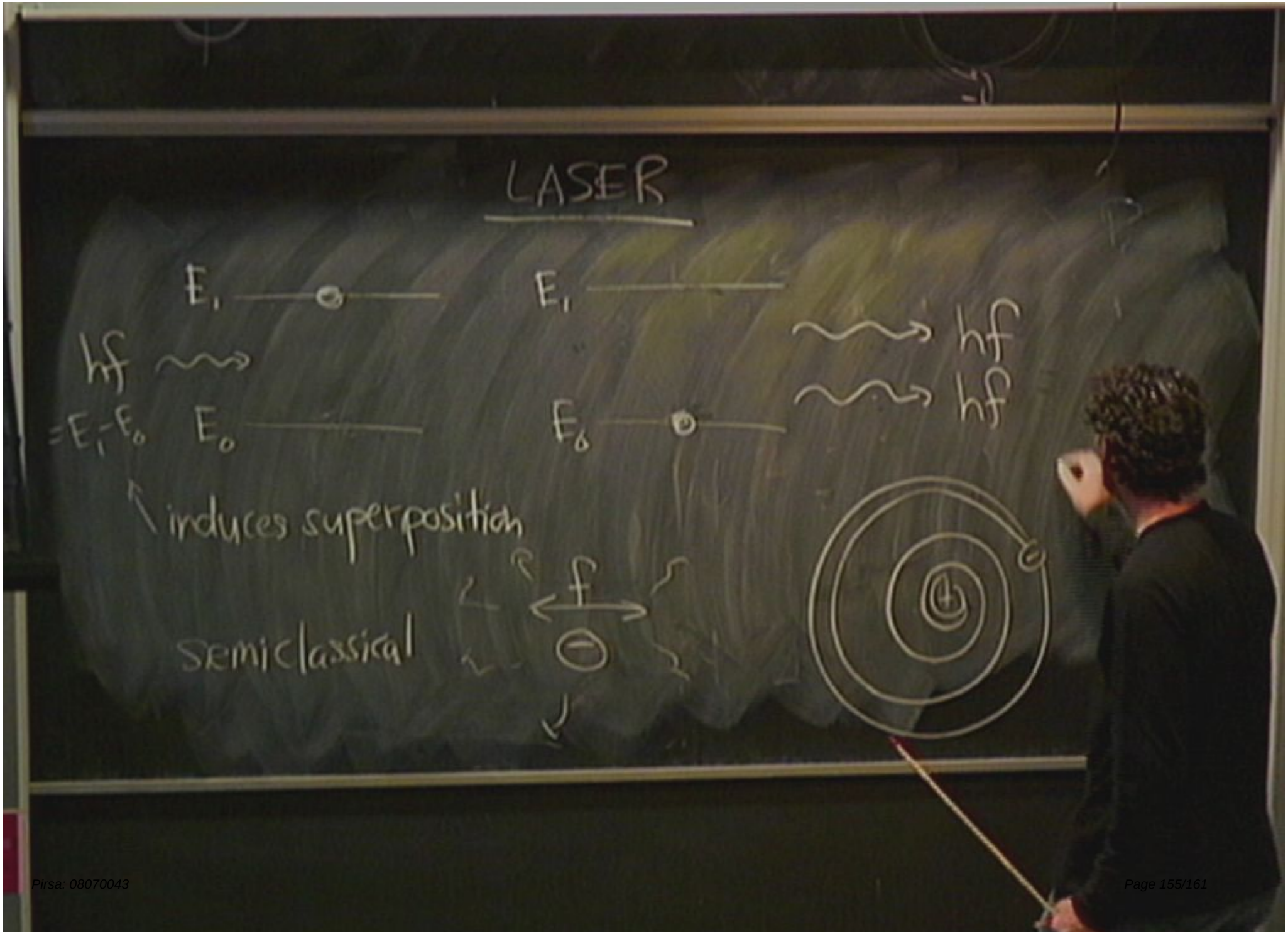
LASER
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E_1
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hf
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$=E_1-E_0$
E_0
E_0
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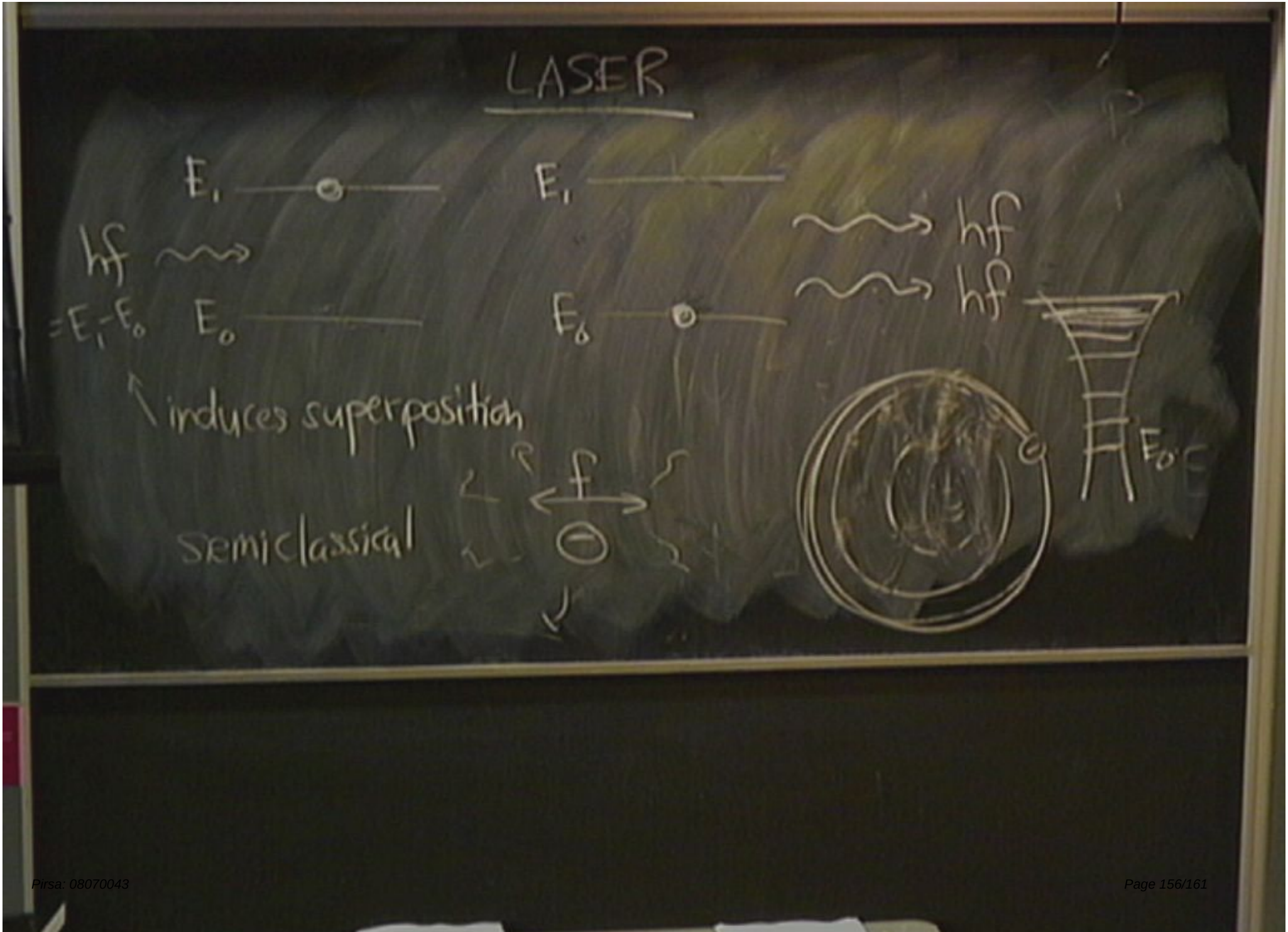
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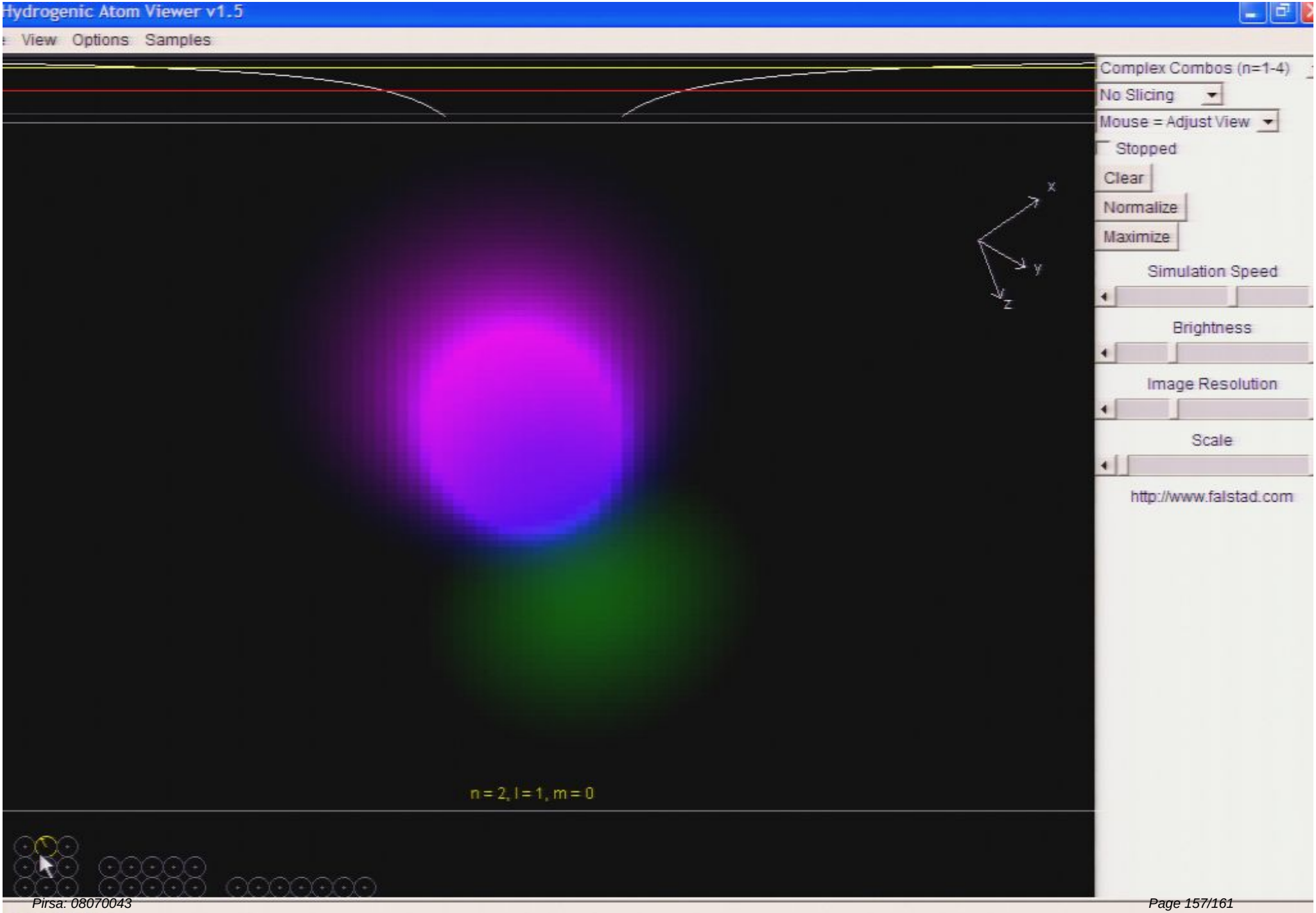
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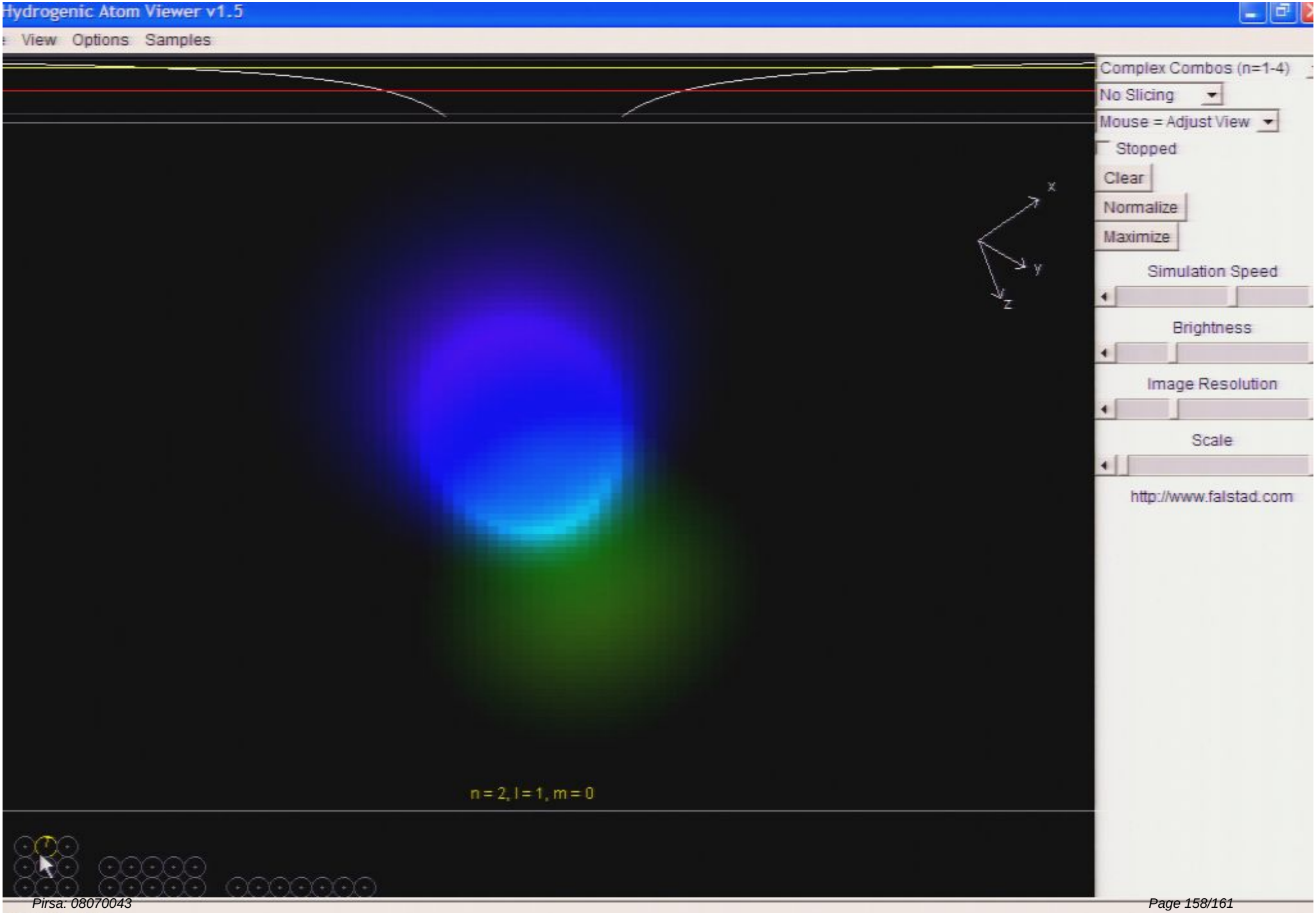
Applet Window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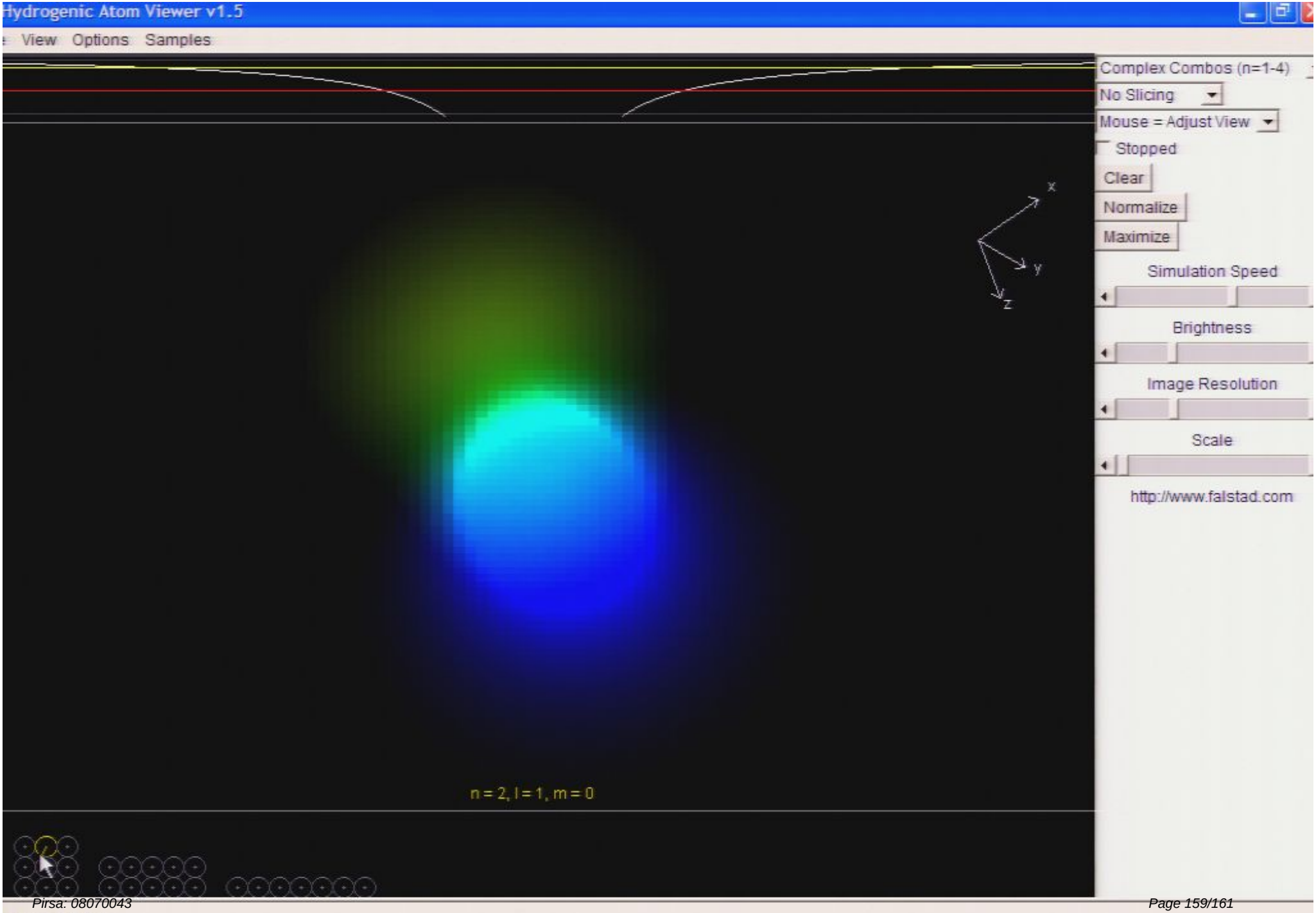
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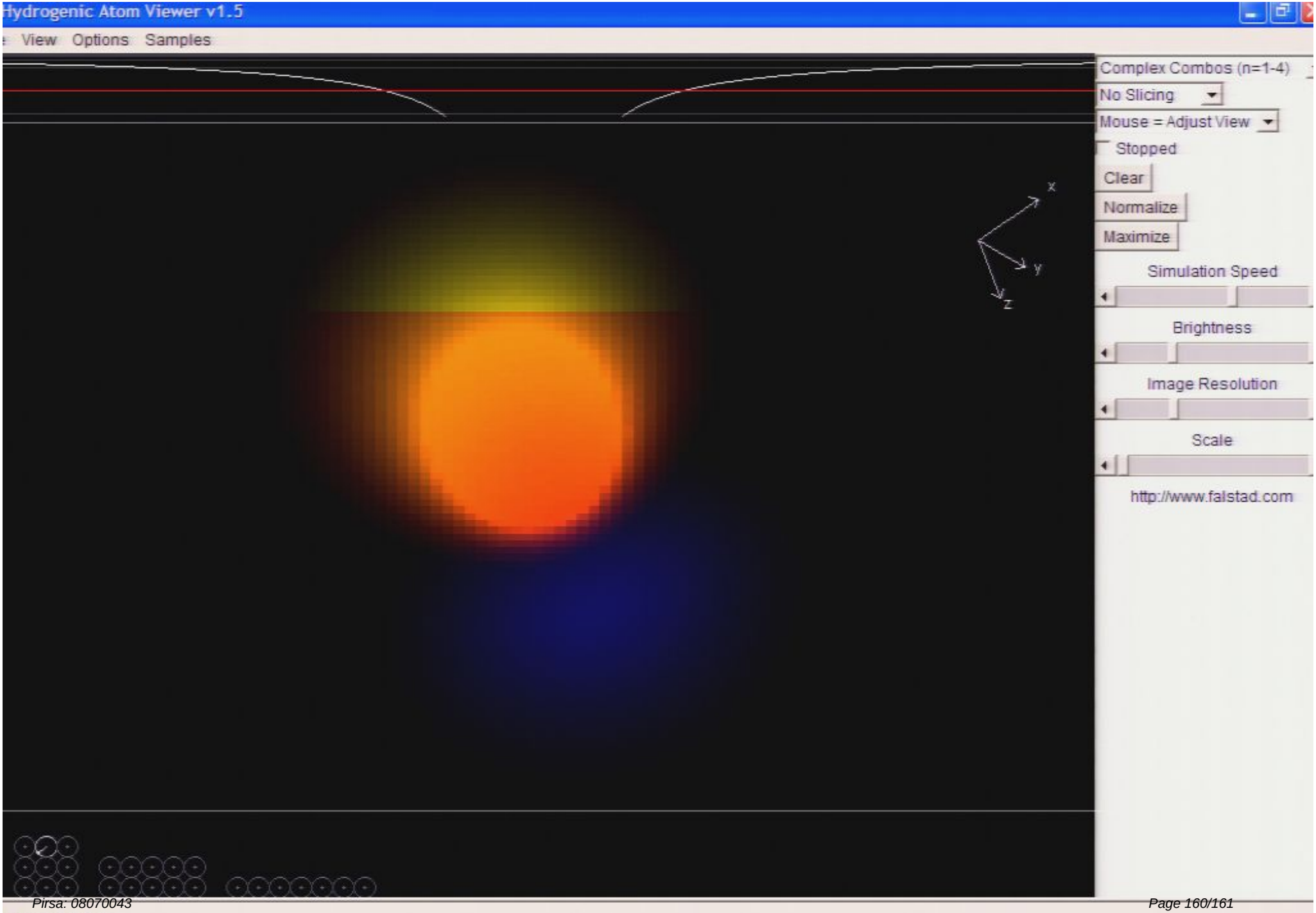
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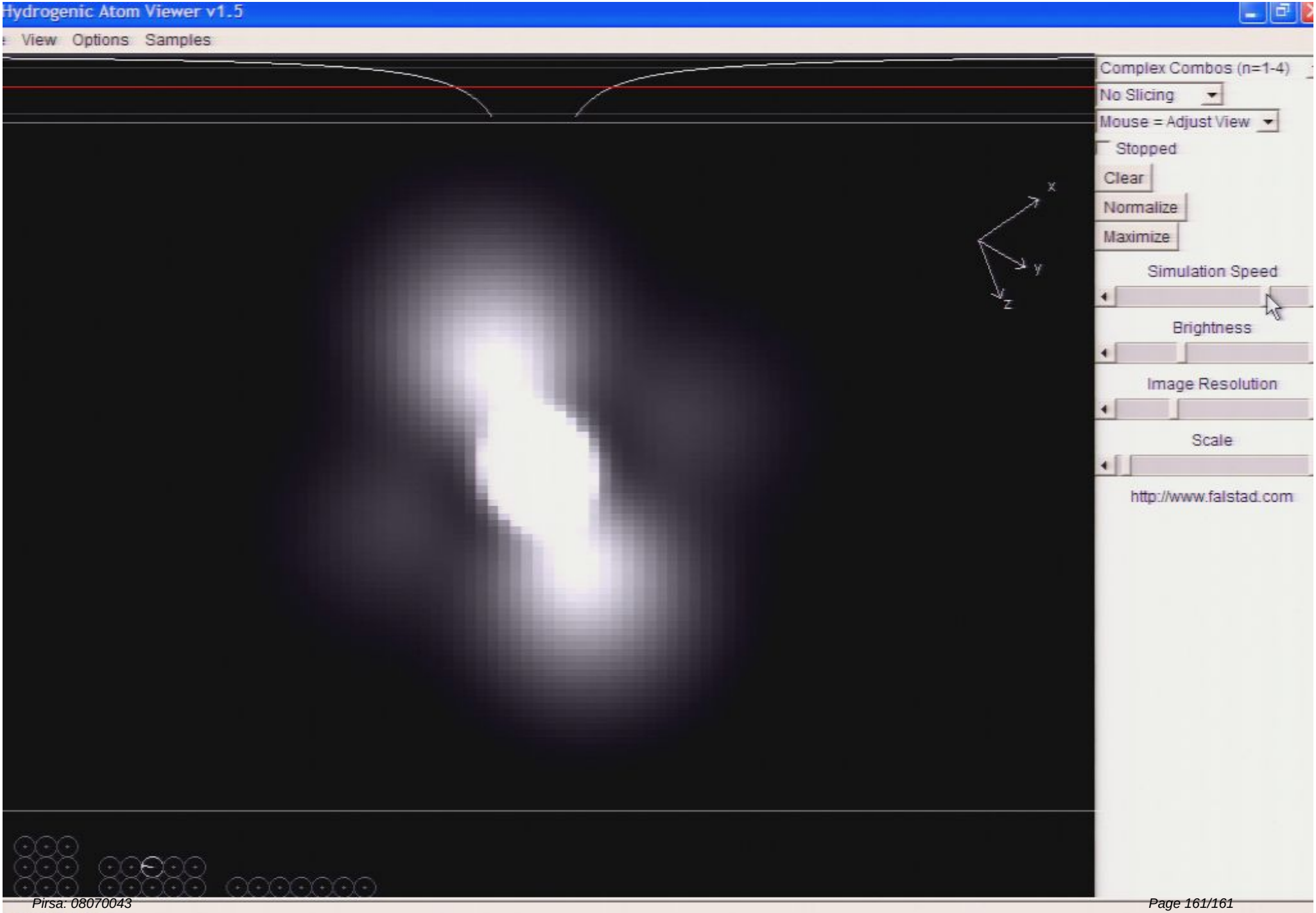
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