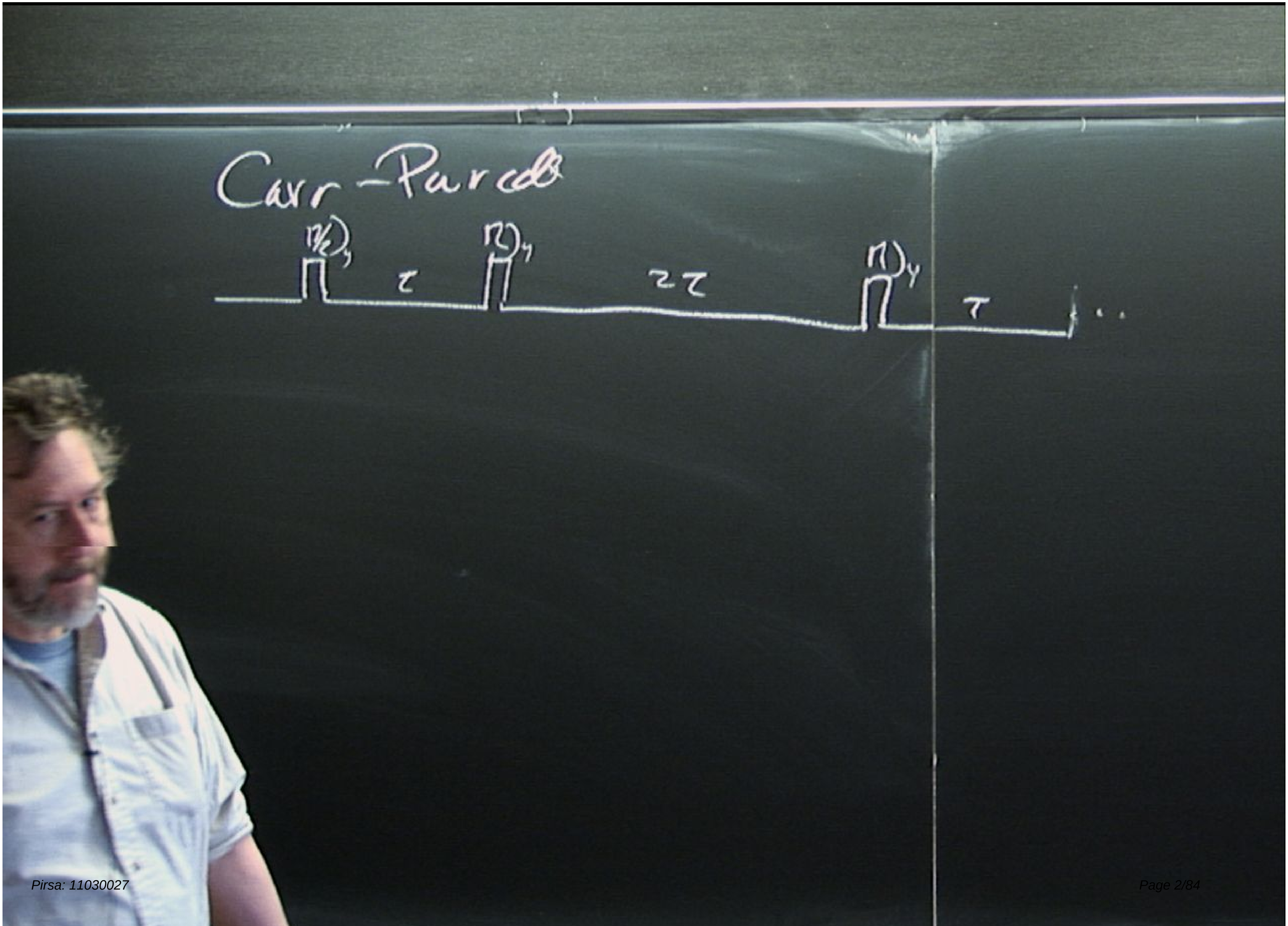
Title: Explorations in Quantum Information - Lecture 12

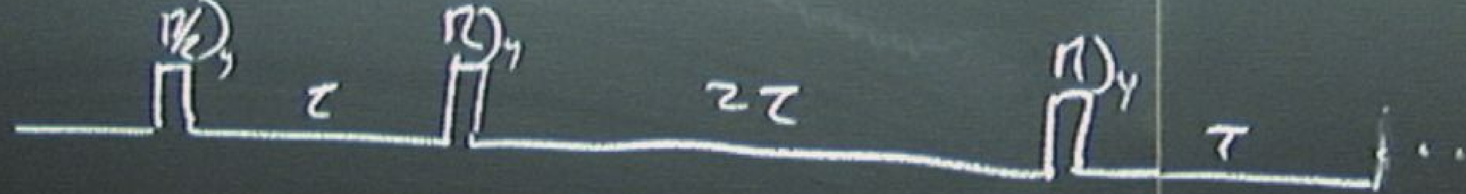
Date: Mar 30, 2011 09:00 AM

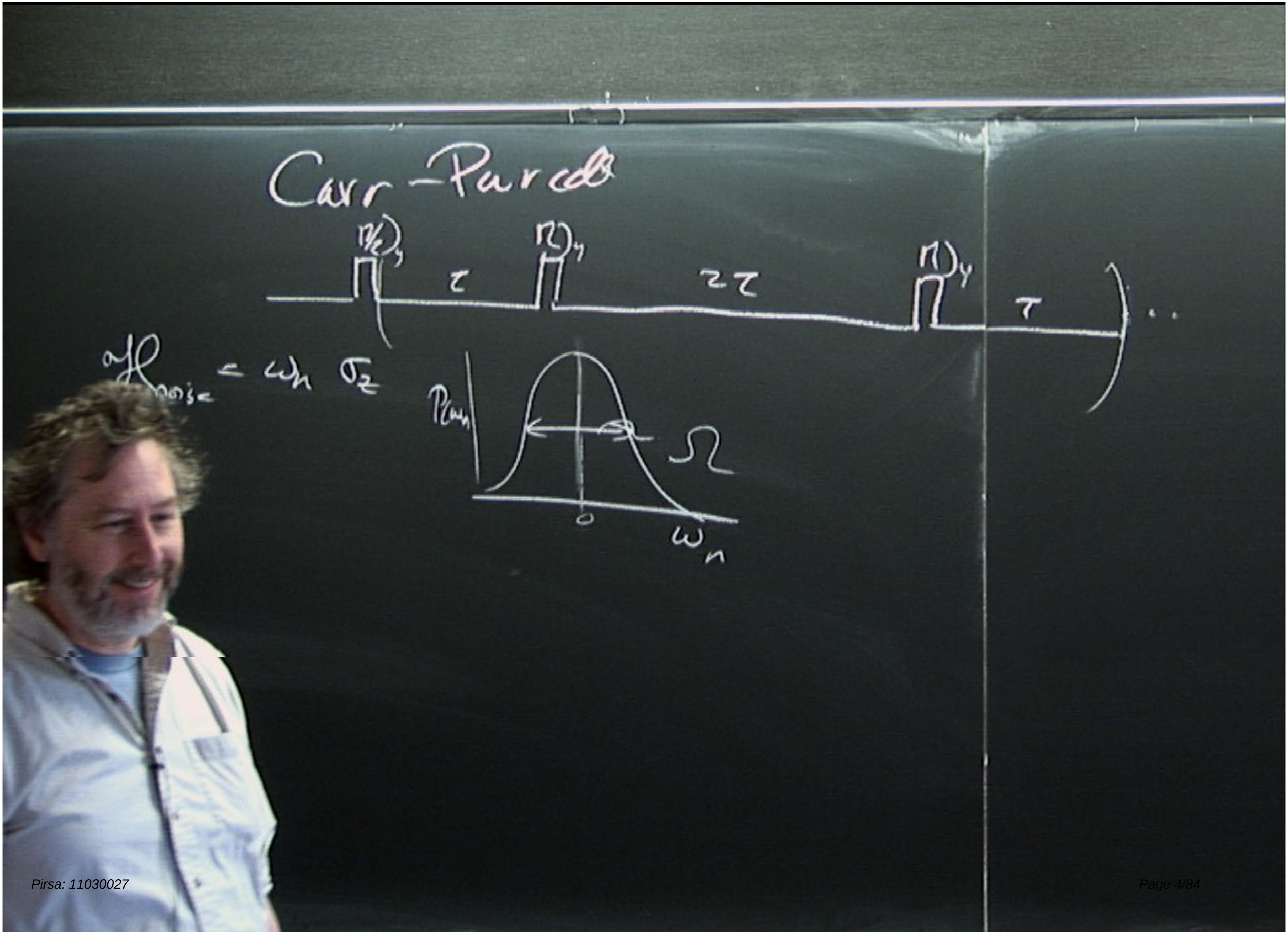
URL: http://pirsa.org/11030027

Abstract:

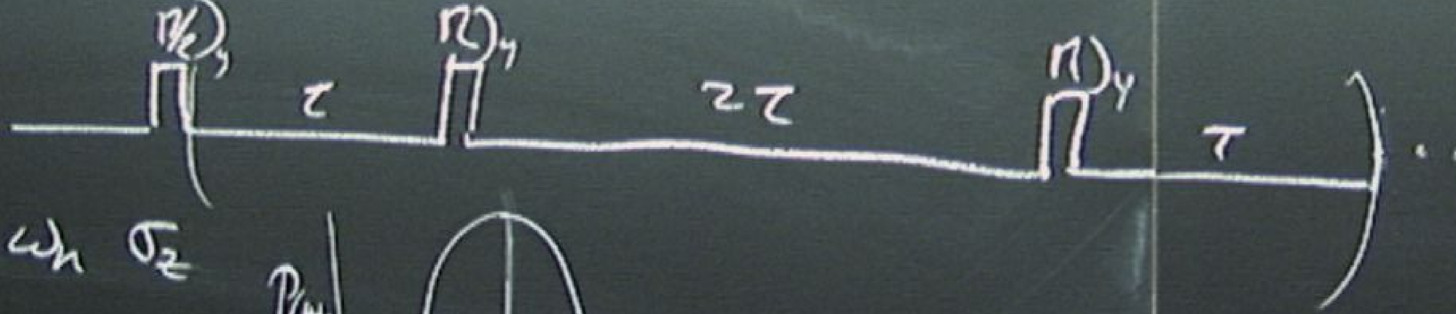

Carr-Purcell
π/2)y
τ
π)y
2τ
π)y
τ
...

Carr-Purcell

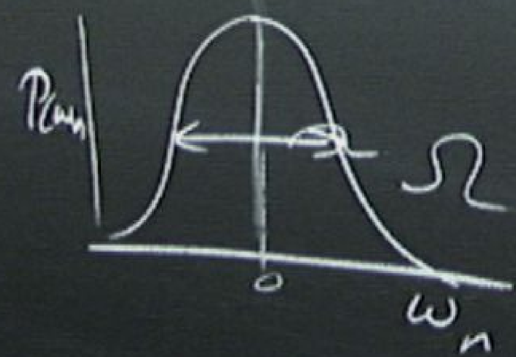


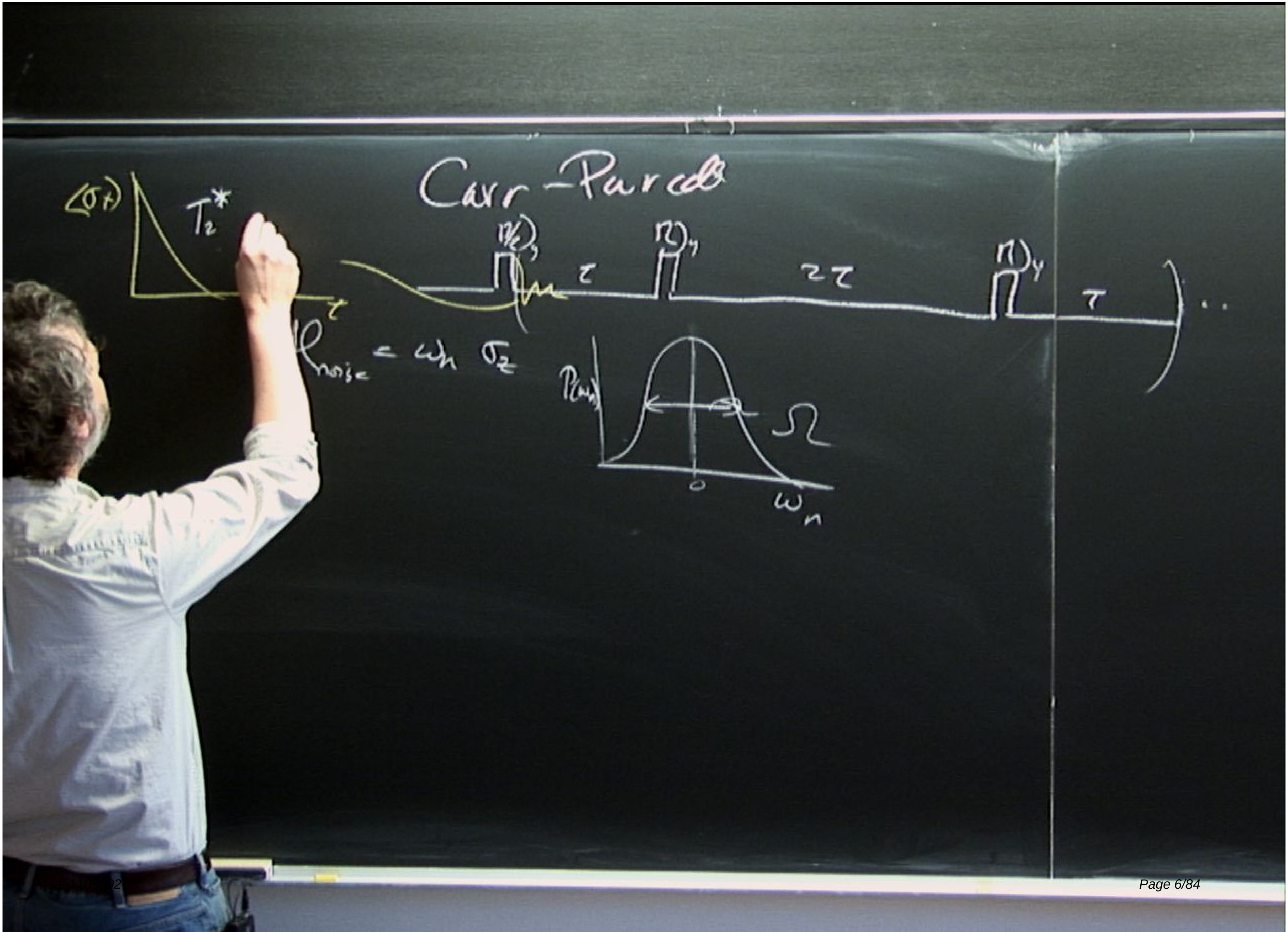

Carr-Purcell
π/2)y
π)y
τ
2τ
π)y
τ
H noise = ωn σz
P(ωn)
Ω
0
ωn

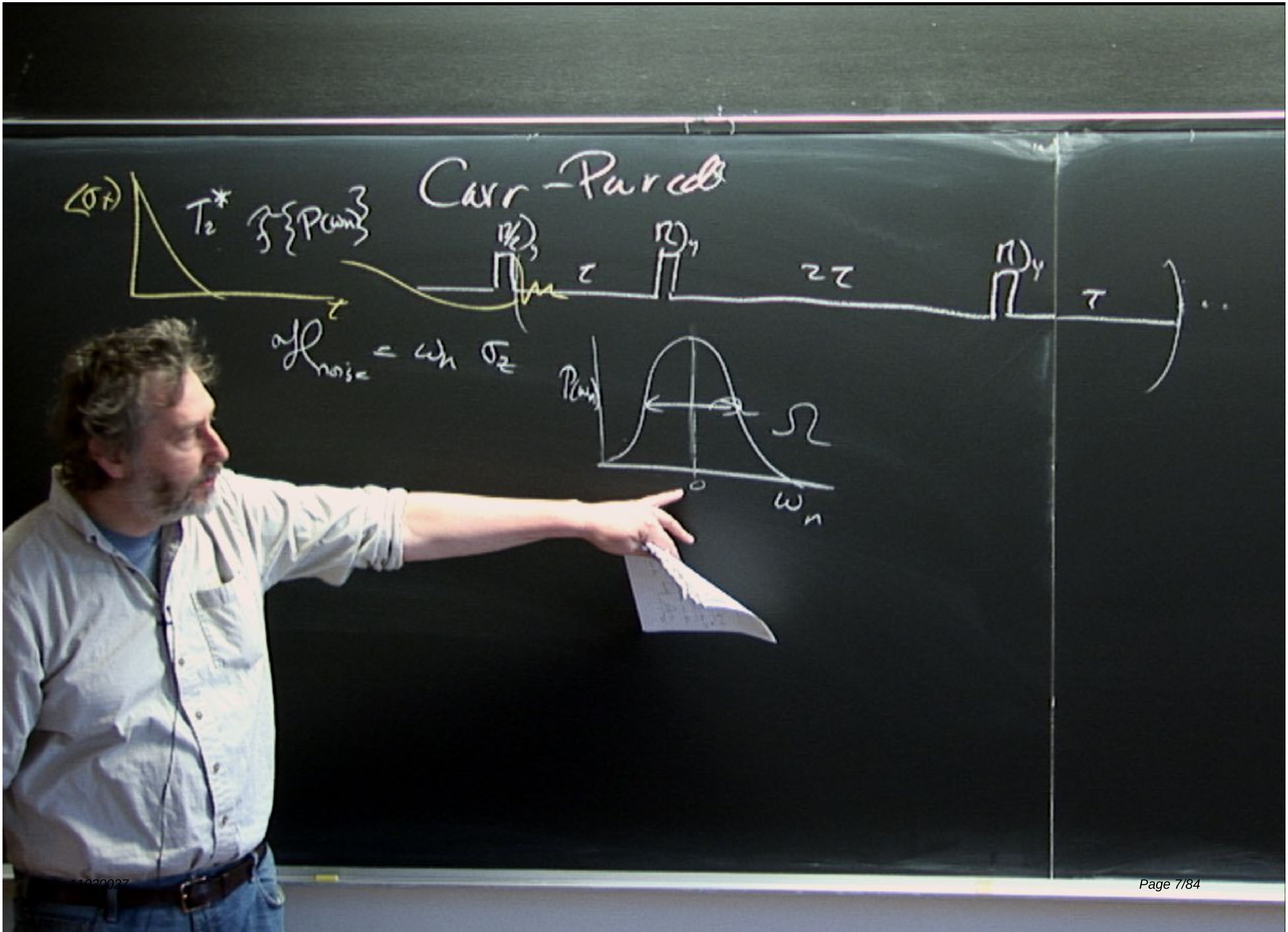
Carr-Purcell

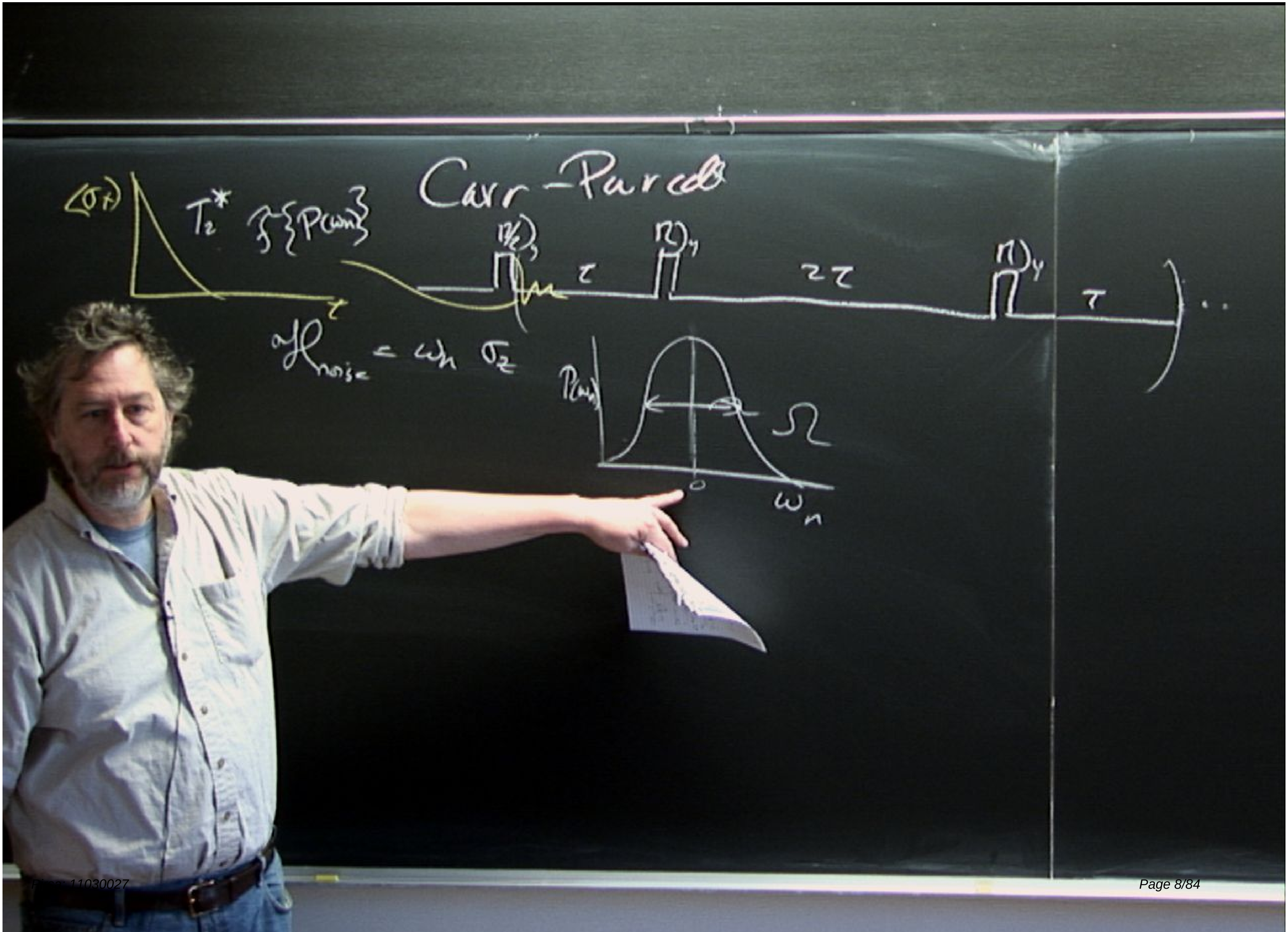


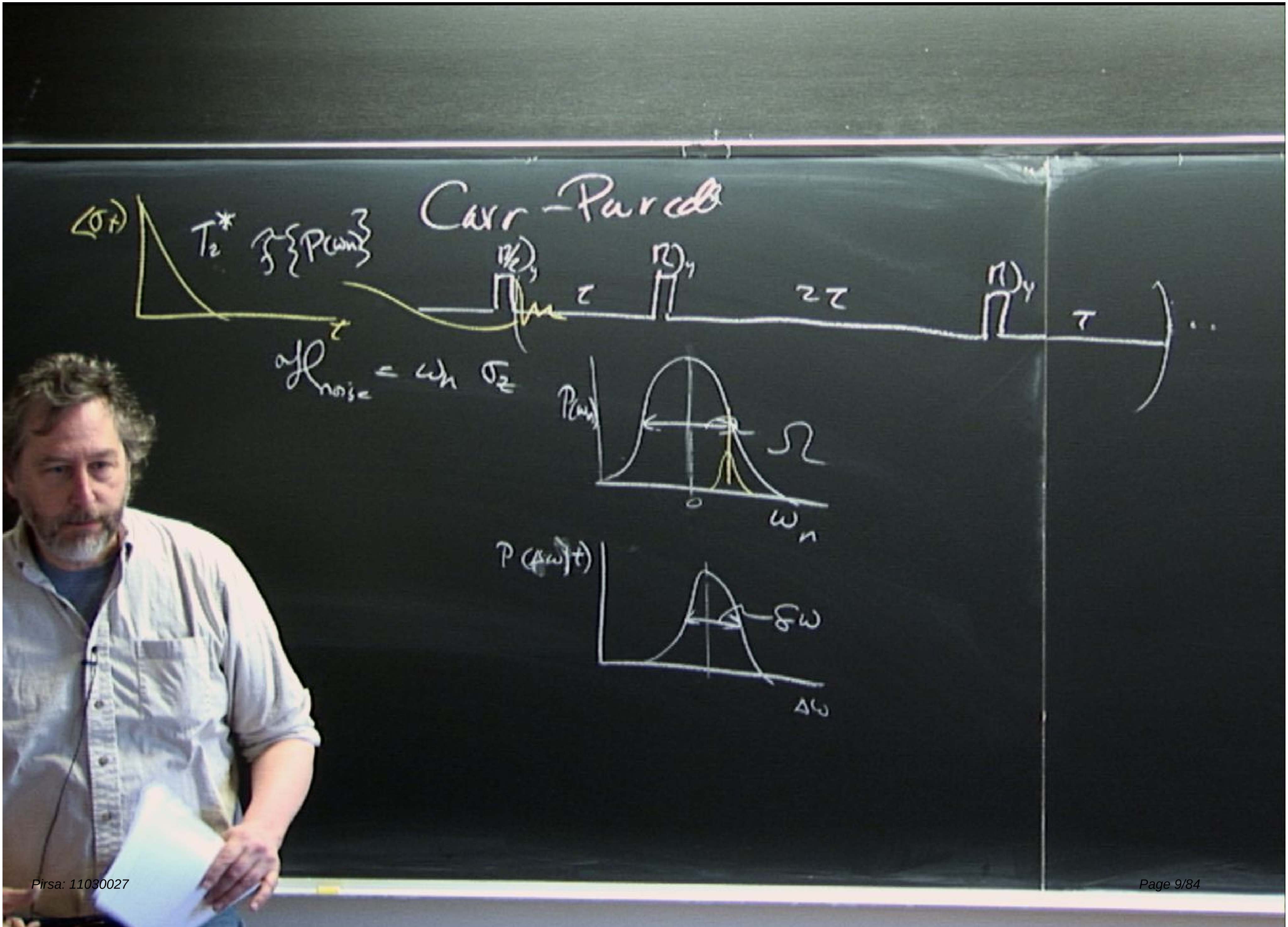
$$\mathcal{H}_{noise} = \omega_n \sigma_z$$

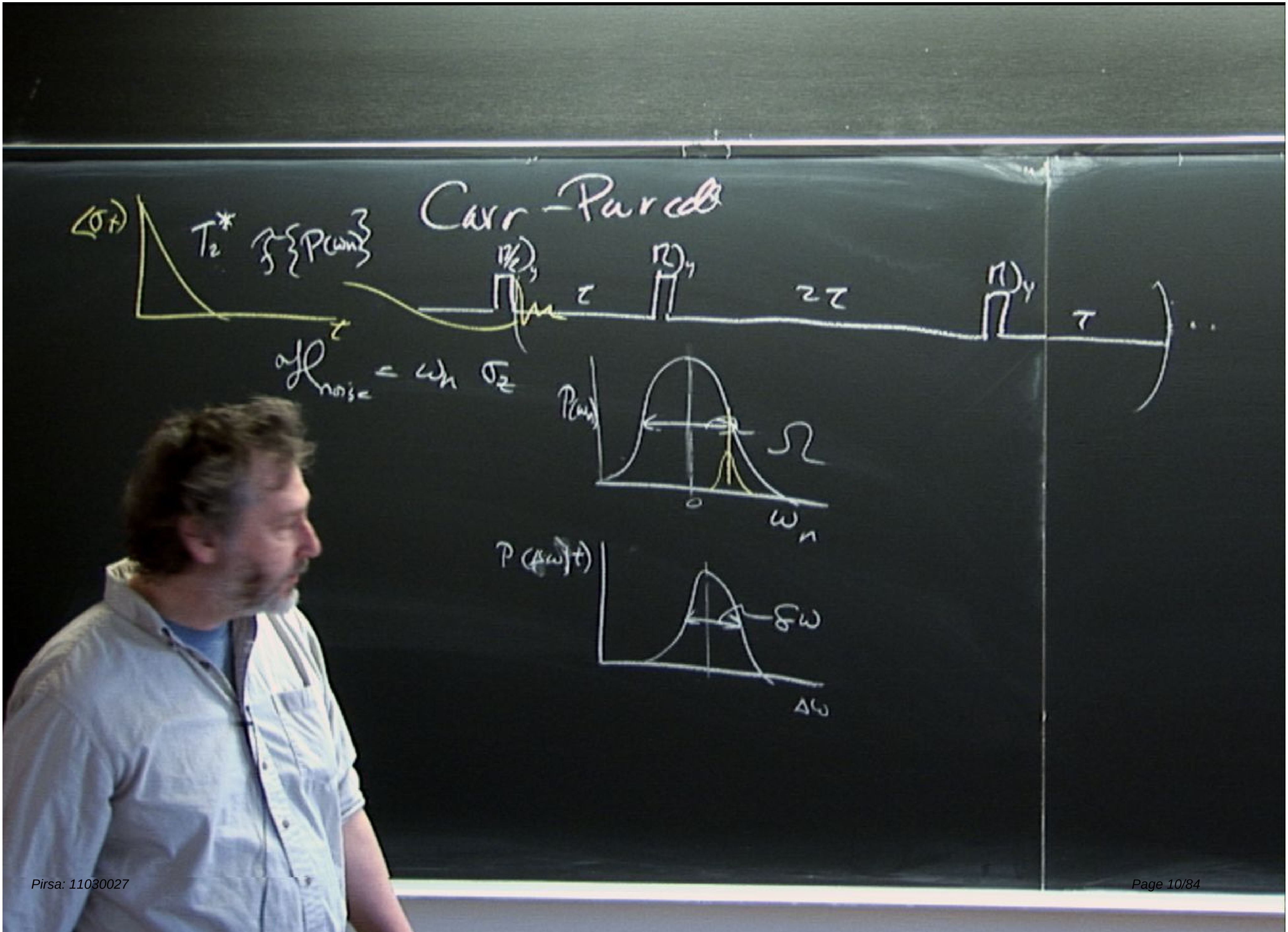


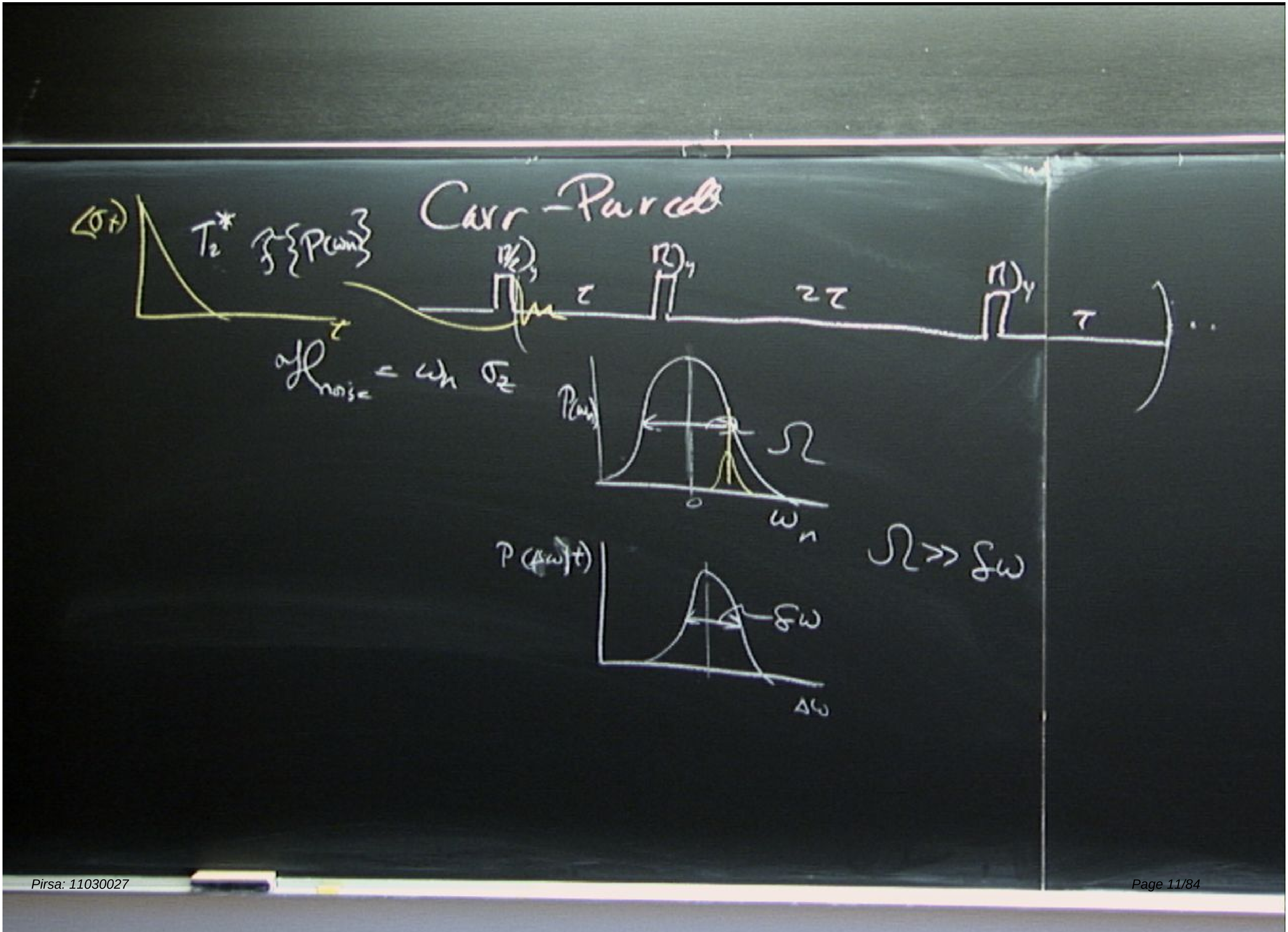

Carr-Purcell
T_2^*
τ
2τ
Ω
ω_n

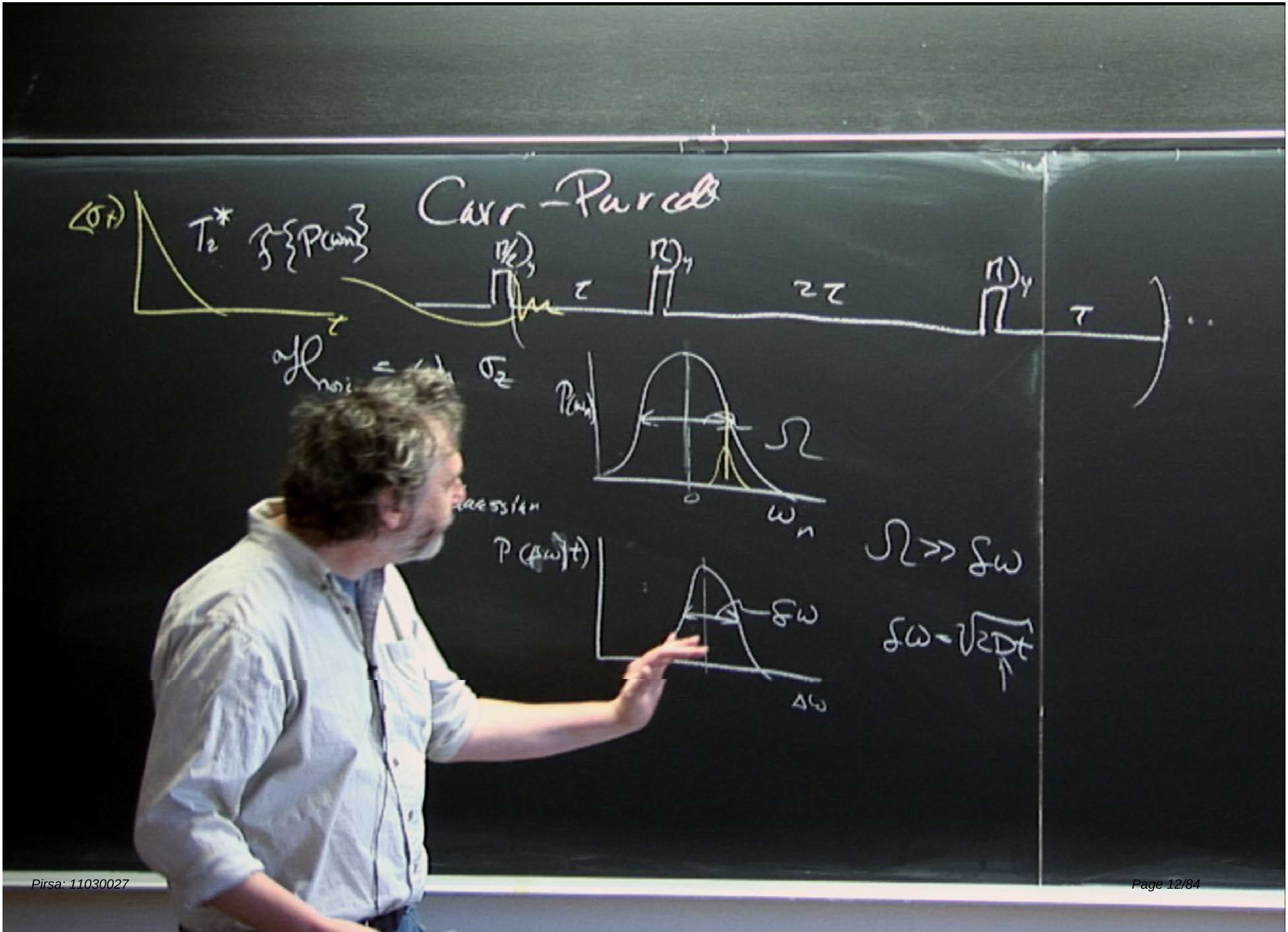

Carr-Purcell
T2*
τ
2τ
τ
ωn
Ω

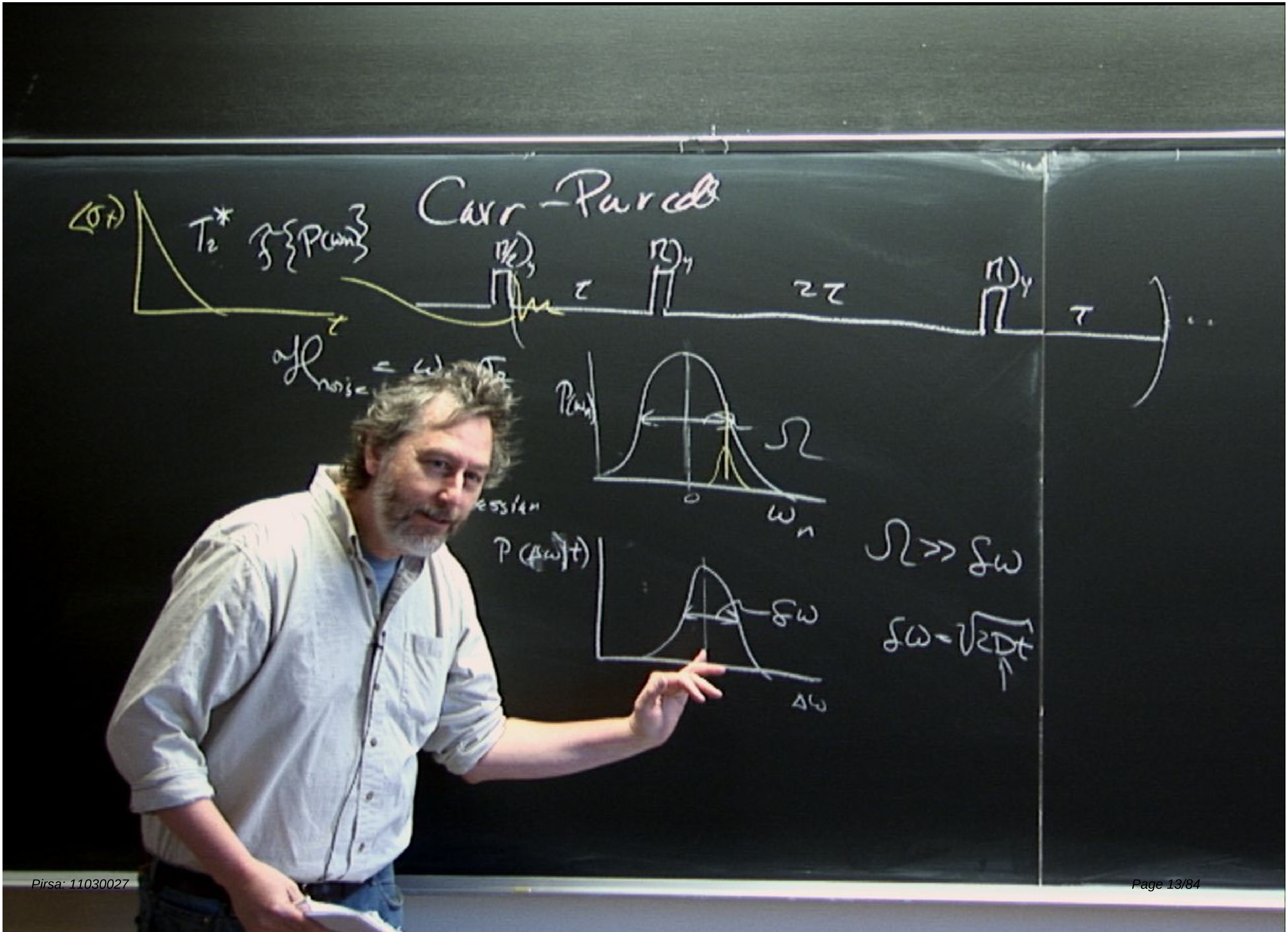

Carr-Purcell
τ
2τ
τ
Ω

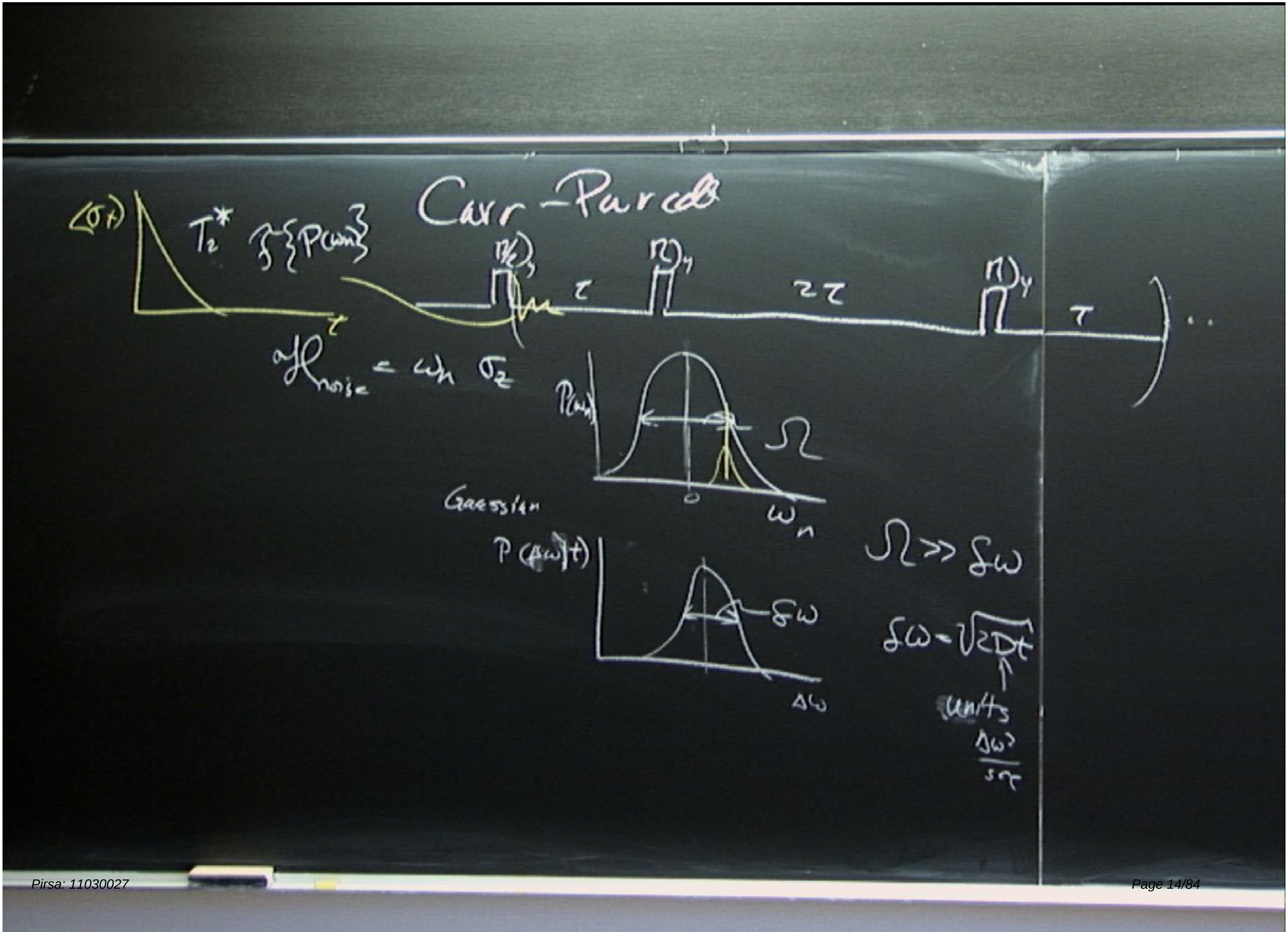

Carr-Purcell
T_2^*
$\mathfrak{F}\{P(\omega_n)\}$
$(\pi/2)_y$
$(\pi)_y$
τ
2τ
$\mathcal{H}_{noise} = \omega_n \sigma_z$
$P(\omega_n)$
Ω
ω_n
$P(\Delta\omega, t)$
$\delta\omega$
$\Delta\omega$

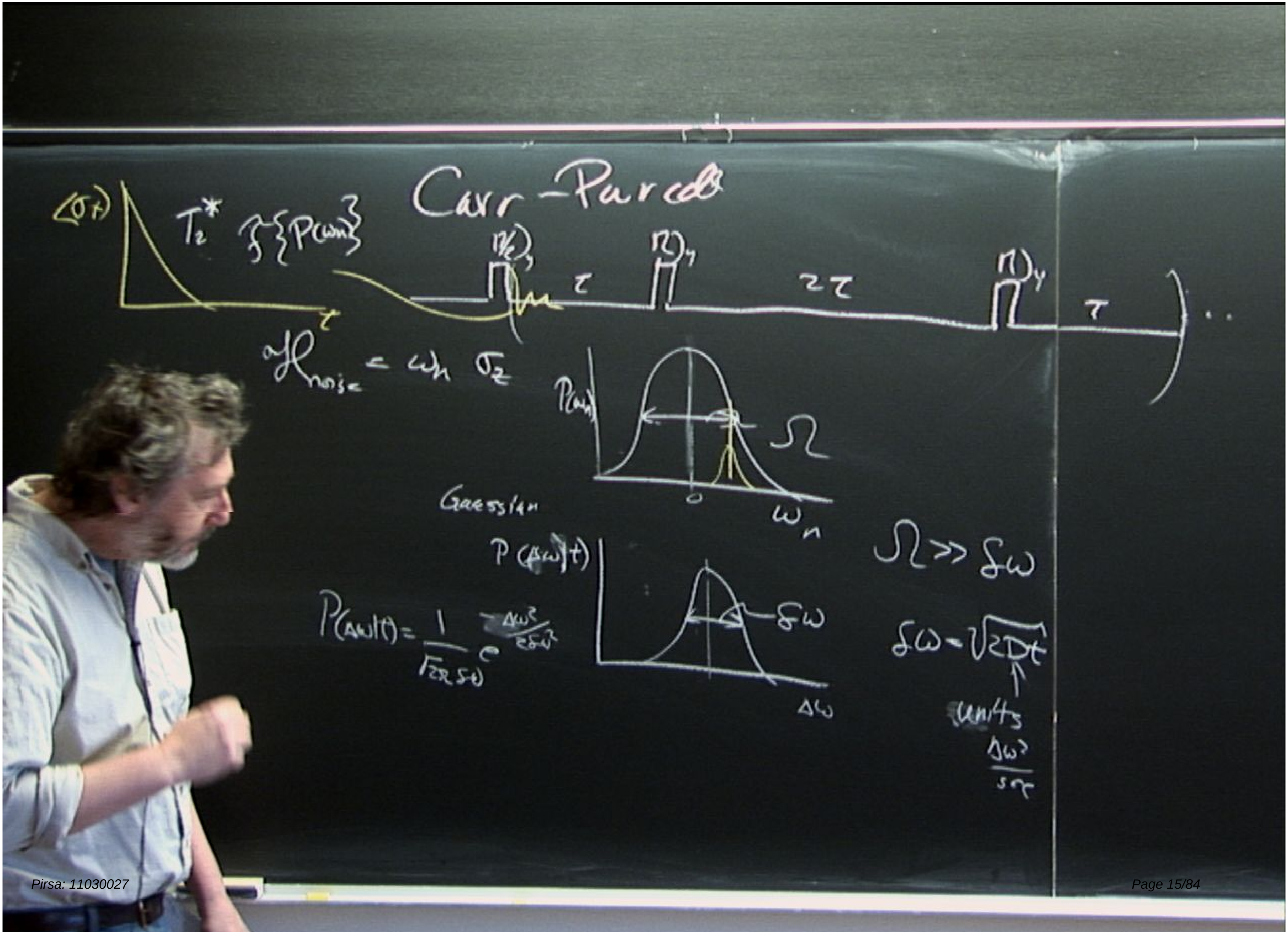

Carr-Purcell
T_2^*
τ
2τ
Ω
ω_n
δω
Δω

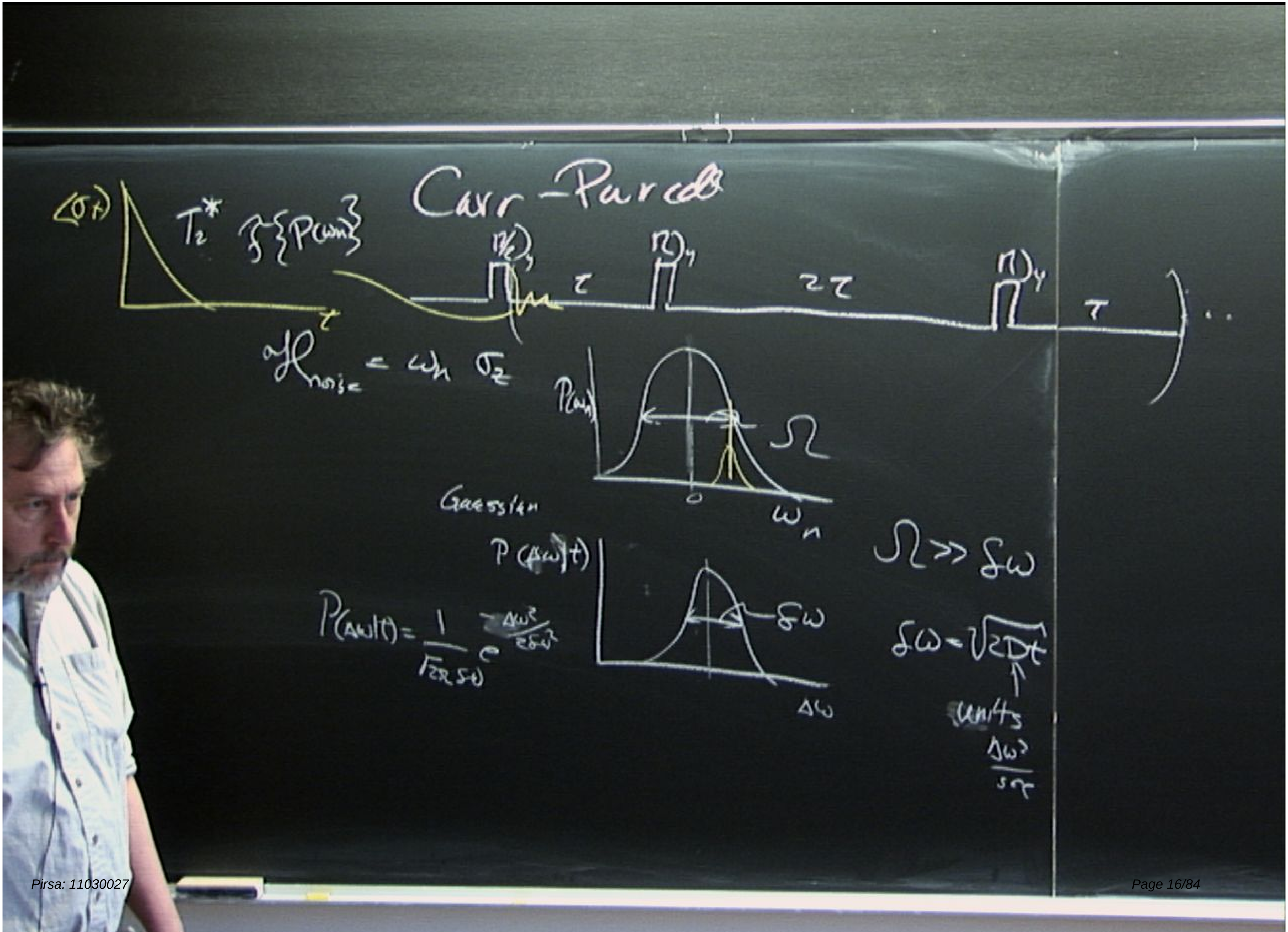

Carr-Purcell
T2*
(π/2)y
τ
(π)y
2τ
(π)y
τ
Hnoise = ωn σz
P(ωn)
Ω
ωn
P(Δω|t)
δω
Δω
Ω >> δω

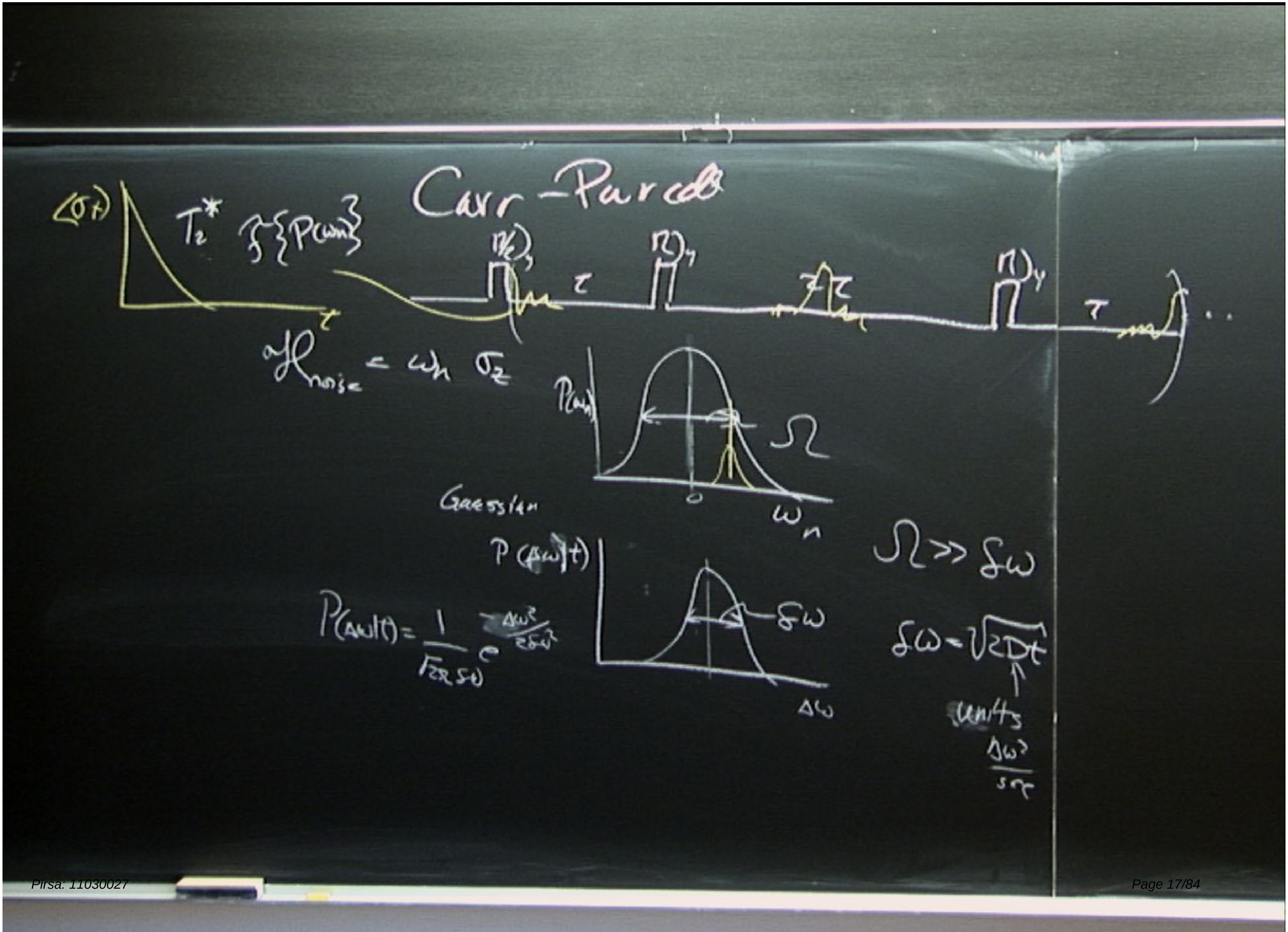

Carr-Purcell
T_2^*
$\mathfrak{F}\{P(\omega_n)\}$
τ
2τ
τ
Ω
ω_n
$\Omega \gg \delta\omega$
$\delta\omega$
$\delta\omega = \sqrt{2Dt}$
$\Delta\omega$

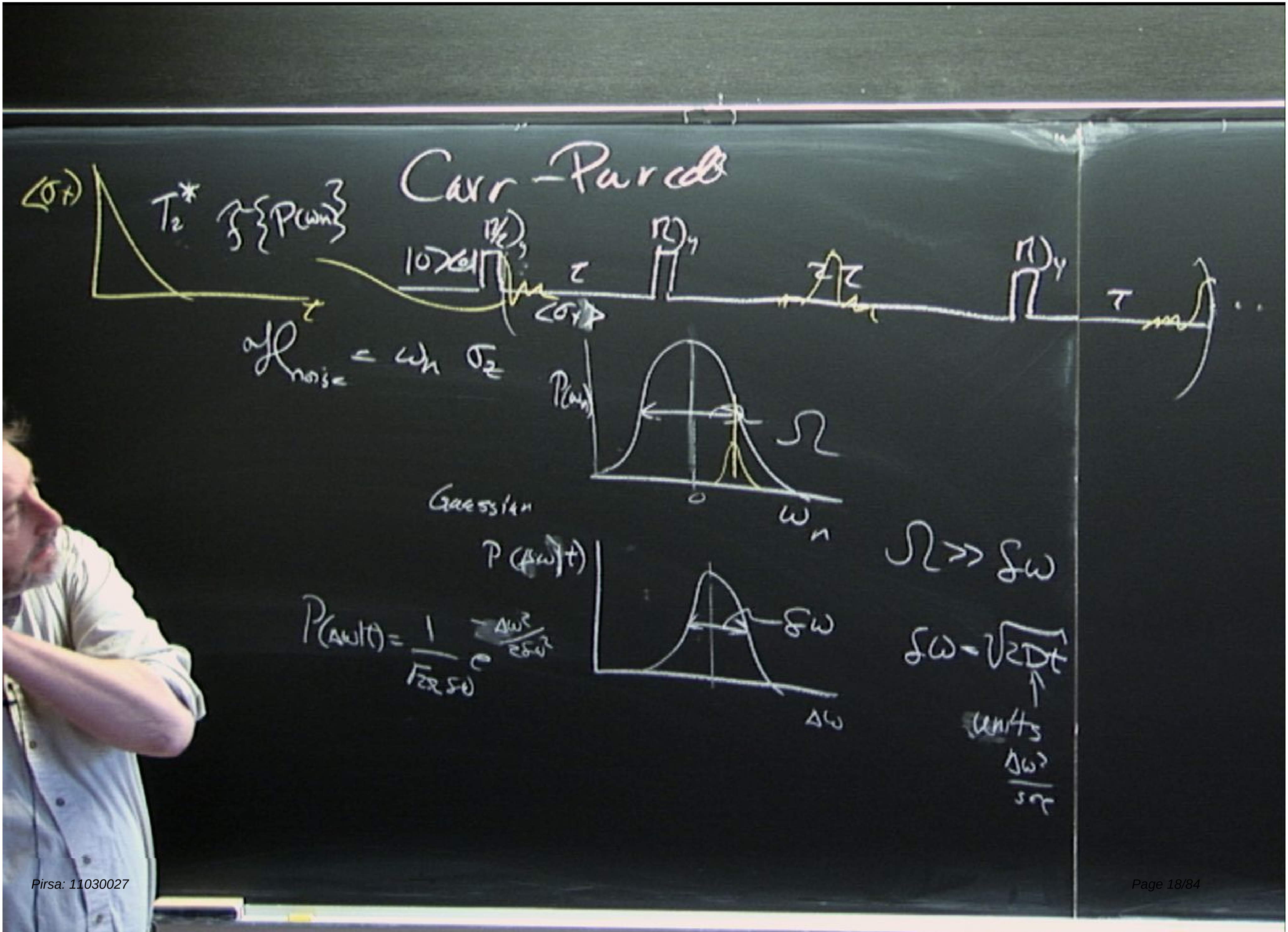

Carr-Purcell
T2*
τ
2τ
τ
P(ωn)
Ω
ωn
P(Δω|t)
δω
Δω
Ω >> δω
δω = √2Dt


Carr-Purcell
T_2^*
Gaussian
$\Omega \gg \delta\omega$
$\delta\omega = \sqrt{2Dt}$
units


Carr-Purcell
Gaussian
Ω >> δω
δω = √2Dt
units


Carr-Purcell
T2*
τ
2τ
τ
Gaussian
ωn
Ω
Ω >> δω
δω
δω = √2Dt
units
Δω


Carr-Purcell
⟨σ(t)⟩
T₂*
ℱ{P(ω_n)}
(π/2)_x
(π)_y
τ
2τ
𝓗_noise = ω_n σ_z
P(ω_n)
Ω
Gaussian
0
ω_n
P(Δω|t)
P(Δω|t) = 1/(√(2π) δω) e^(−Δω²/2δω²)
δω
Δω
Ω >> δω
δω = √(2Dt)
units
Δω²/sec

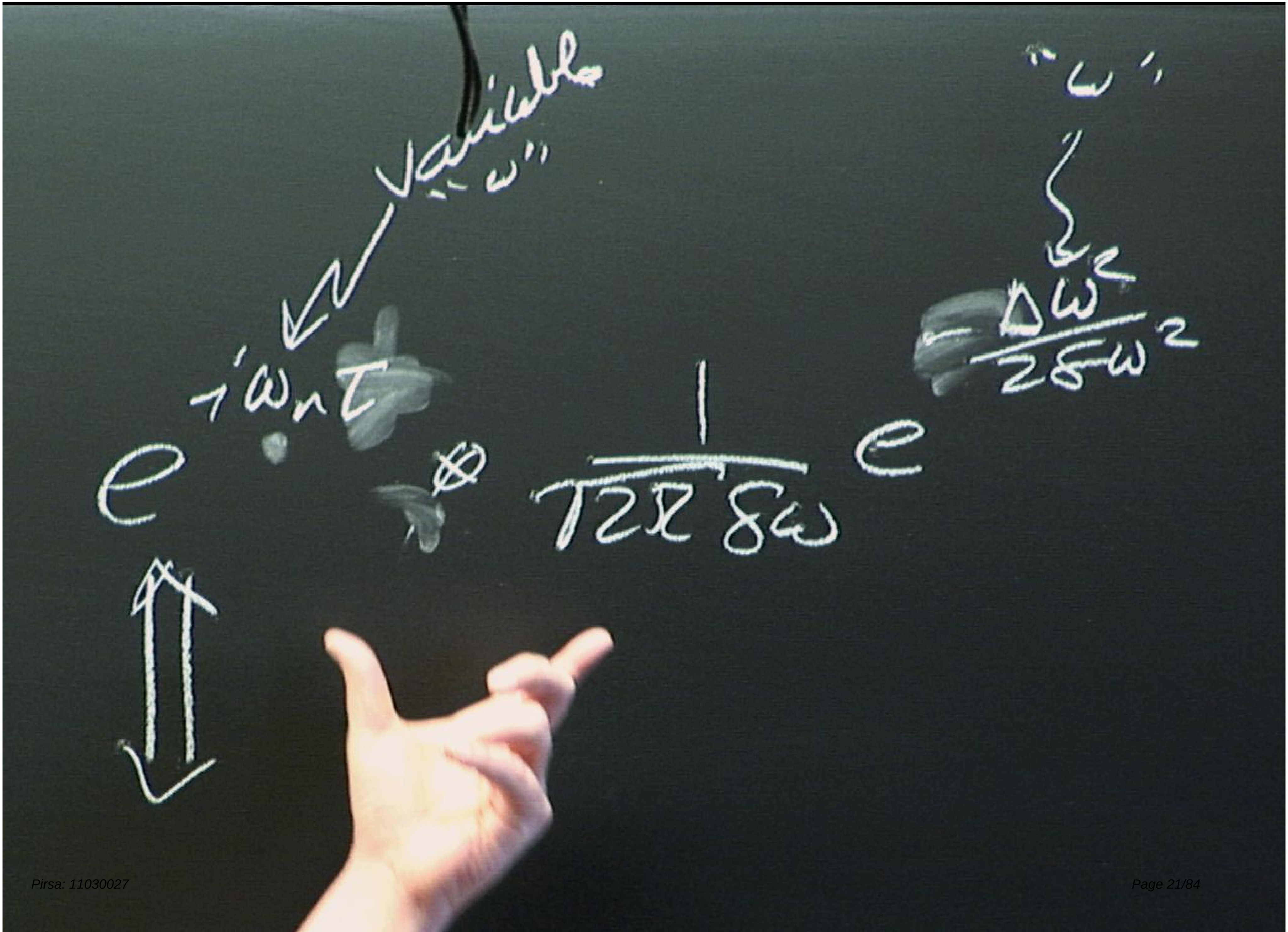

Carr-Purcell
Gaussian
units

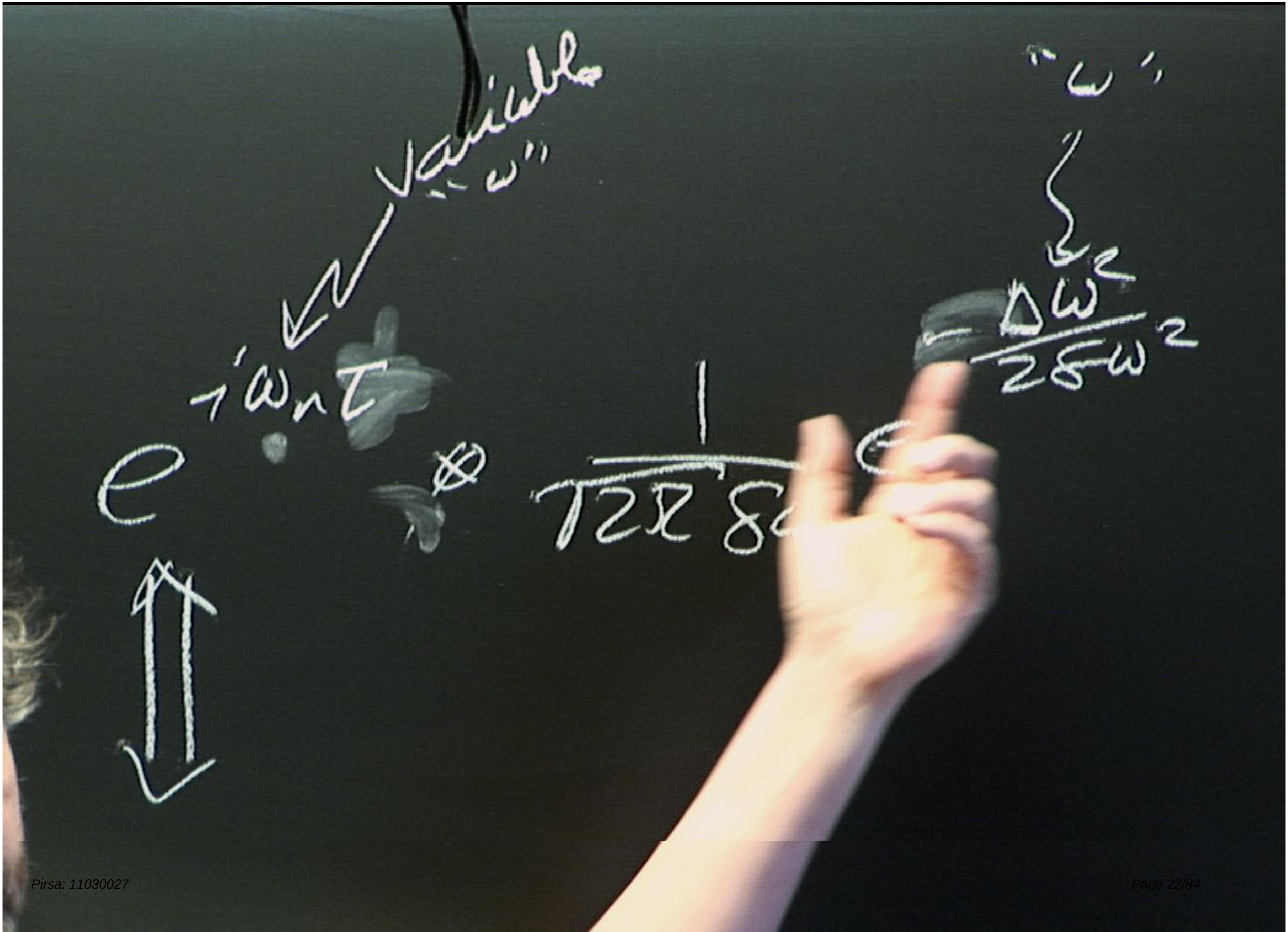
$$e^{-i\omega_n t} \otimes \frac{1}{\sqrt{2\pi}\,\delta\omega} e^{-\frac{\Delta\omega^2}{2\delta\omega^2}}$$

$$\Updownarrow$$

$$e^{-i\omega_n \tau} \otimes \frac{1}{\sqrt{2\pi}\,\delta\omega}\, e^{-\frac{\Delta\omega^2}{2\delta\omega^2}}$$

$\Updownarrow$

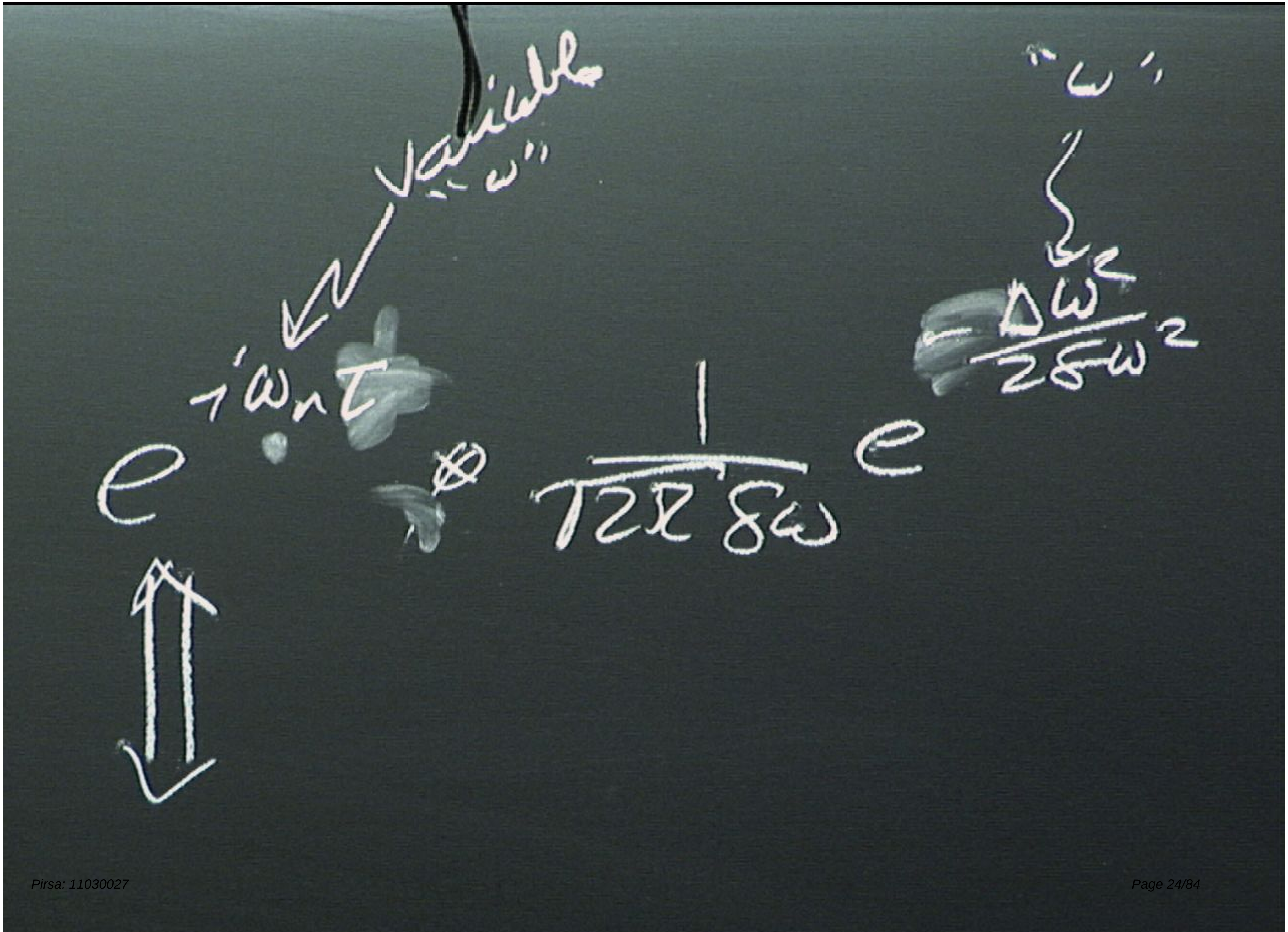

variable
"ω"
"ω"


variable
"ω"
"ω"

variable "ω"

"ω"

$$e^{-i\omega_n t} \otimes \frac{1}{\sqrt{2\pi}\,\delta\omega}\, e^{-\frac{\Delta\omega^2}{2\delta\omega^2}}$$


variable
"ω"
"ω"
$e^{-i\omega_n \tau} \otimes \frac{1}{\sqrt{2\pi}\,\delta\omega} e^{-\frac{\Delta\omega^2}{2\delta\omega^2}}$

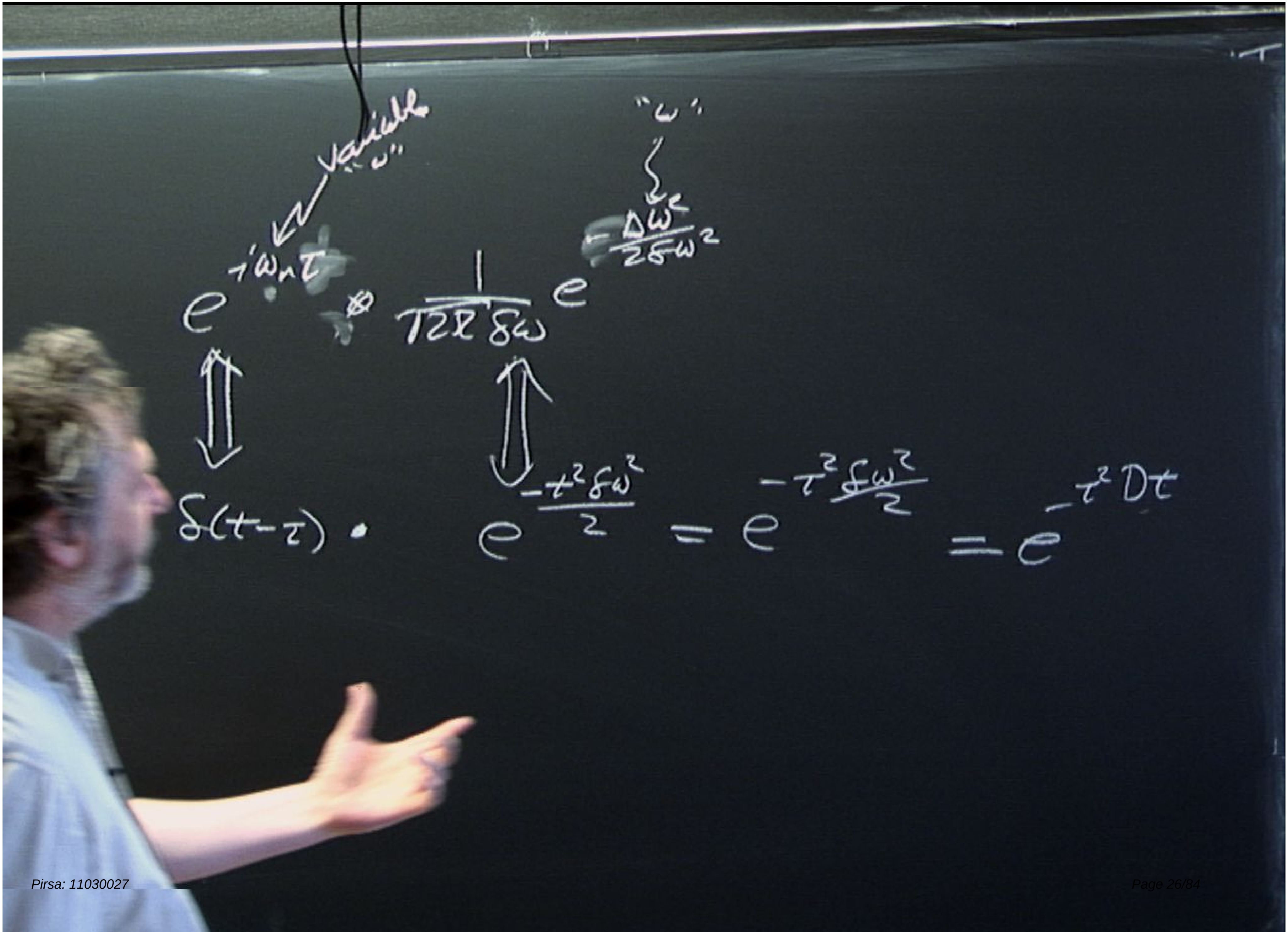
variable "ω"

"ω"

$$e^{-i\omega_n \tau} \otimes \frac{1}{\sqrt{2\pi}\,\delta\omega} e^{-\frac{\Delta\omega^2}{2\delta\omega^2}}$$

$$\Updownarrow \qquad\qquad \Updownarrow$$

$$\delta(t-\tau) \cdot e^{-\frac{t^2 \delta\omega^2}{2}} = e^{-\tau^2 \frac{\delta\omega^2}{2}}$$


variable
"ω"
"ω"
$e^{-i\omega_n\tau} \otimes \frac{1}{\sqrt{2\pi}\,\delta\omega} e^{-\frac{\Delta\omega^2}{2\delta\omega^2}}$
$\delta(t-\tau) \cdot e^{-\frac{t^2\delta\omega^2}{2}} = e^{-\tau^2\frac{\delta\omega^2}{2}} = e^{-\tau^2 Dt}$

variable "ω"

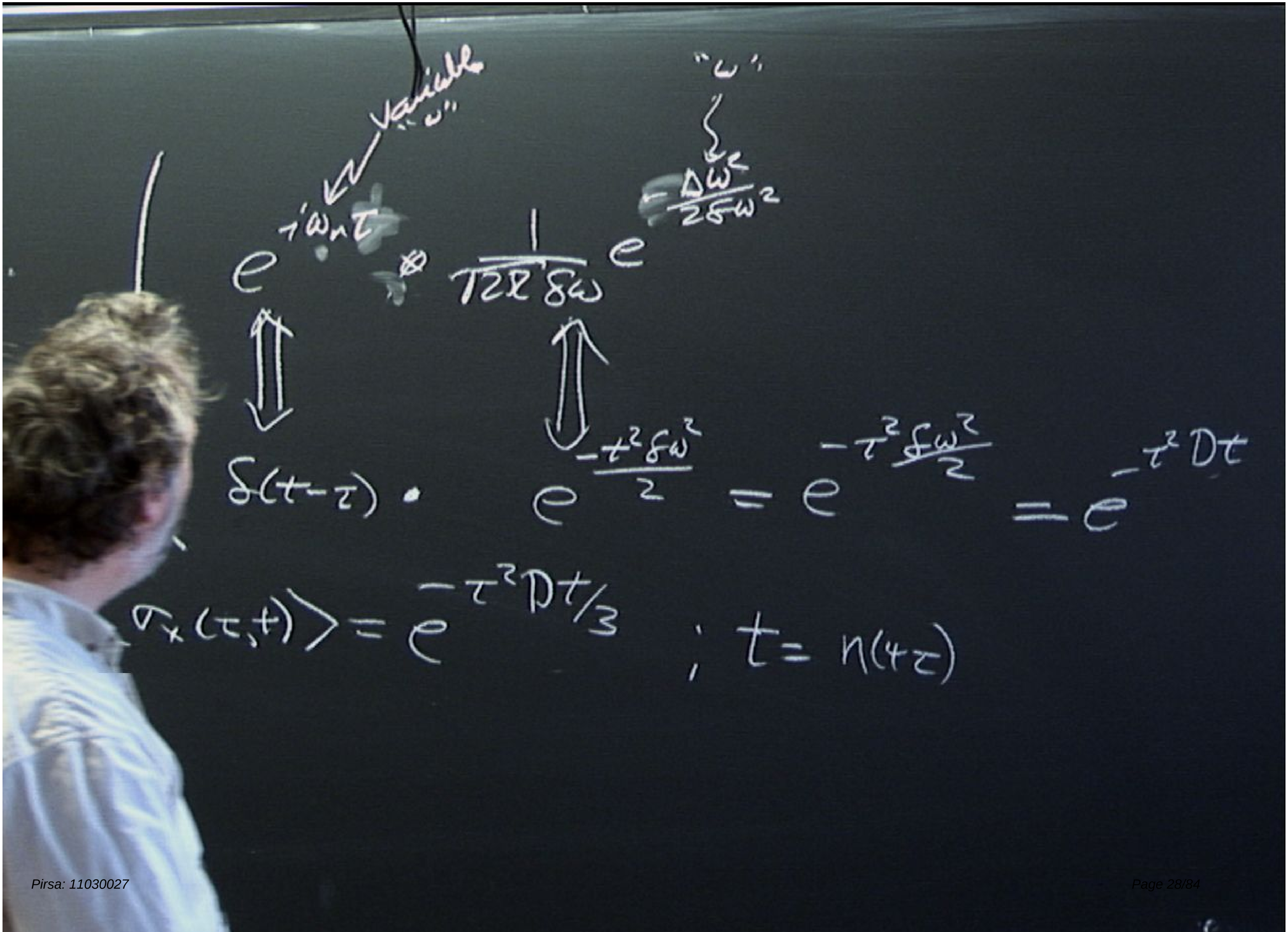
"ω"

$$e^{-i\omega_n \tau} \otimes \frac{1}{\sqrt{2\pi}\,\delta\omega} e^{-\frac{\Delta\omega^2}{2\delta\omega^2}}$$

$$\Updownarrow \qquad\qquad \Updownarrow$$

$$\delta(t-\tau) \cdot \quad e^{-\frac{t^2\delta\omega^2}{2}} = e^{-\tau^2\frac{\delta\omega^2}{2}} = e^{-\tau^2 D t}$$

$$\langle \sigma_x(\tau,t)\rangle = e^{-\tau^2 D t/3}$$



variable
"ω"
$e^{-i\omega_n \tau} \otimes \frac{1}{\sqrt{2\pi}\,\delta\omega} e^{-\frac{\Delta\omega^2}{2\delta\omega^2}}$
$\delta(t-\tau) \cdot e^{-\frac{t^2\delta\omega^2}{2}} = e^{-\tau^2\frac{\delta\omega^2}{2}} = e^{-\tau^2 Dt}$
$\langle\sigma_x(\tau,t)\rangle = e^{-\tau^2 Dt/3}$; $t = n(4\tau)$

"variable" "ω"   "ω"

$$\left(e^{-i\omega_n \tau} \otimes \frac{1}{\sqrt{2\pi}\,\delta\omega} e^{-\frac{\Delta\omega^2}{2\delta\omega^2}} \right.$$

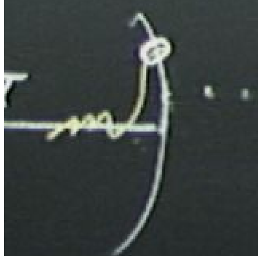
$$\Updownarrow \qquad \Updownarrow$$

$$\left. \delta(t-\tau) \cdot e^{-\frac{t^2\delta\omega^2}{2}} = e^{-\tau^2 \frac{\delta\omega^2}{2}} = e^{-\tau^2 D t} \right)$$

$$\langle \sigma_x(\tau,t) \rangle = e^{-\tau^2 D t/3} \; ; \; t = n(4\tau)$$

$$\langle \sigma_x(\tau,n) \rangle = e^{-\tau^3 D \frac{4}{3} n}$$

n = echo #



"variable" "ω" → $e^{-i\omega_n\tau}$

$$e^{-i\omega_n\tau} \otimes \frac{1}{\sqrt{2\pi}\,\delta\omega}\, e^{-\frac{\Delta\omega^2}{2\delta\omega^2}}$$

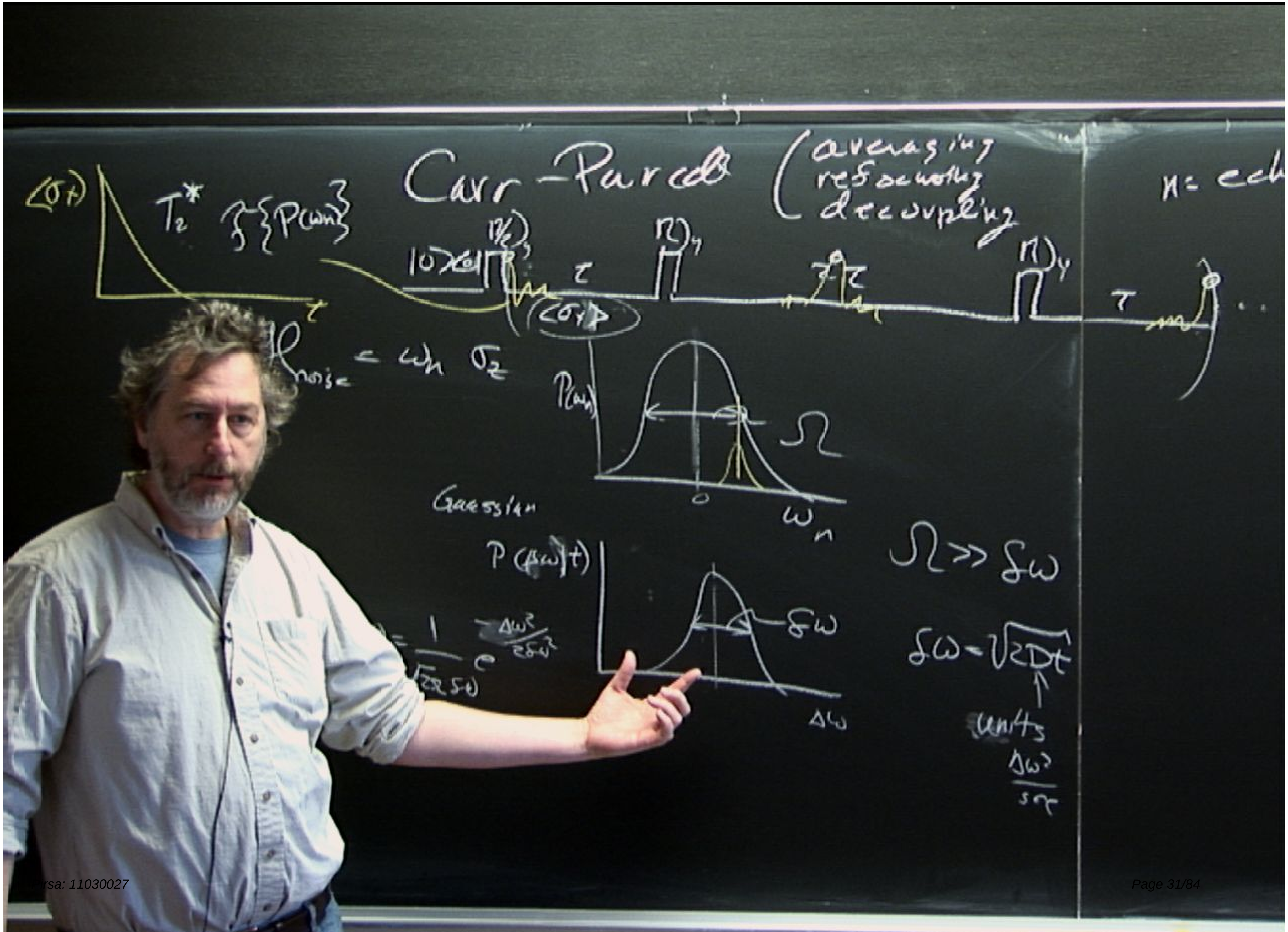
("ω" → $\Delta\omega^2$)

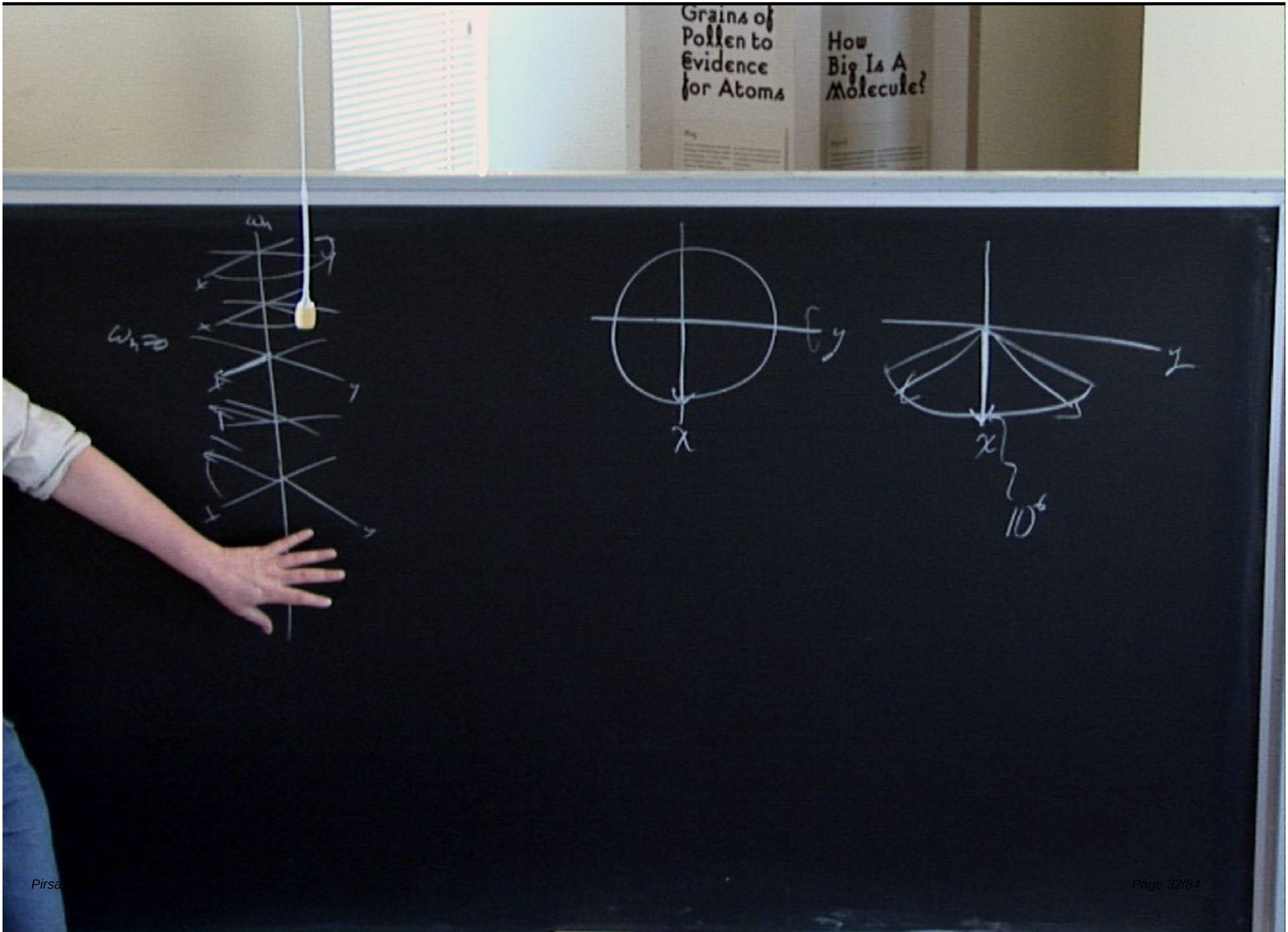
$$\Updownarrow \qquad\qquad \Updownarrow$$

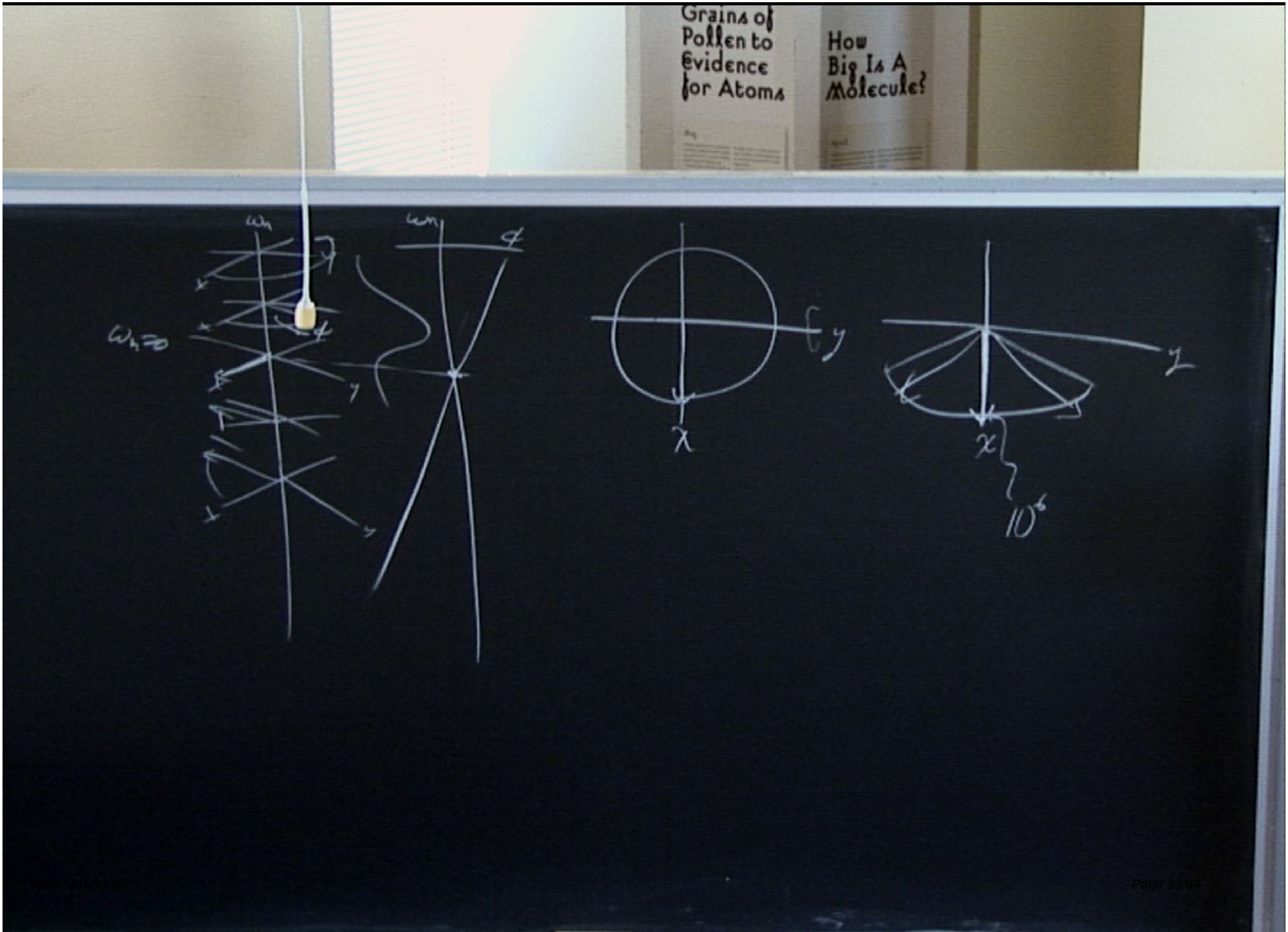
$$\delta(t-\tau)\cdot e^{-\frac{\tau^2\delta\omega^2}{2}} = e^{-\tau^2\frac{\delta\omega^2}{2}} = e^{-\tau^2 D t}$$

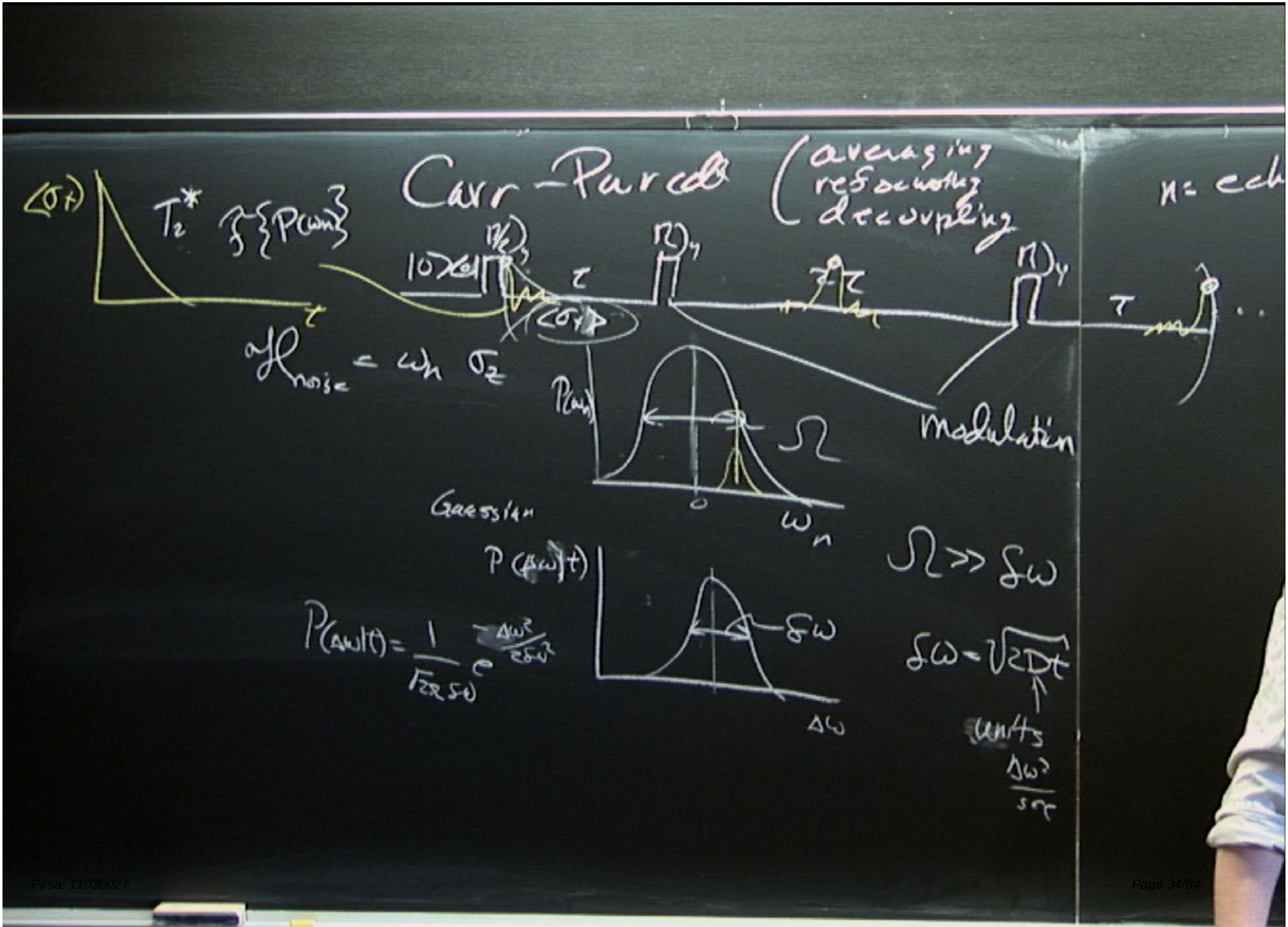
$$\langle \sigma_x(\tau,t)\rangle = e^{-\tau^2 D t/3} \quad ; \quad t = n(4\tau)$$

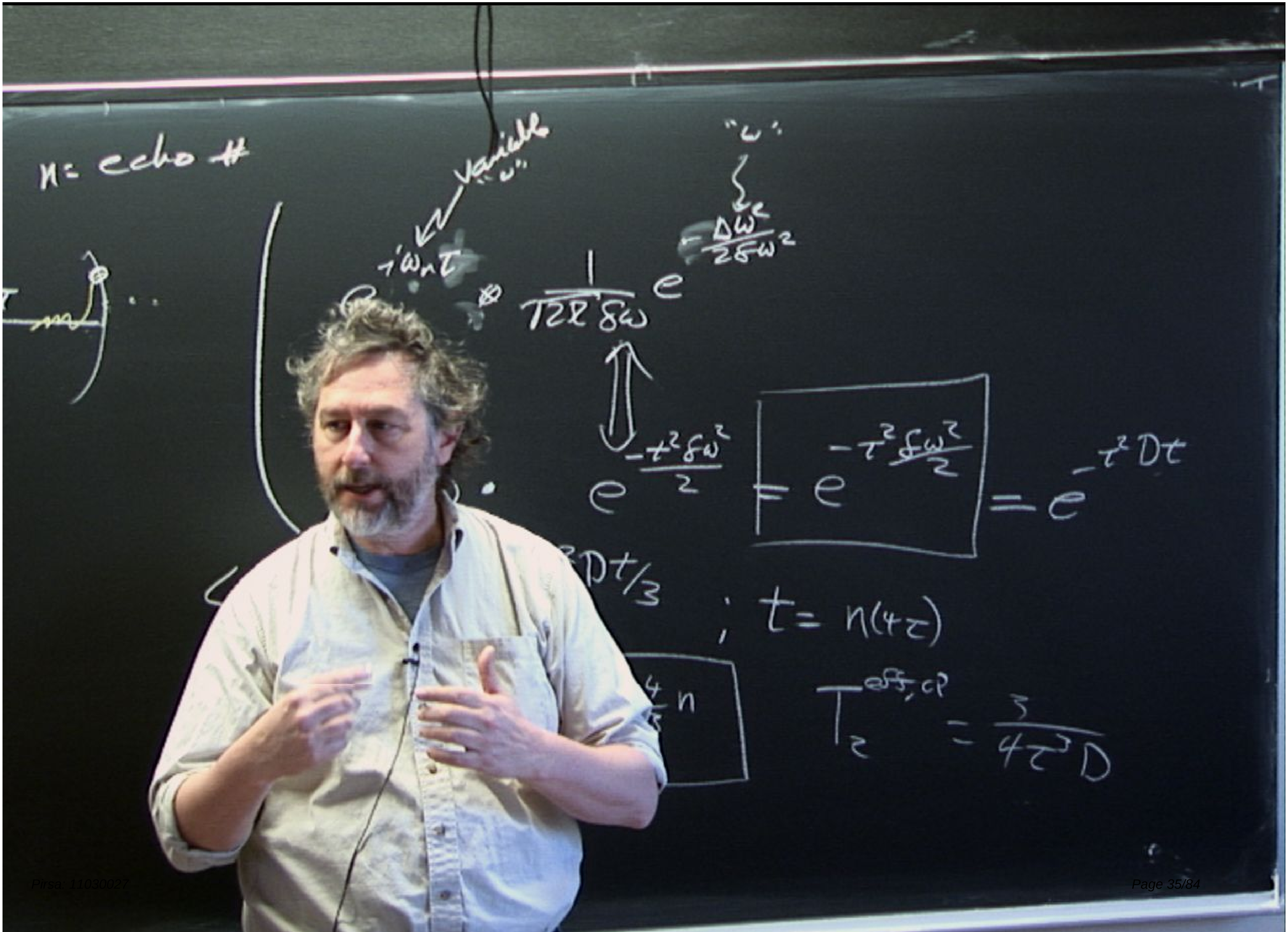
$$\langle \sigma_x(\tau,n)\rangle = \boxed{e^{-\tau^3 D \frac{4}{3} n}} \qquad T_2^{\text{eff, CP}} = \frac{3}{4\tau^3 D}$$

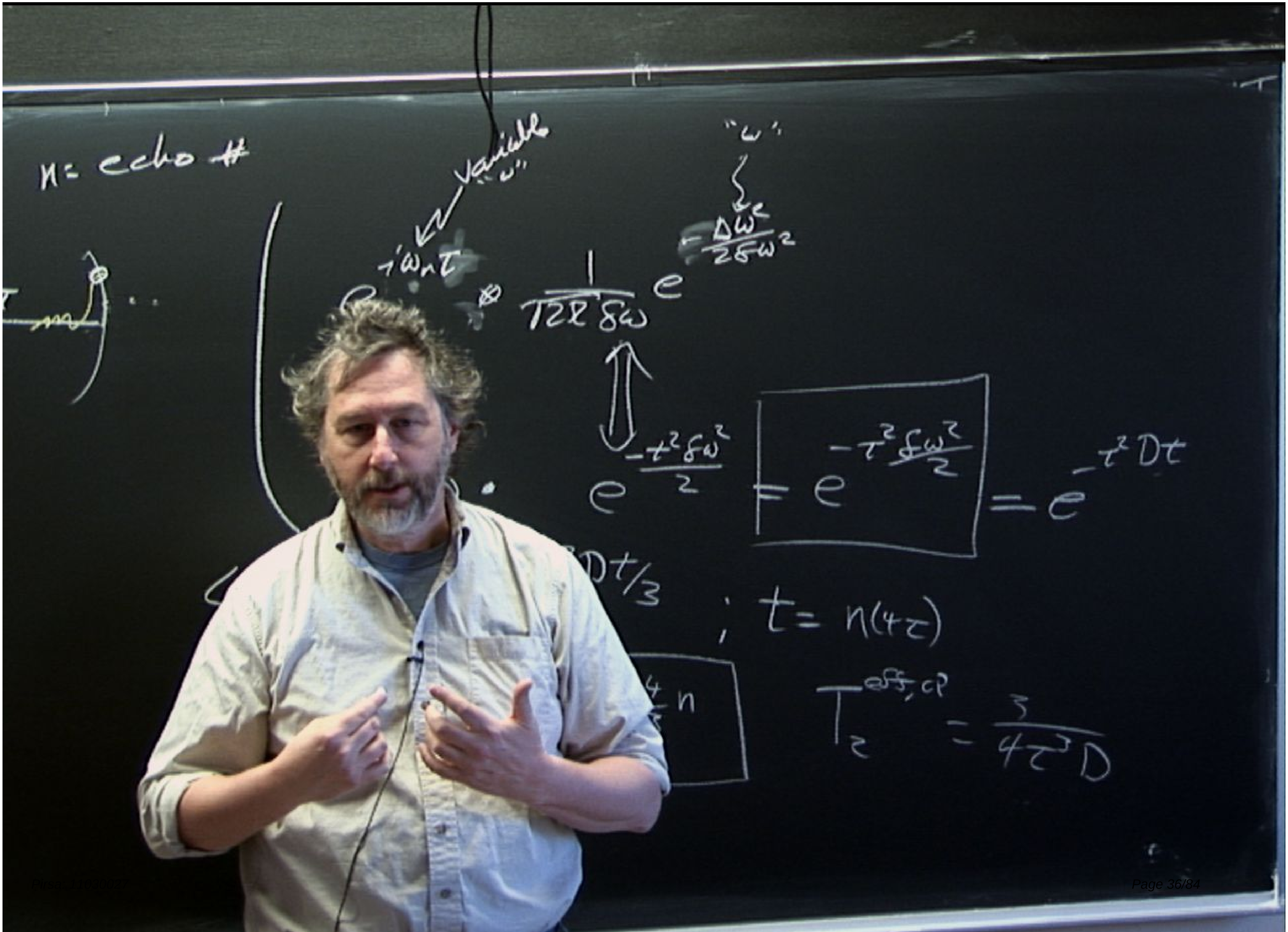

Carr-Purcell
averaging
refocusing
decoupling
Gaussian
Ω >> δω
δω = √2Dt
units
Δω²/sec

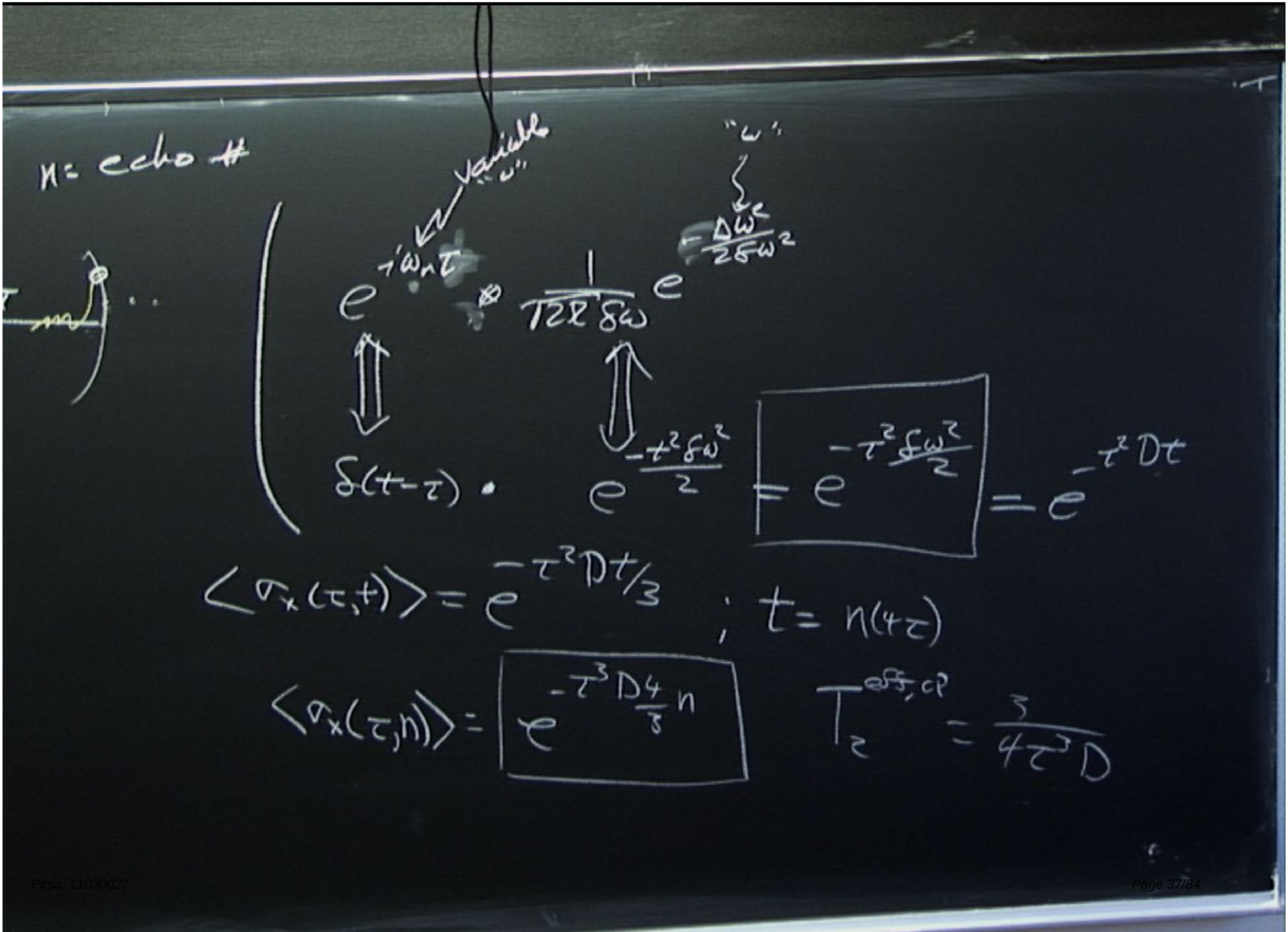

Grains of Pollen to Evidence for Atoms
How Big Is A Molecule?
x
y
x
y
x
10^6

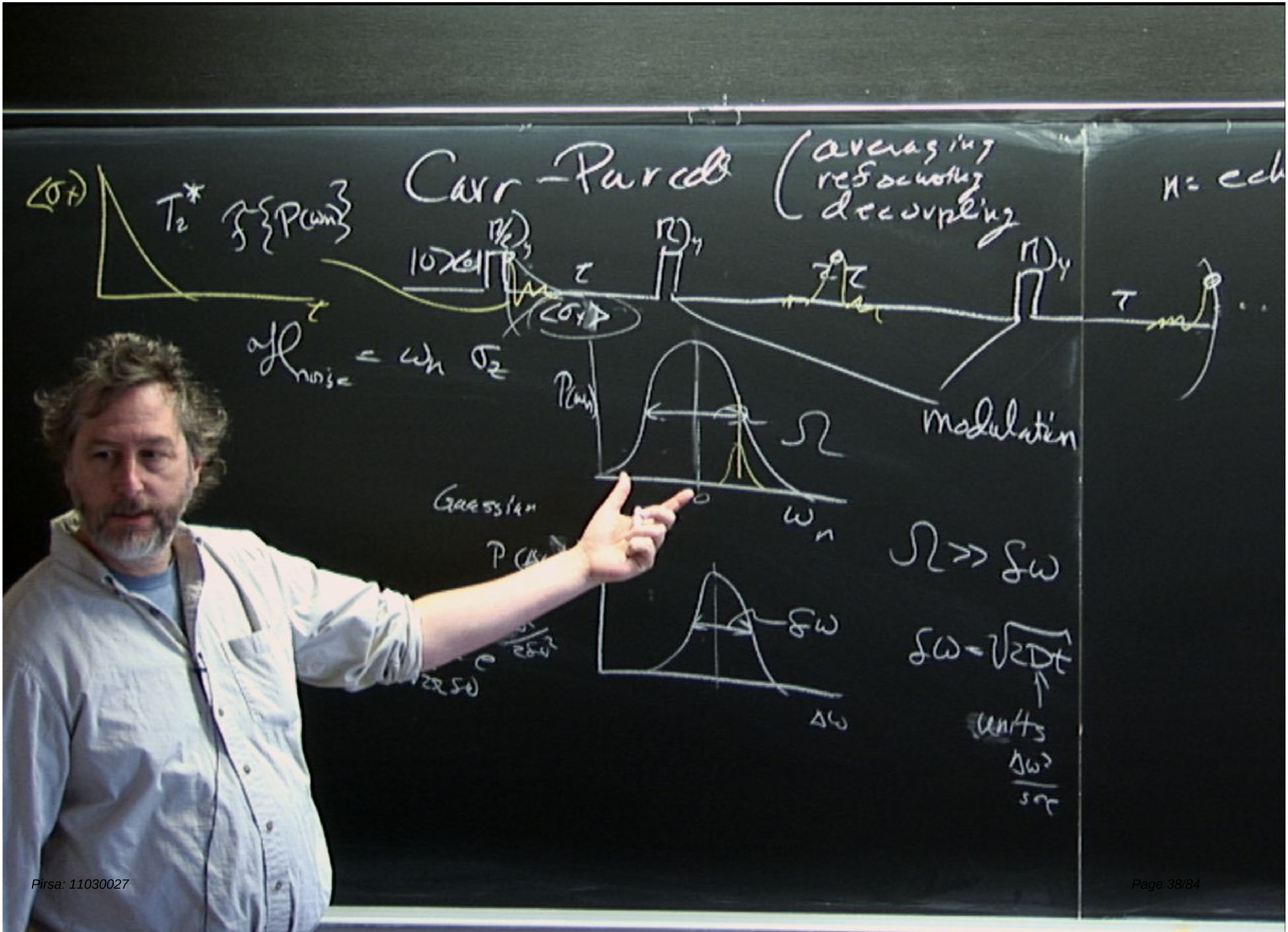

Grains of Pollen to Evidence for Atoms
How Big Is A Molecule?

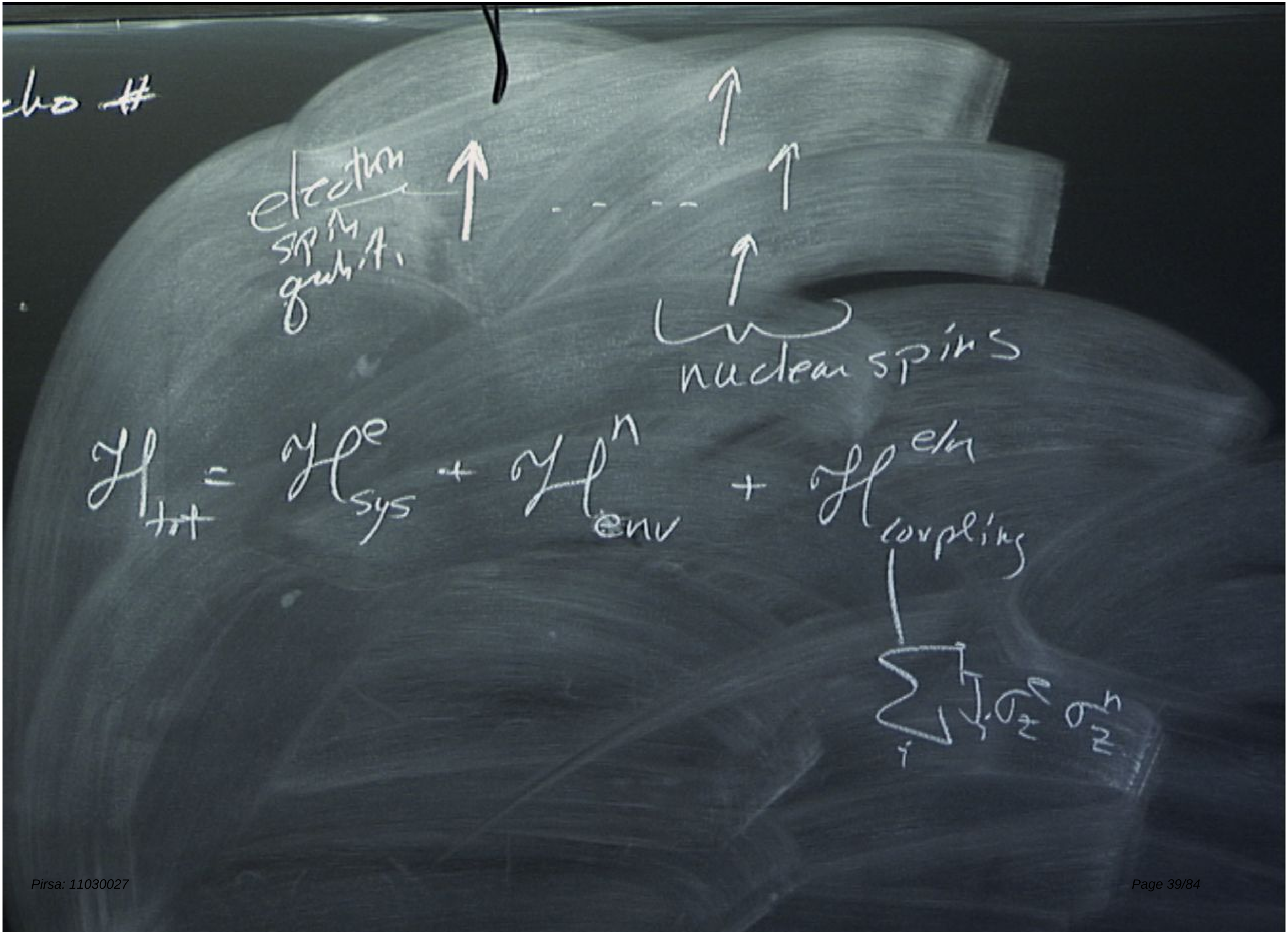

Carr-Purcell
averaging
refocusing
decoupling
modulation
Gaussian
units


n = echo #
variable
"ω"
"ω"
; t = n(4τ)


n = echo #
variable
"ω"
t = n(4τ)


n = echo #
variable "ω"
"ω"
$e^{-i\omega_n\tau} \otimes \frac{1}{\sqrt{2\pi}\,\delta\omega} e^{-\frac{\Delta\omega^2}{2\delta\omega^2}}$
$\delta(t-\tau) \cdot e^{-\frac{\tau^2\delta\omega^2}{2}} = e^{-\tau^2\frac{\delta\omega^2}{2}} = e^{-\tau^2 Dt}$
$\langle\sigma_x(\tau,t)\rangle = e^{-\tau^2 Dt/3}$; $t = n(4\tau)$
$\langle\sigma_x(\tau,n)\rangle = e^{-\tau^3 D\frac{4}{3}n}$
$T_2 = \frac{3}{4\tau^3 D}$


Carr-Purcell
averaging
refocusing
decoupling
modulation
Gaussian
units


cho #
electron spin qubit
nuclear spins
$\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$
$\sum_i J_i \sigma_z^e \sigma_z^n$

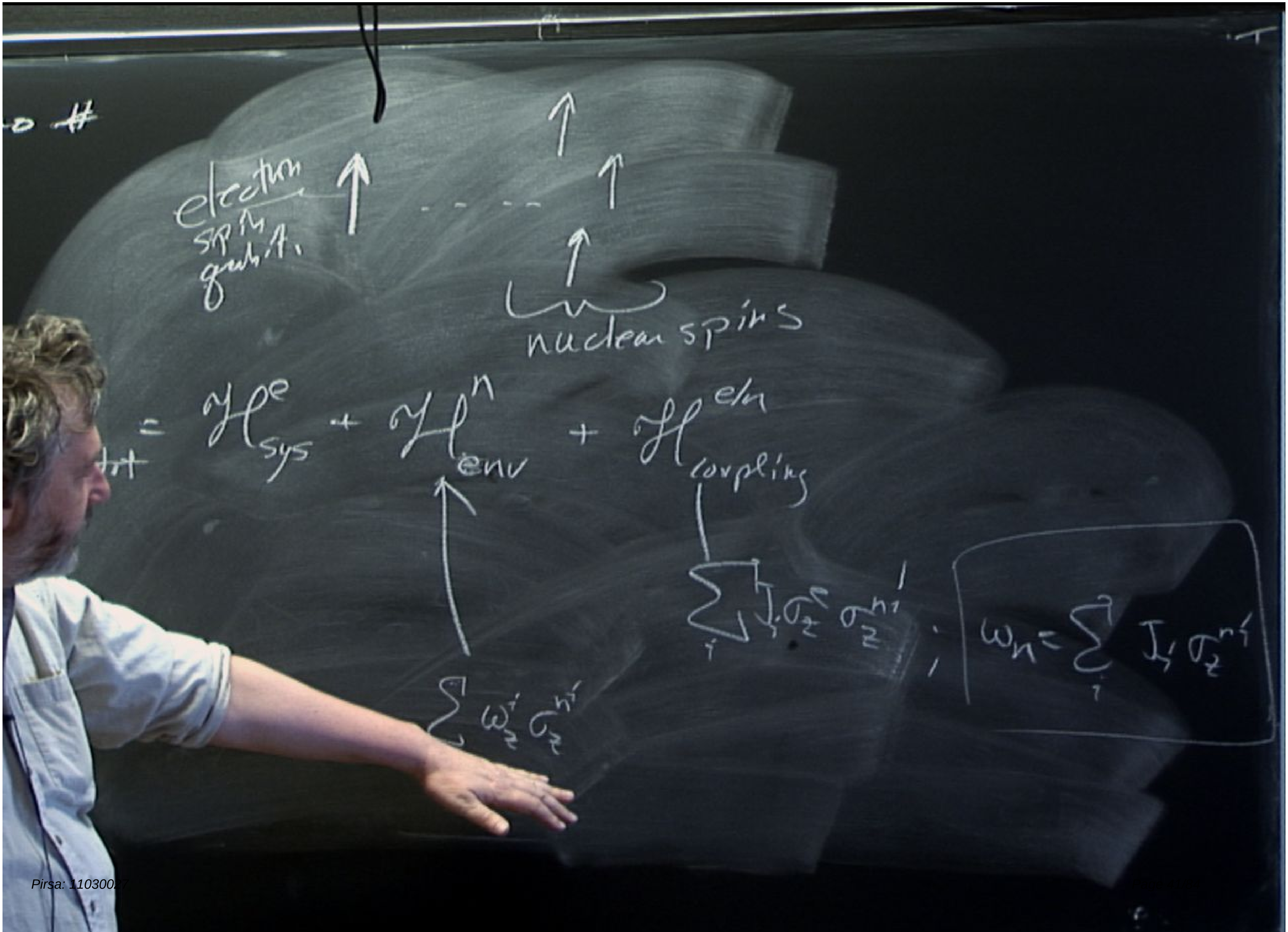
→ $\mathcal{H}$

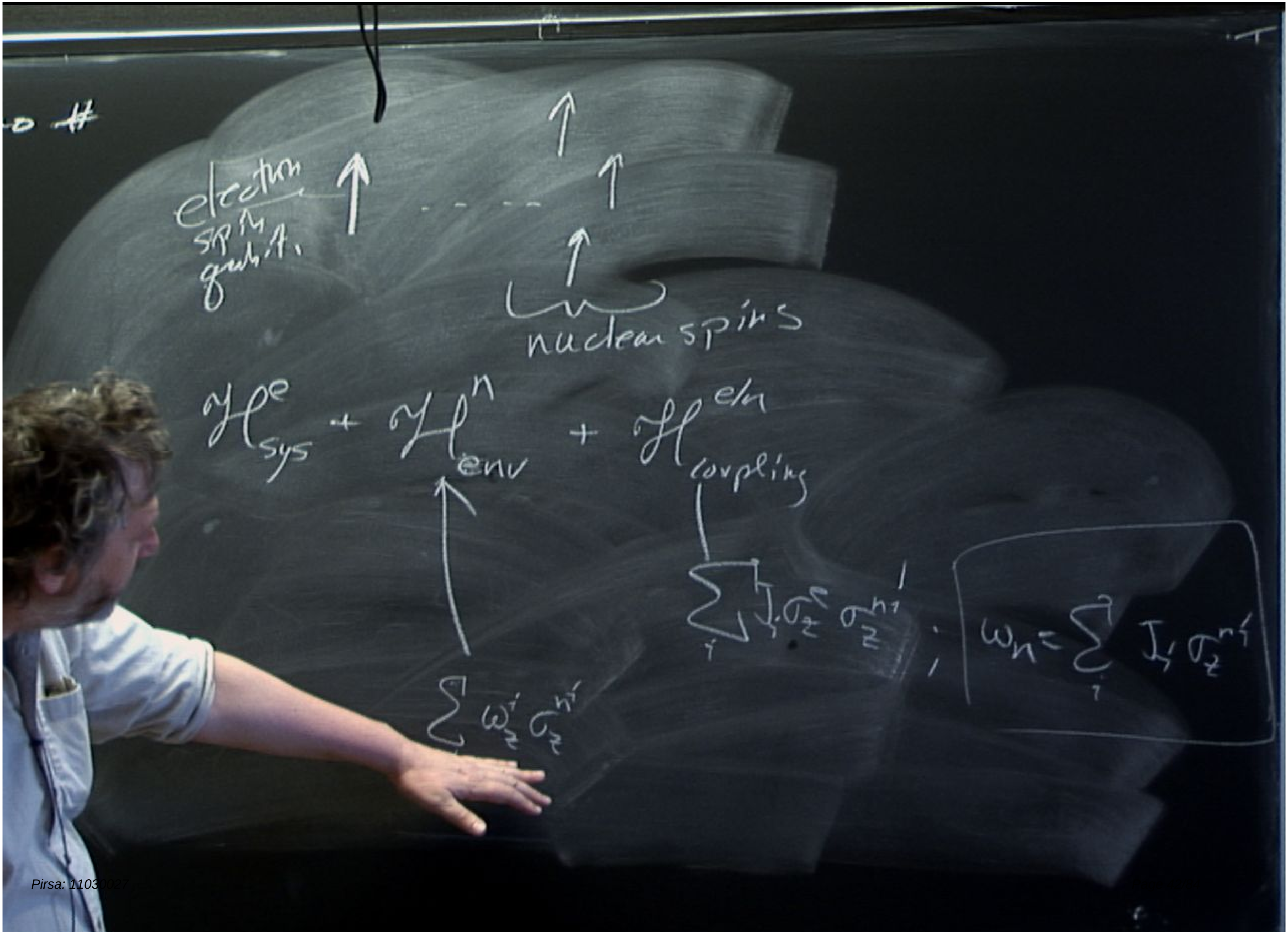
electron spin qubit.

nuclear spins

$$\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$$

$$\mathcal{H}^{e/n}_{coupling} = \sum_i J_i \sigma_z^e \sigma_z^{n_i} \; ; \quad \omega_n = \sum_i J_i \sigma_z^{n_i}$$


electron spin qubit
nuclear spins
$= \mathcal{H}^{e}_{sys} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$
$\sum_i \omega^i_z \sigma^{ni}_z$
$\sum_i J_i \sigma^e_z \sigma^{ni}_z$; $\omega_n = \sum_i J_i \sigma^{ni}_z$


electron spin qubit
nuclear spins
$H^{e}_{sys} + H^{n}_{env} + H^{e/n}_{coupling}$
$\sum_i \omega^i_z \sigma^{ni}_z$
$\sum_i J_i \sigma^e_z \sigma^{ni}_z$;
$\omega_n = \sum_i J_i \sigma^{ni}_z$

→ $\mathcal{H}$

electron spin qubit ↑ - - - - - ↑ ↑ ↑ nuclear spins

$$\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$$

$$\mathcal{H}^{n}_{env} \leftarrow \sum_i \omega_z^i \sigma_z^{ni}$$

$$\mathcal{H}^{e/n}_{coupling} \rightarrow \sum_i J_i \sigma_z^e \sigma_z^{ni} \; ; \quad \boxed{\omega_n = \sum_i J_i \sigma_z^{ni}}$$

$$\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$$

$\mathcal{H}^{n}_{env}$: $\sum_i \omega_z^i \sigma_z^{n^i}$

$\mathcal{H}^{e/n}_{coupling}$: $\sum_i J_i \sigma_z^e \sigma_z^{n^i}$;

$$\omega_n = \sum_i J_i \sigma_z^{n^i}$$

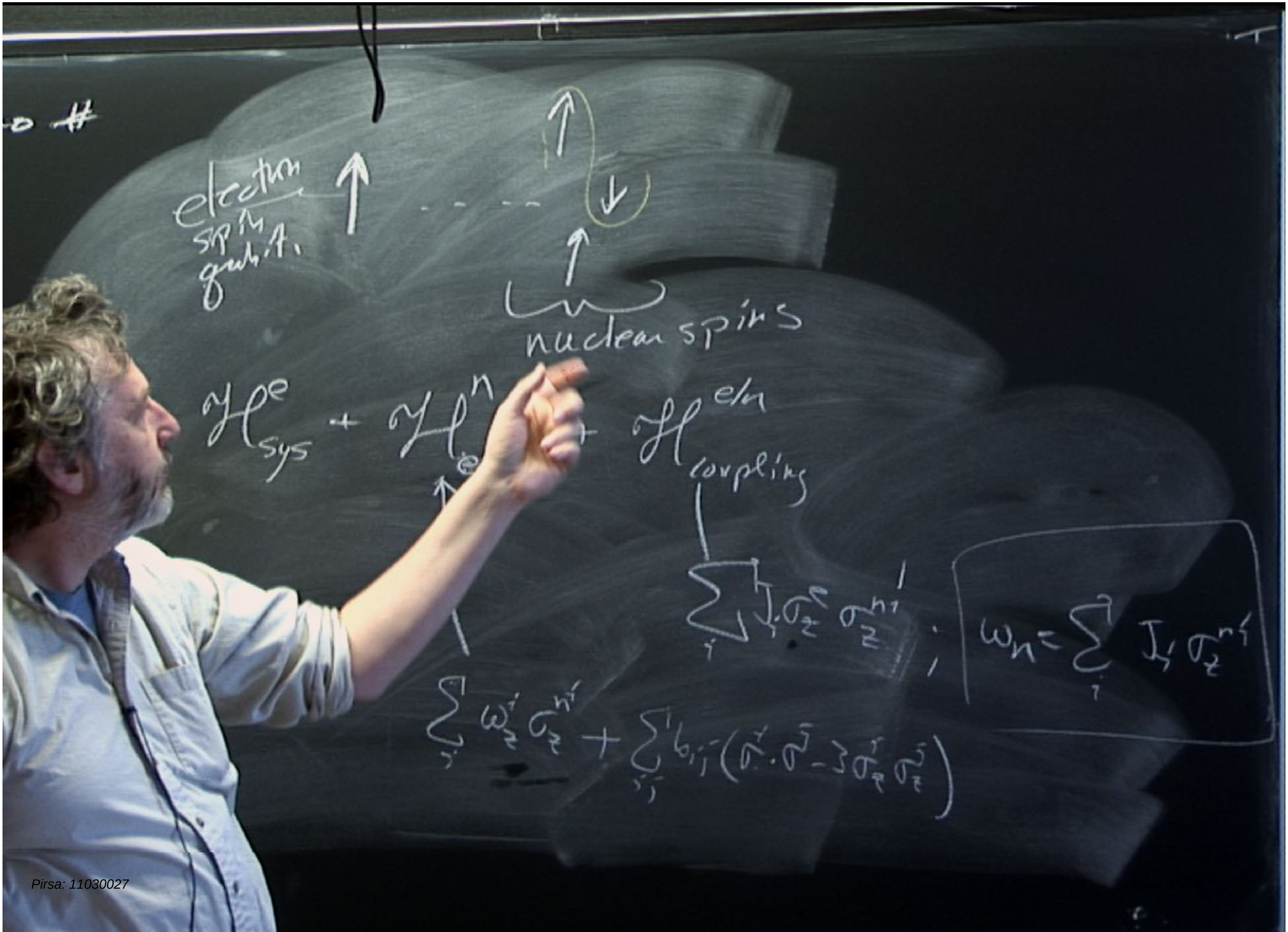
$\to \mathcal{H}$

electron spin qubit — nuclear spins

$$\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$$

$$\mathcal{H}_{env} = \sum_i \omega_z^i \sigma_z^{n i} + \sum_{i,j} b_{ij} \left(\vec{\sigma}^i \cdot \vec{\sigma}^j - 3 \sigma_z^i \sigma_z^j \right)$$

$$\mathcal{H}_{coupling} = \sum_i J_i \sigma_z^e \sigma_z^{n i} \; ; \quad \boxed{\omega_n = \sum_i J_i \sigma_z^{n i}}$$


electron
nuclear spins
coupling

o #

$$\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$$

$$\mathcal{H}^{e/n}_{coupling}: \quad \sum_i J_i \sigma_z^e \sigma_z^{n_i} \; ; \quad \boxed{\omega_n = \sum_i J_i \sigma_z^{n_i}}$$

$$\mathcal{H}^{n}_{env}: \quad \sum_i \omega_z^i \sigma_z^{n_i} + \sum_{i,j} \omega_{ij} \left(\sigma^i \cdot \sigma^j - 3 \sigma_z^i \sigma_z^j \right)$$

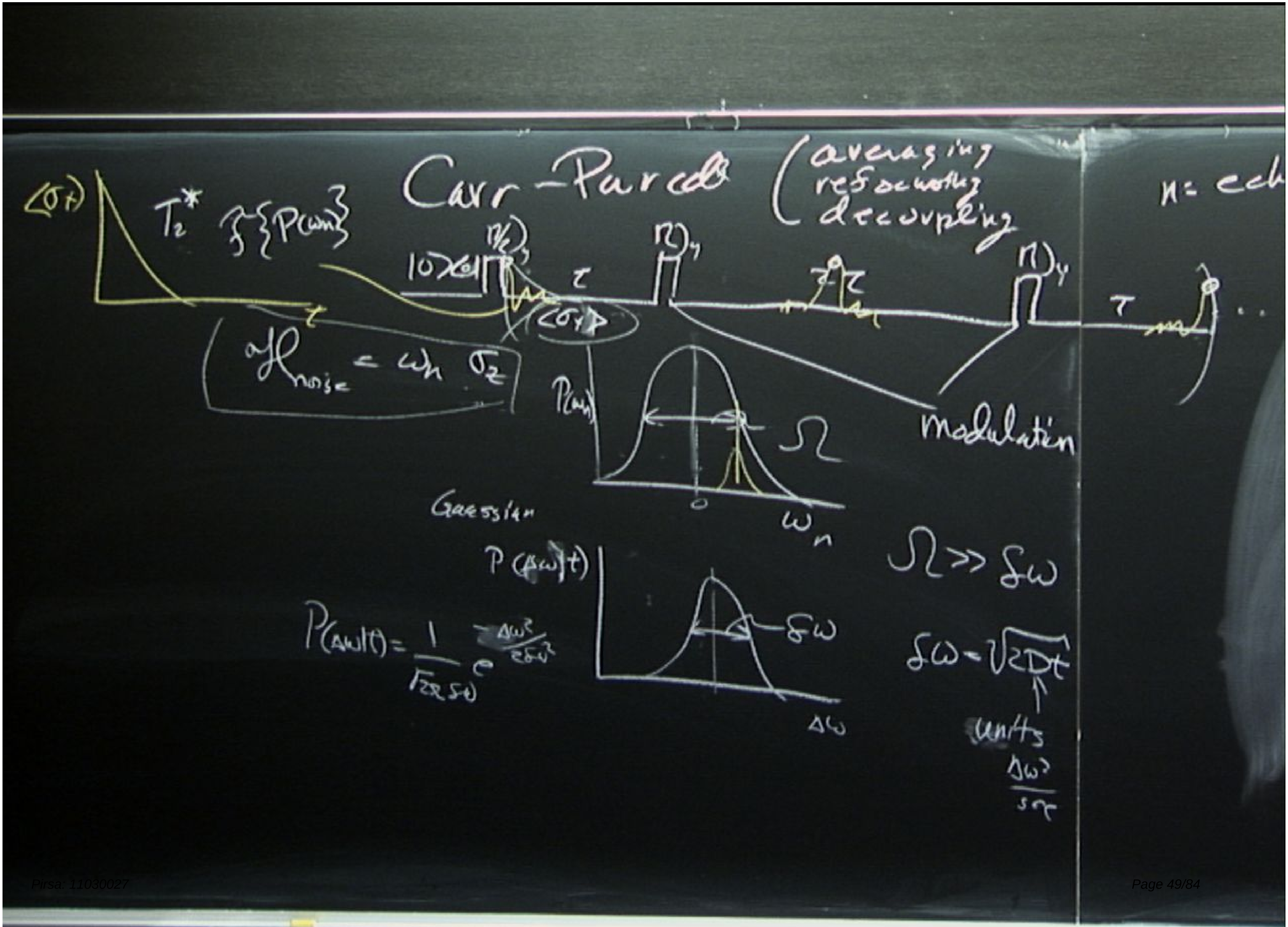
electron spin qubit ↑ . . . . . ↑ ↓ ↑

nuclear spins

$$\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$$

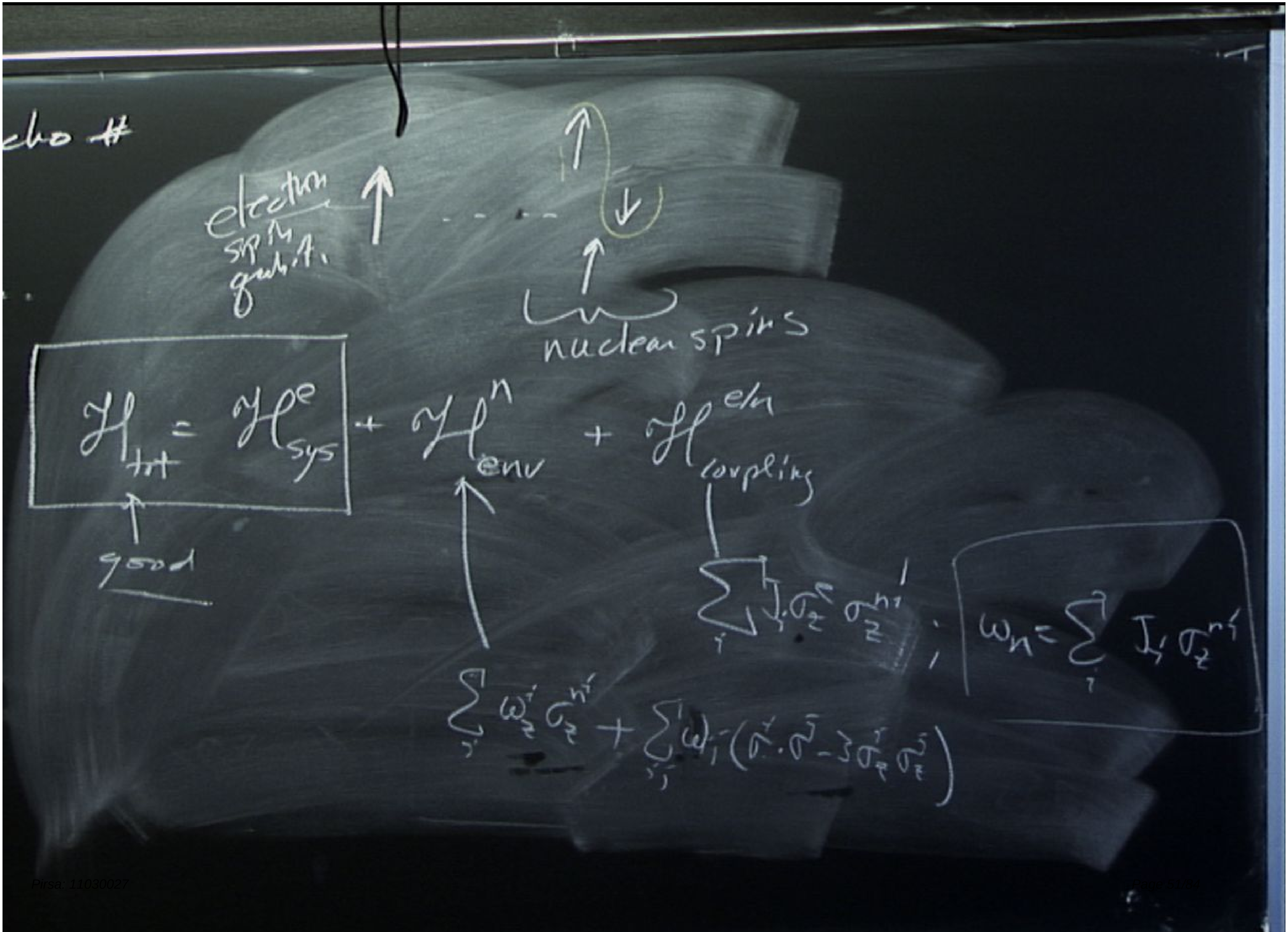
$$\mathcal{H}^{e/n}_{coupling}: \quad \sum_i J_i \sigma_z^e \sigma_z^{n i} \, ; \qquad \boxed{\omega_n = \sum_i J_i \sigma_z^{n i}}$$

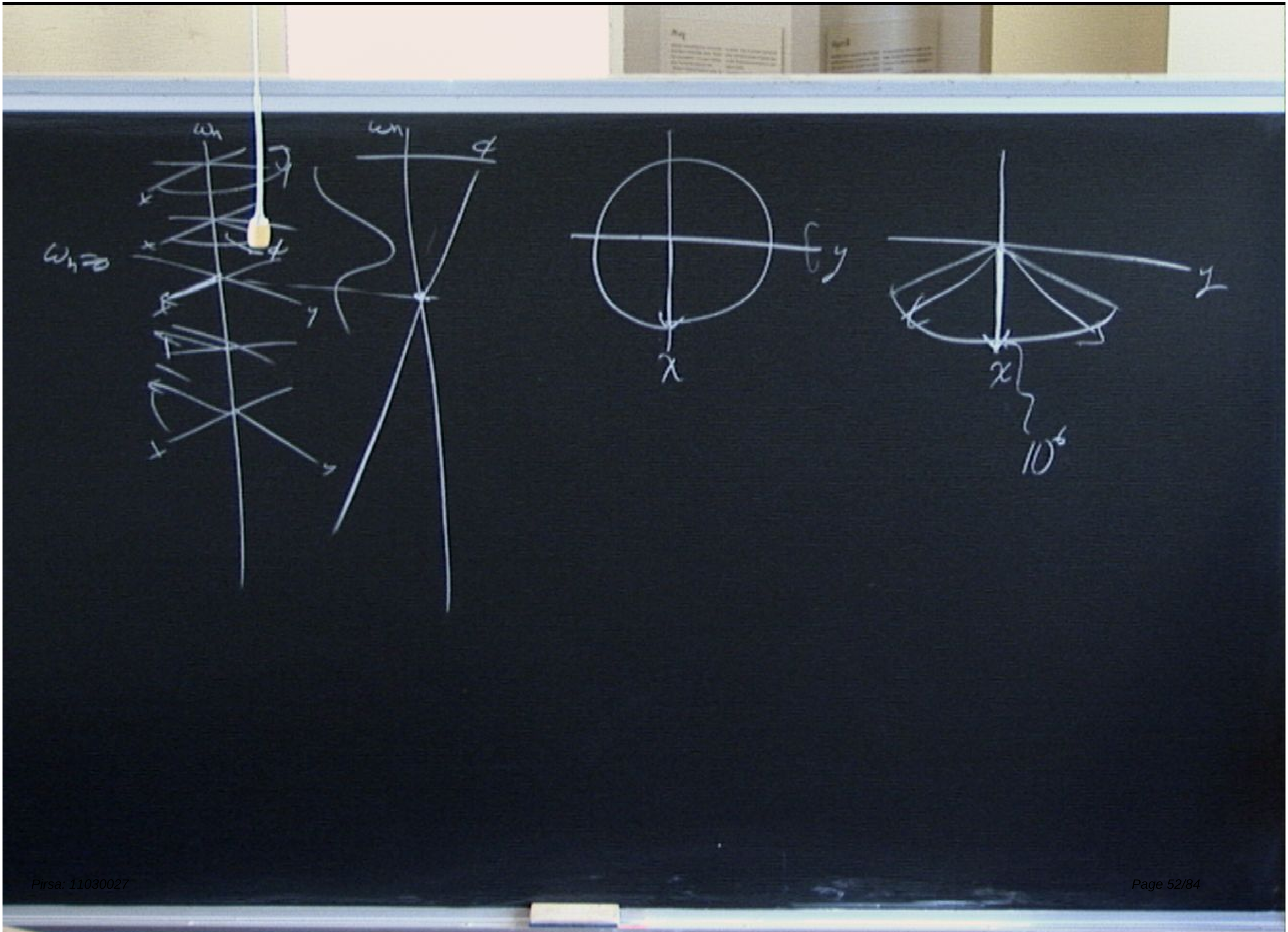
$$\mathcal{H}^{n}_{env}: \quad \sum_i \omega_z^i \sigma_z^{n i} + \sum_{i,j} \omega_{ij} \left(\vec{\sigma}^i \cdot \vec{\sigma}^j - 3 \sigma_z^i \sigma_z^j \right)$$

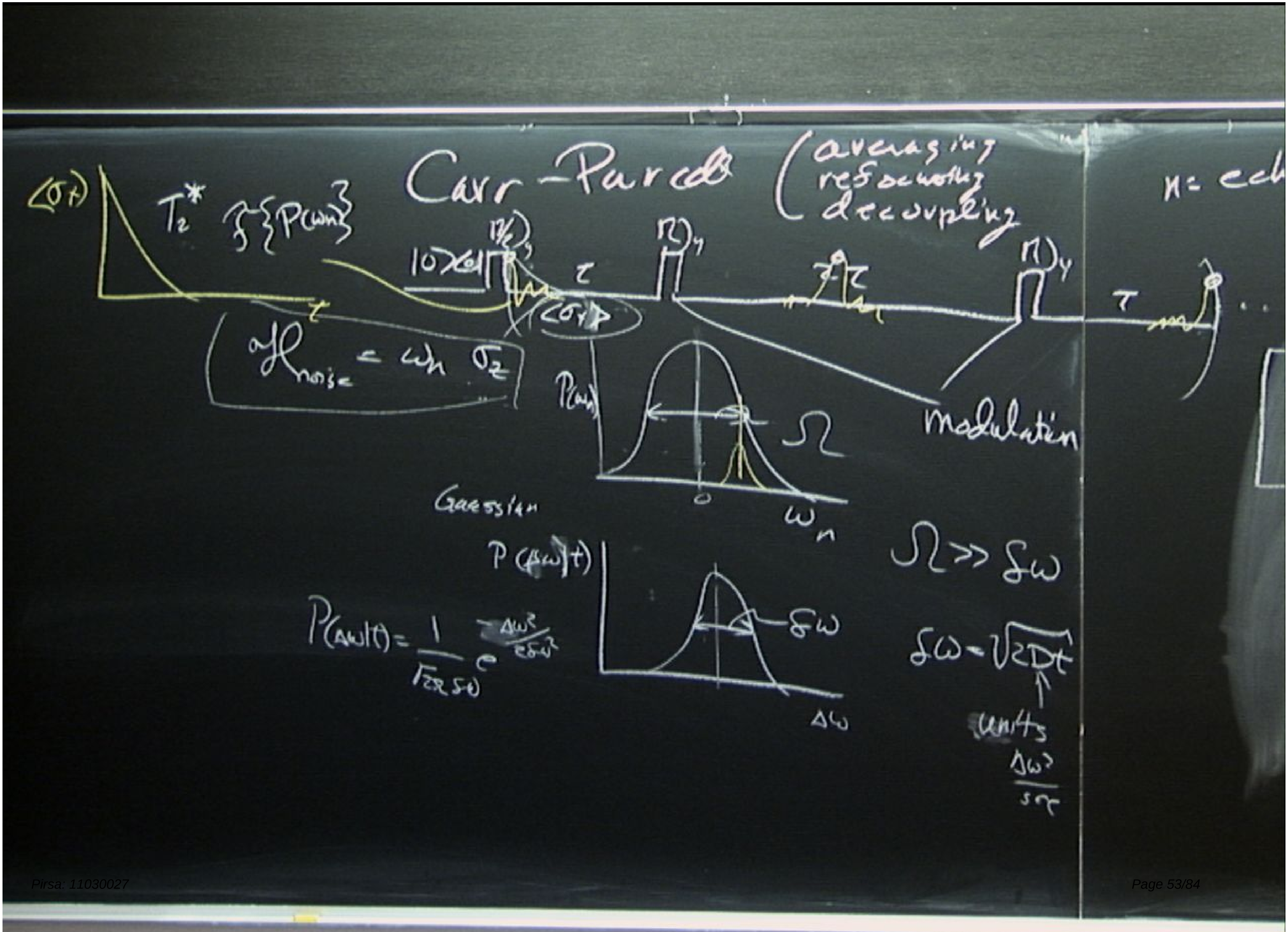


Carr-Purcell
averaging
refocusing
decoupling
Gaussian
modulation
Ω >> δω
δω = √2Dt
units


Grains of Pollen to Evidence for Atoms
How Big Is A Molecule?


echo #
electron spin qubit
nuclear spins
H_tot = H^e_sys + H^n_env + H^e/n_coupling
good
Σ_i J_i σ_z^e σ_z^n_i ; ω_n = Σ_i J_i σ_z^n_i
Σ_i ω_z^i σ_z^n_i + Σ_ij ω_ij (σ^i · σ^j − 3 σ_z^i σ_z^j)


$\omega_h = 0$
x
y
10^6


Carr-Purcell
averaging
refocusing
decoupling
modulation
Gaussian
units

cho #

1. CP on e-spin takes $\overline{\mathcal{H}_{coupl}} \Rightarrow 0$

2. CP on n-spins

electron spin qubit.

$\uparrow$ . . . . . $\uparrow$ $\downarrow$ $\uparrow$

nuclear spins

$$\boxed{\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys}} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$$

good

$\mathcal{H}^{e/n}_{coupling}$: $\sum_i J_i \sigma_z^e \sigma_z^{n^i}$; $\boxed{\omega_n = \sum_i J_i \sigma_z^{n^i}}$

$\mathcal{H}^{n}_{env}$: $\sum_i \omega_z^i \sigma_z^{n^i} + \sum_{i,j} \omega_{ij} (\vec{\sigma}^i \cdot \vec{\sigma}^j - 3 \sigma_z^i \sigma_z^j)$

cho #

1. CP on e-spin takes $\bar{\mathcal{H}}_{coupl} \Rightarrow 0$
2. CP on n-spins — $\bar{\mathcal{H}}_{coupling} \Rightarrow 0$

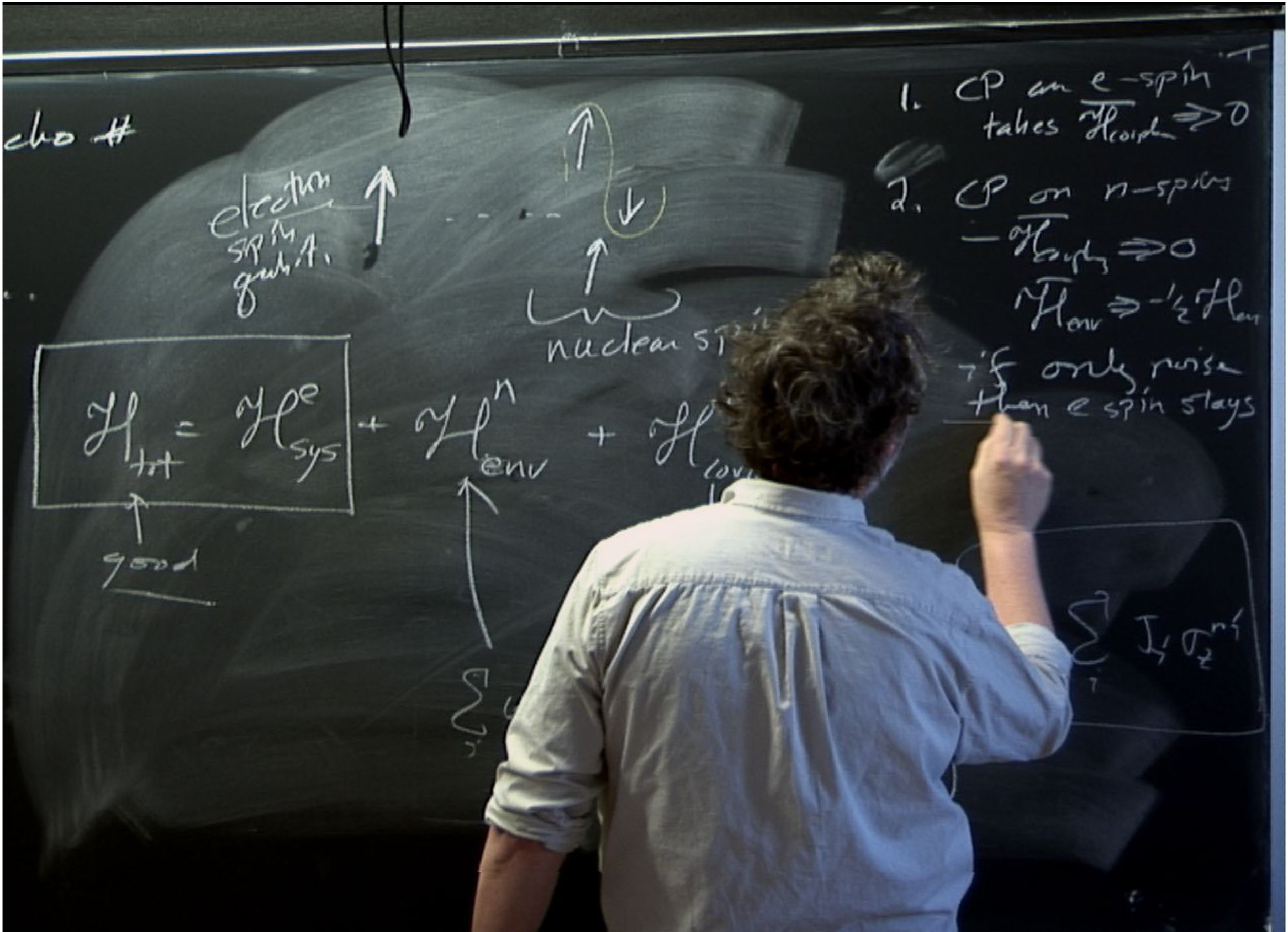
   $\bar{\mathcal{H}}_{env} \Rightarrow -\frac{1}{2}\mathcal{H}_{env}$

$$\boxed{\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys}} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$$

good

$$\mathcal{H}_{coupling} : \sum_i J_i \sigma_z^e \sigma_z^{n^i} ; \qquad \boxed{\omega_n = \sum_i J_i \sigma_z^{n^i}}$$

$$\mathcal{H}_{env} : \sum_i \omega_z^i \sigma_z^{n^i} + \sum_{i,j} \omega_{ij} \left(\sigma^i \cdot \sigma^j - 3\sigma_z^i \sigma_z^j\right)$$


cho #
electron spin qubit
nuclear
$H_{tot} = H^{e}_{sys} + H^{n}_{env} +$
good
1. CP on e-spin takes $H_{coupl} \Rightarrow 0$
2. CP on n-spins
$- H_{coupling} \Rightarrow 0$
$H_{env} \Rightarrow -\frac{1}{2} H_{env}$
if only noise then e spin stays
$\sum_i J_i \sigma_z^{ni}$

echo #

electron spin qubit

nuclear spins

$$\boxed{\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys}} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$$

good

$$\sum_i J_i \sigma_z^e \sigma_z^{n^i} \, ; \qquad \boxed{\omega_n = \sum_i J_i \sigma_z^{n^i}}$$

$$\sum_i \omega_z^i \sigma_z^{n^i} + \sum_{i,j} \omega_{ij} (\vec{\sigma}^i \cdot \vec{\sigma}^j - 3 \sigma_z^i \sigma_z^j)$$

1. CP on e-spin takes $\overline{\mathcal{H}}_{coupl} \Rightarrow 0$

2. CP on n-spins
   - $\overline{\mathcal{H}}_{coupl} \Rightarrow 0$
   - $\overline{\mathcal{H}}_{env} \Rightarrow -\frac{1}{2}\mathcal{H}_{env}$

   if only noise then e spin stays

3.


1. CP on e-spin
CP on n-spins
if only noise
then e spin stays
electron
good

cho #

electron spin qubit

nuclear spins

$$\boxed{\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys}} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$$

good

$\sum_i J_i \sigma_z^e \sigma_z^{ni}$;

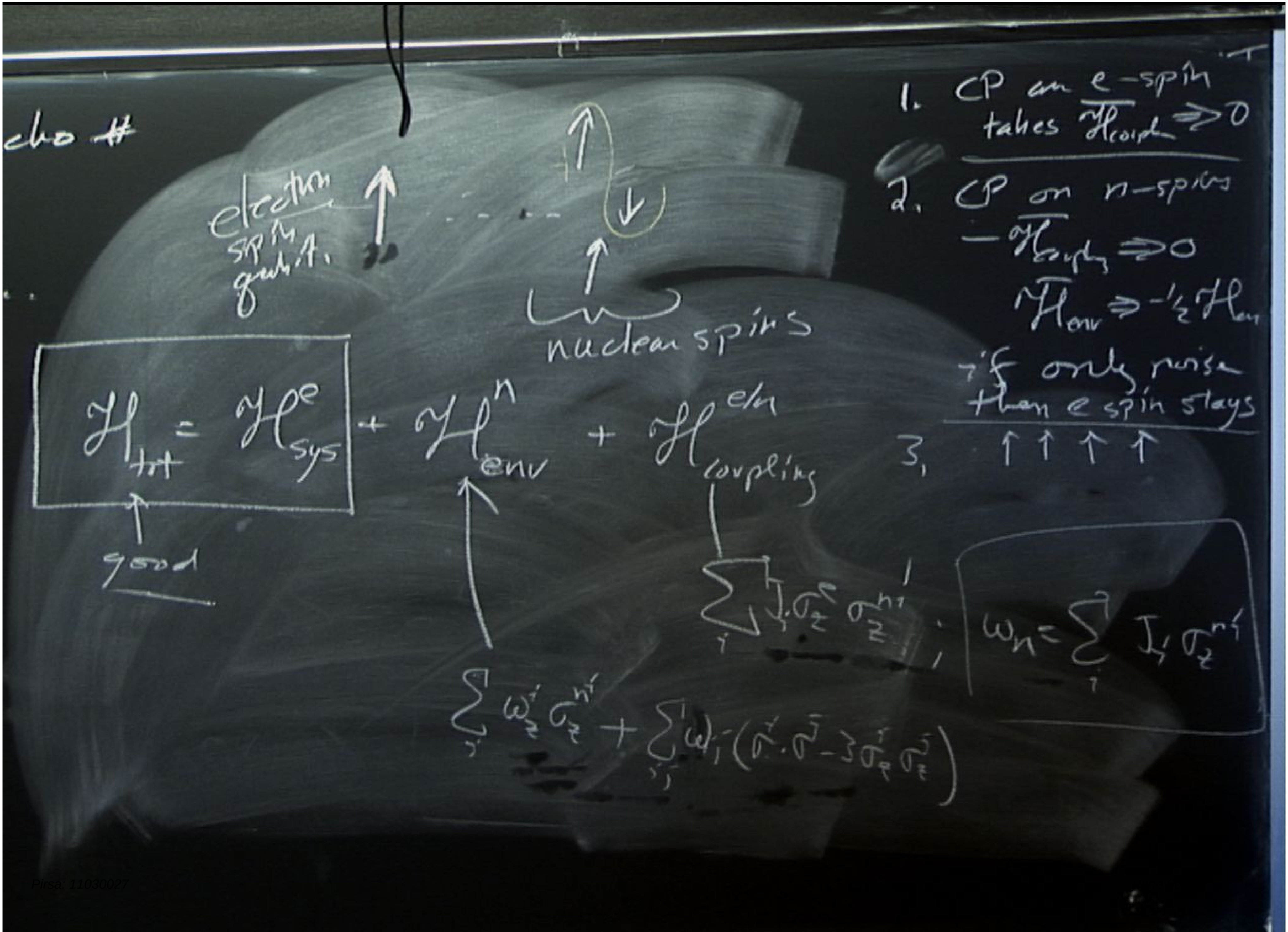
$\sum_i \omega_z^i \sigma_z^{ni} + \sum_{ij} \omega_{ij} (\vec{\sigma}^i \cdot \vec{\sigma}^j - 3\sigma_z^i \sigma_z^j)$

$$\boxed{\omega_n = \sum_i J_i \sigma_z^{ni}}$$

1. CP on e-spin takes $\overline{\mathcal{H}}_{coupl} \Rightarrow 0$
2. CP on n-spins $-\overline{\mathcal{H}}_{coupling} \Rightarrow 0$, $\overline{\mathcal{H}}_{env} \Rightarrow -\frac{1}{2}\mathcal{H}_{env}$

if only noise then e spin stays

3.



(cho #
electron spin qubit
nuclear spins
$\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$
good
$\sum_i J_i \sigma_z^e \sigma_z^{ni}$;
$\sum_i \omega_z^i \sigma_z^{ni} + \sum_{i,j} \omega_{ij} (\vec{\sigma}^i \cdot \vec{\sigma}^j - 3\sigma_z^i \sigma_z^j)$
1. CP on e-spin take $\overline{\mathcal{H}}_{coupl} \Rightarrow 0$
2. CP on n-spins
$-\overline{\mathcal{H}}_{coupling} \Rightarrow 0$
$\overline{\mathcal{H}}_{env} \Rightarrow -\frac{1}{2}\mathcal{H}_{env}$
if only noise then e spin stays
3. ↑ ↑ ↑ ↑
$\omega_n = \sum_i J_i \sigma_z^{ni}$

echo #

$$\boxed{\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys}} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$$

good

$$\mathcal{H}^{e/n}_{coupling}: \sum_i J_i \sigma_z^e \sigma_z^{n i} \, ;$$

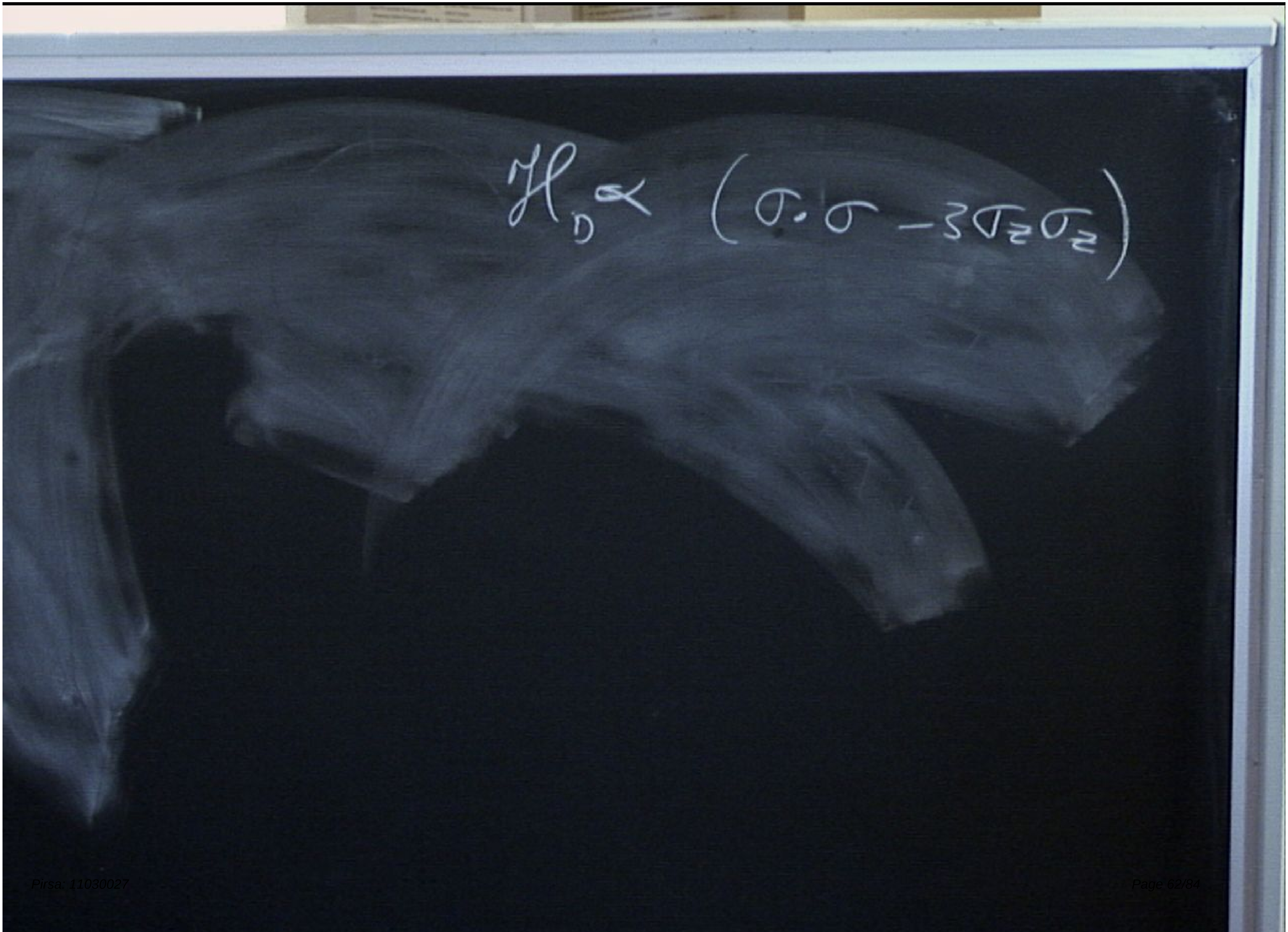
$$\boxed{\omega_n = \sum_i J_i \sigma_z^{n i}}$$

$$\mathcal{H}^{n}_{env}: \sum_i \omega_z^i \sigma_z^{n i} + \sum_{i,j} \omega_{ij} \left(\sigma^i \cdot \sigma^j - 3 \sigma_z^i \sigma_z^j \right)$$

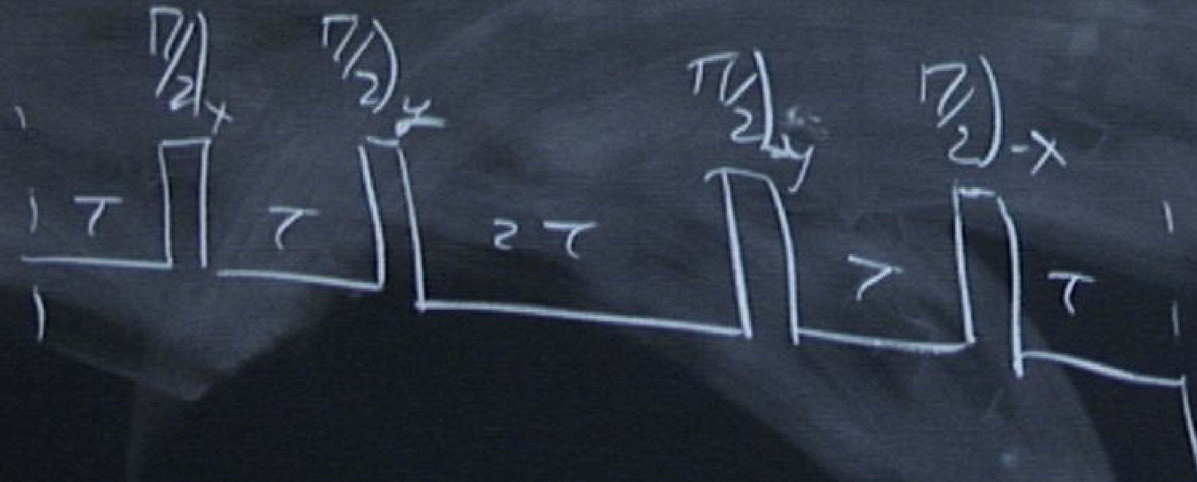
remove this term

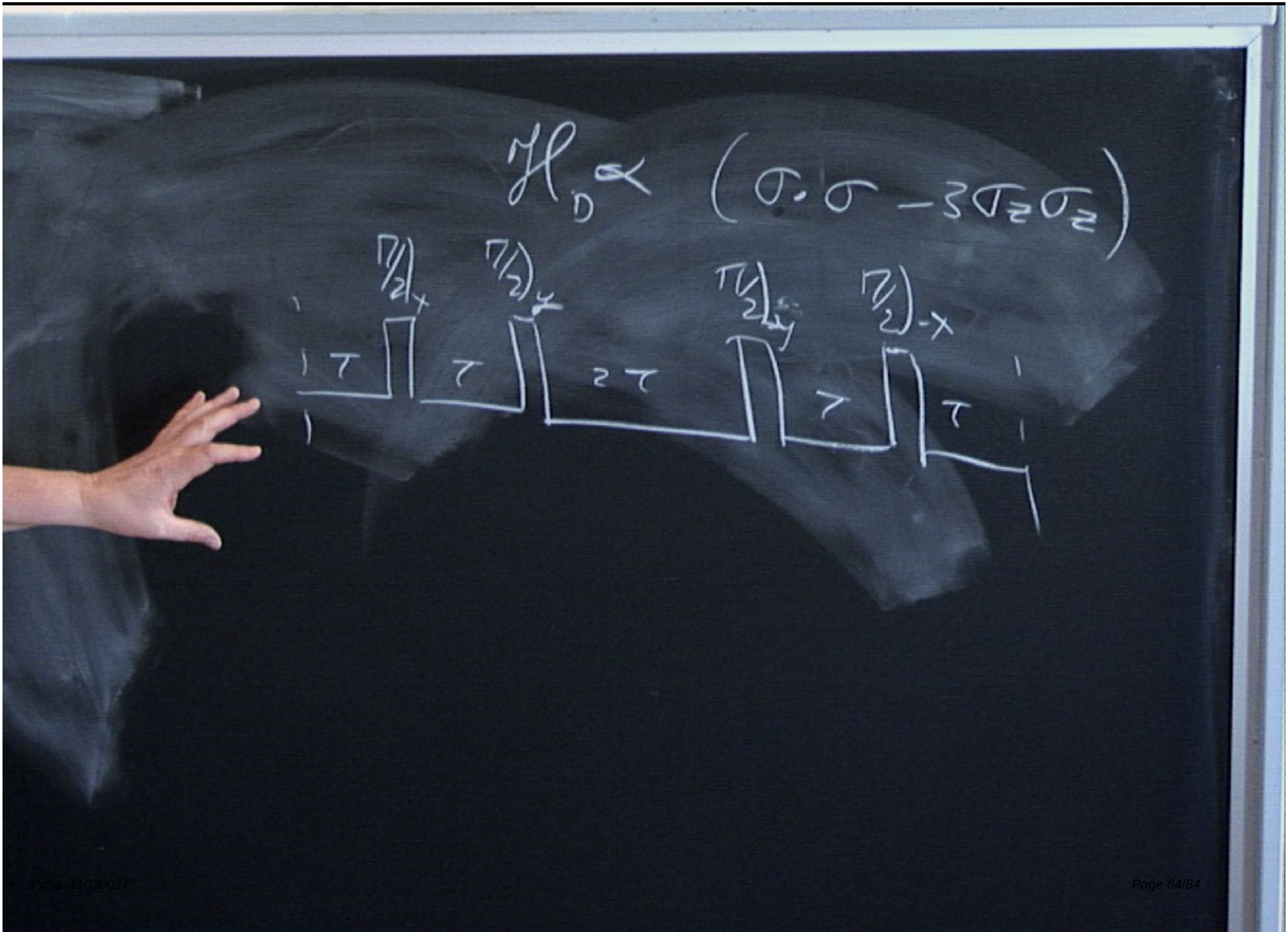
1. CP on e-spin takes $\mathcal{H}_{coupl} \Rightarrow 0$
2. CP on n-spins
   - $\mathcal{H}_{coupling} \Rightarrow 0$
   - $\mathcal{H}_{env} \Rightarrow -\frac{1}{2}\mathcal{H}_{env}$

   if only noise then e spin stays
3. ↑ ↑ ↑ ↑ remove fluct.


$\mathcal{H}_D \propto (\sigma\cdot\sigma - 3\sigma_z\sigma_z)$

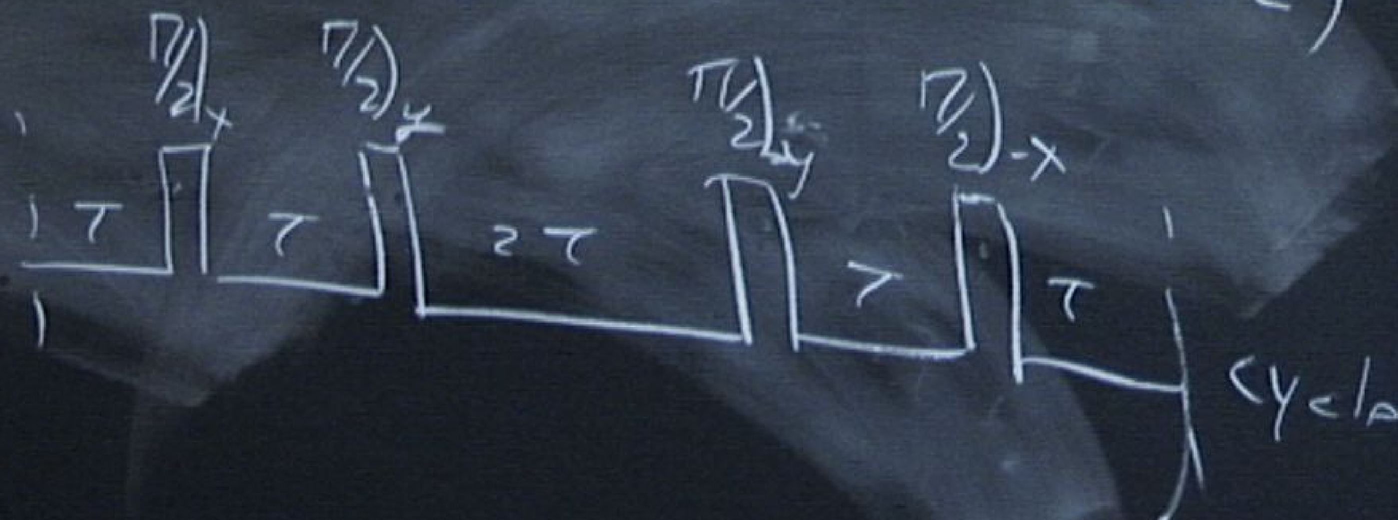
$$\mathcal{H}_D \propto (\sigma\cdot\sigma - 3\sigma_z\sigma_z)$$

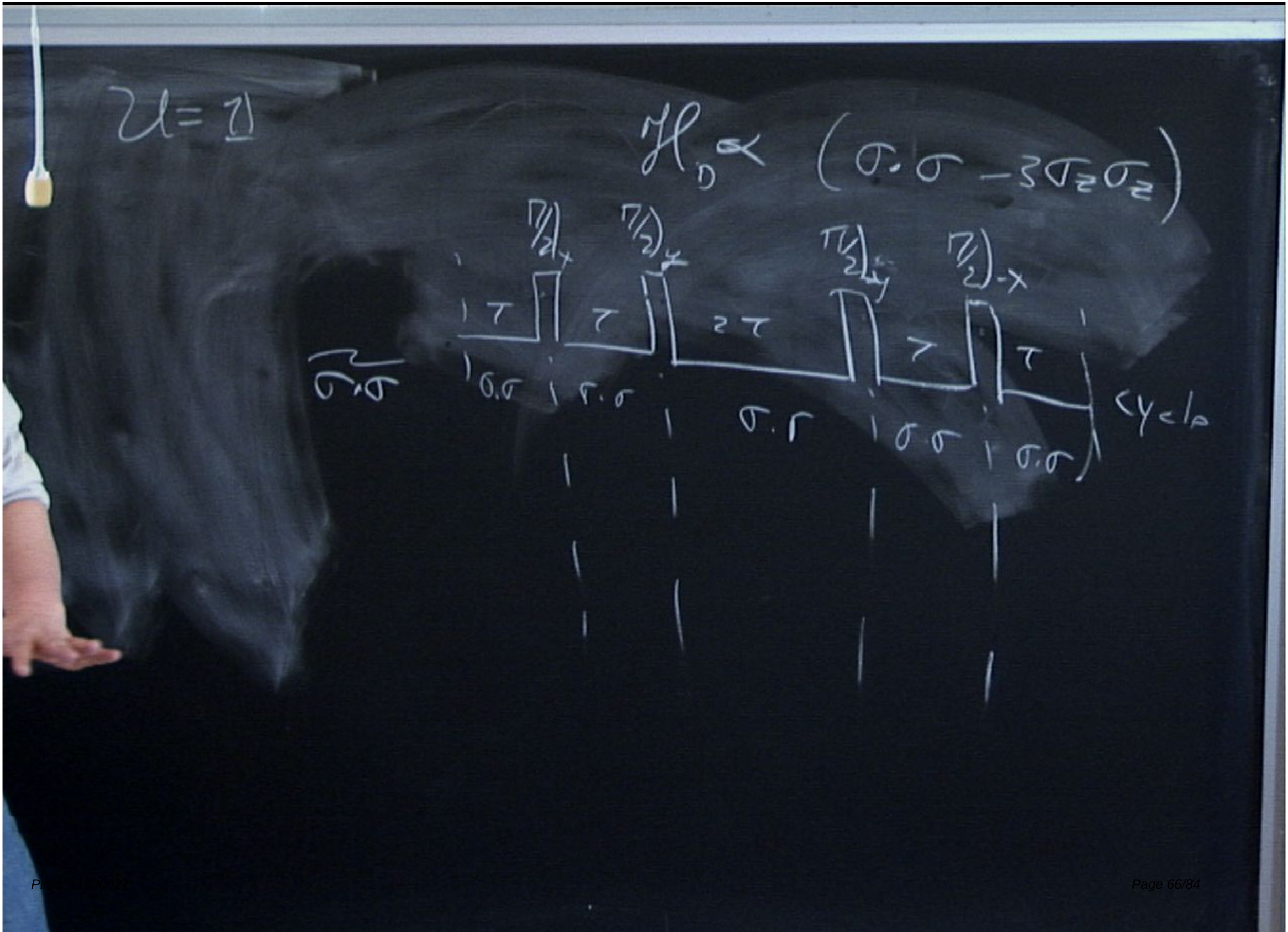


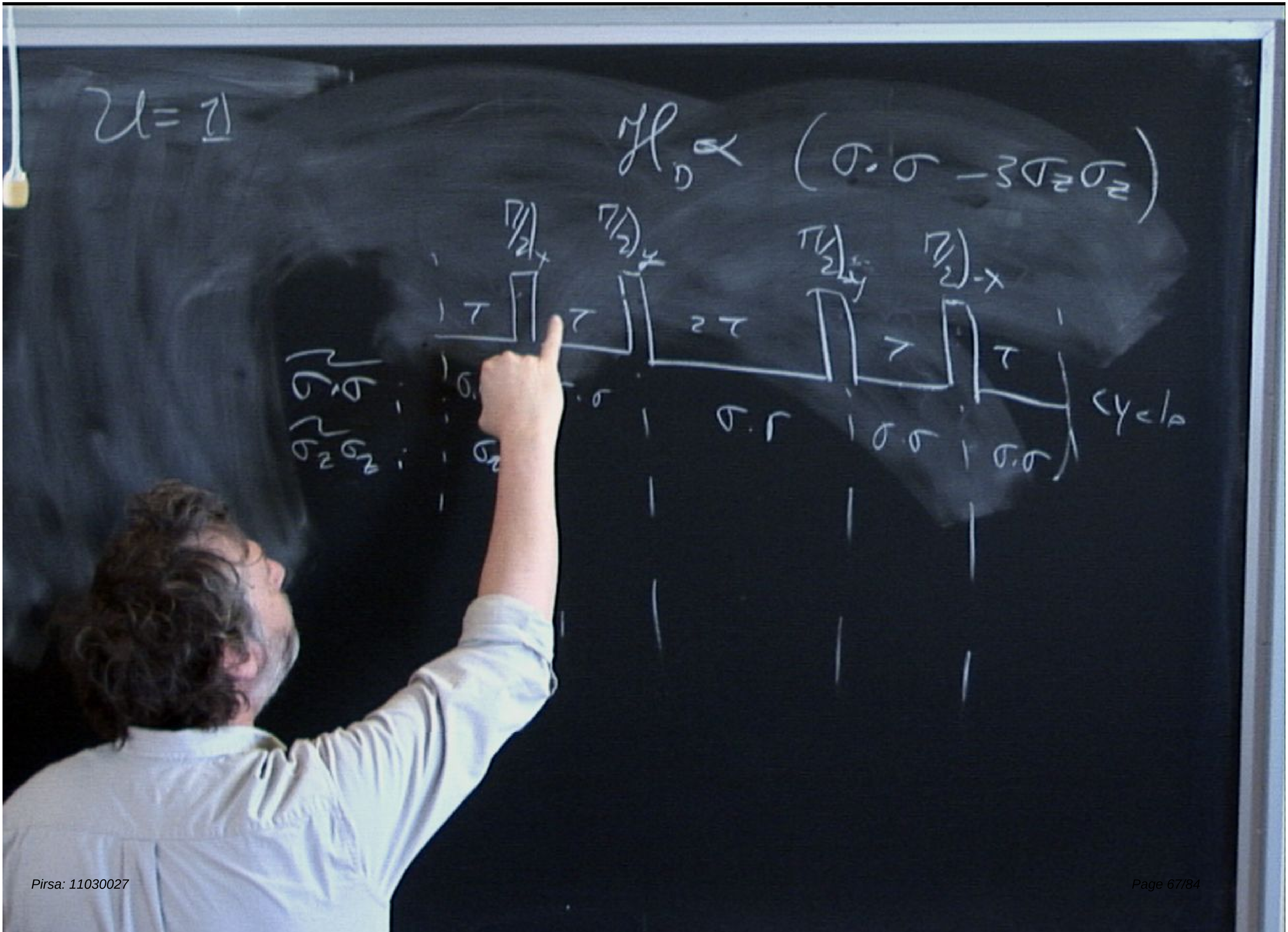

$\mathcal{H}_D \propto (\sigma \cdot \sigma - 3\sigma_z\sigma_z)$
$\pi/2)_x$
$\pi/2)_y$
$\pi/2)_{-x}$
τ
τ
2τ
τ
τ

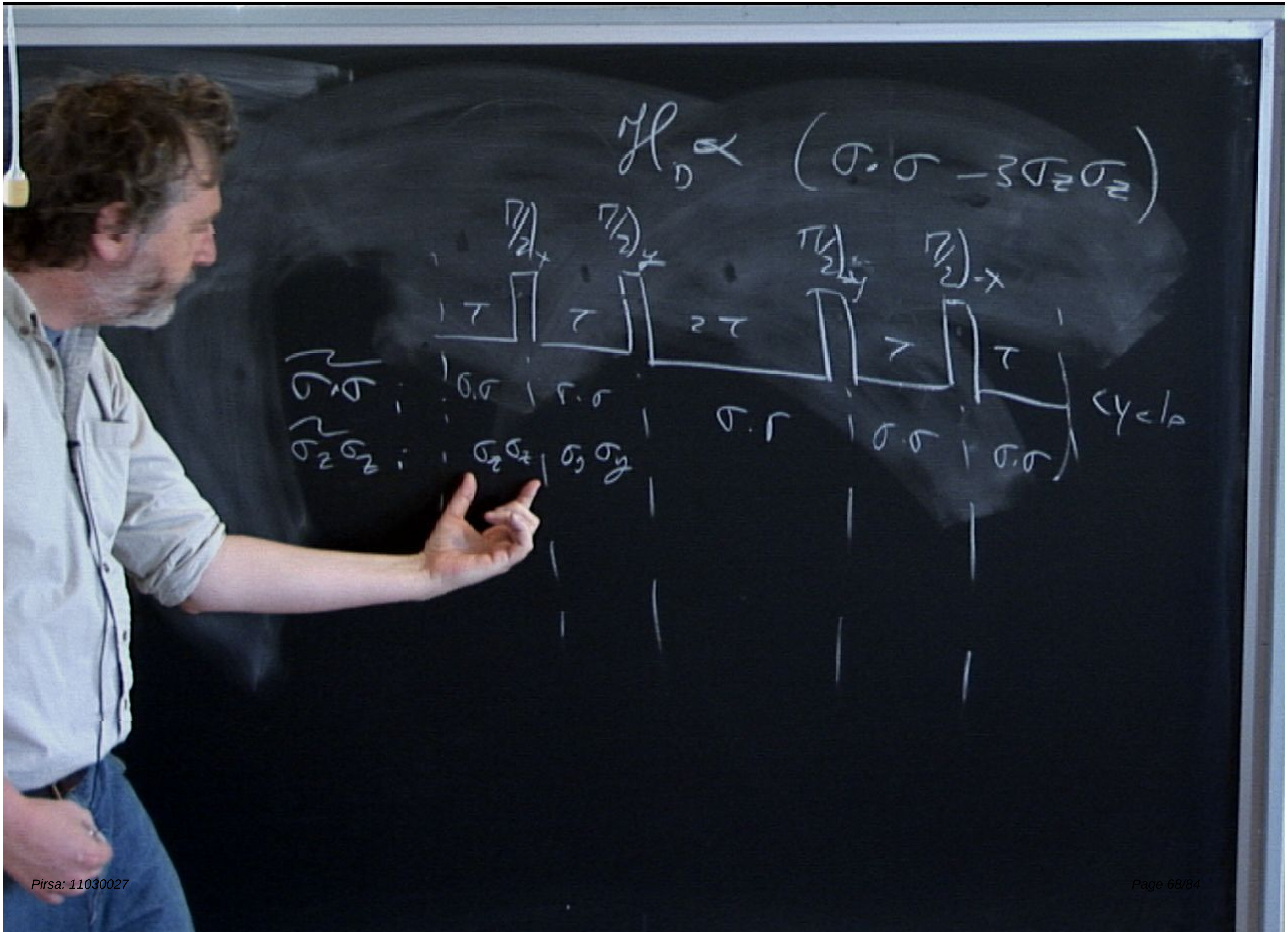
7)

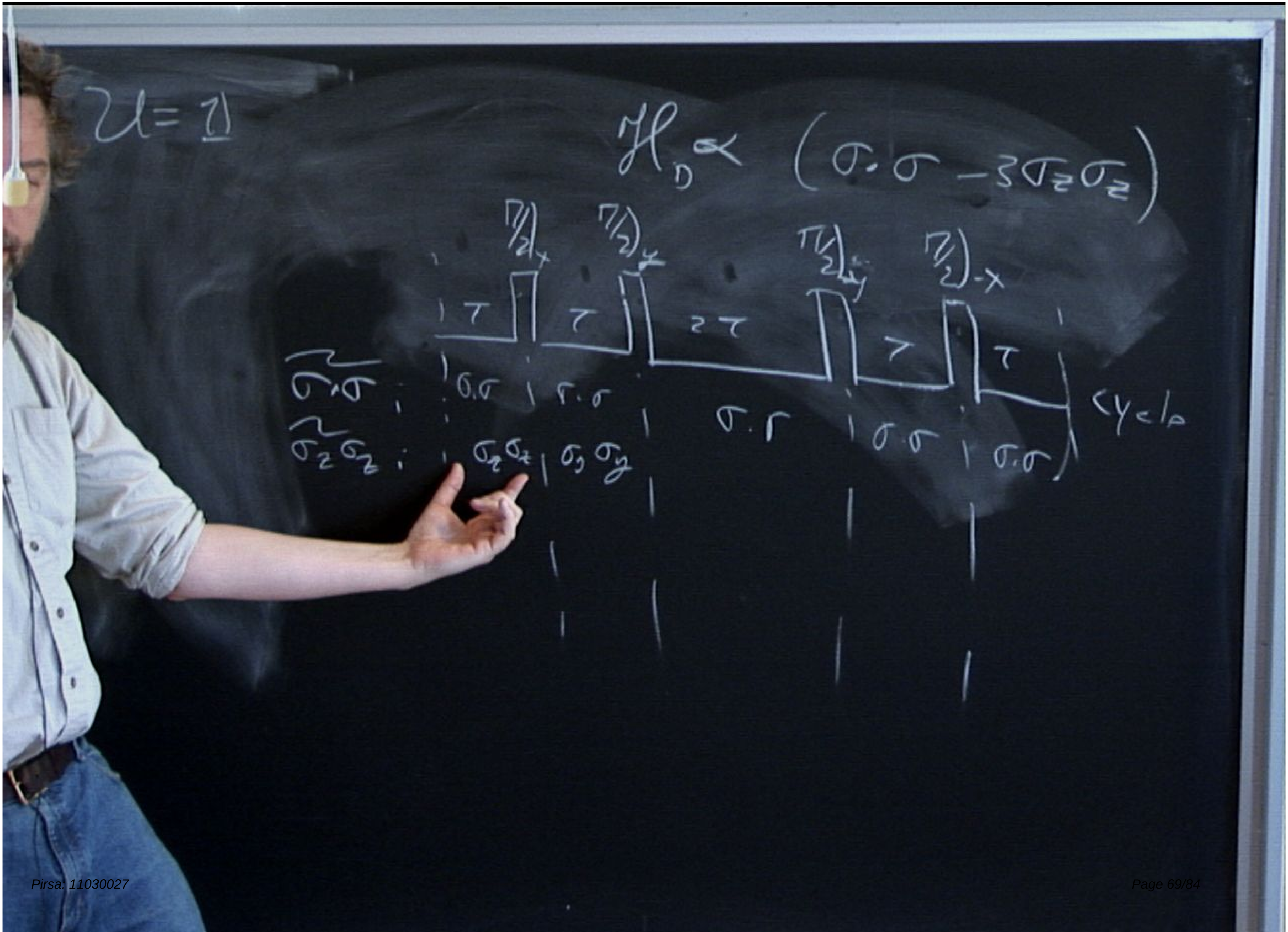
$$\mathcal{H}_D \propto (\sigma\cdot\sigma - 3\sigma_z\sigma_z)$$

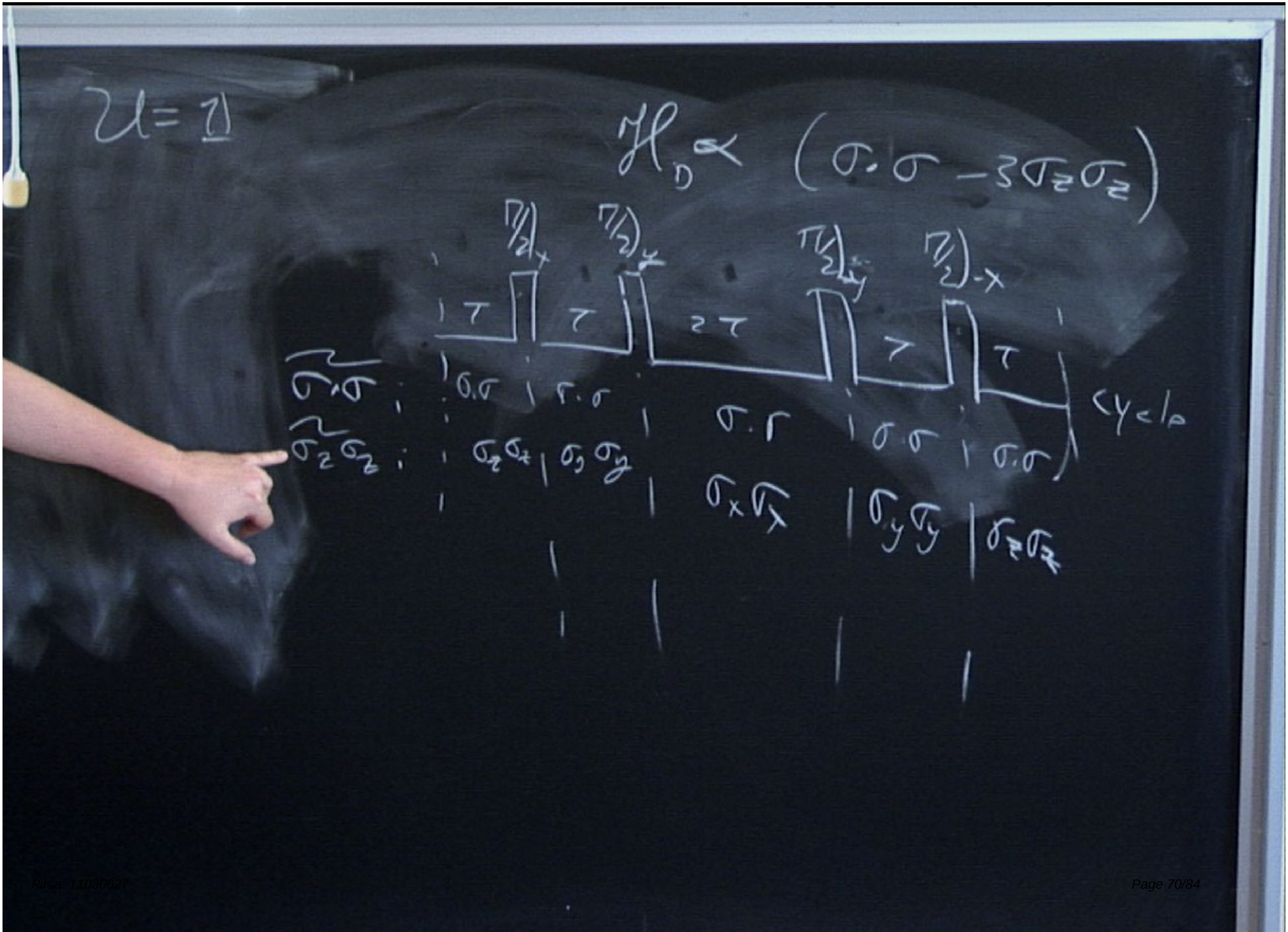


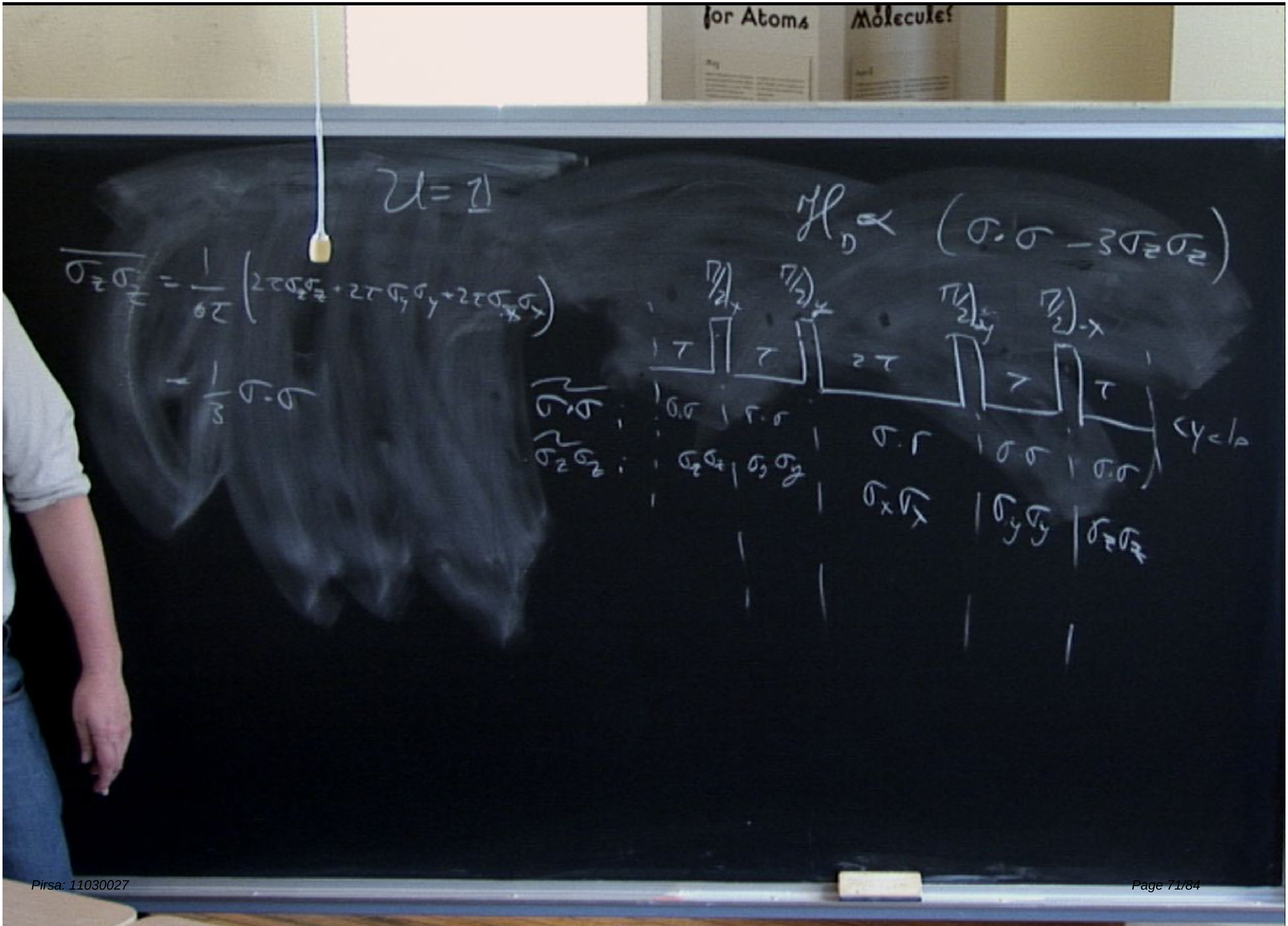

U = 1
H_D ∝ (σ·σ − 3σ_zσ_z)
π/2)_x
π/2)_y
π/2)_y
π/2)_-x
τ
τ
2τ
τ
τ
σ·σ
σ·σ
σ·σ
σ·σ
σ·σ
σ·σ
cycle

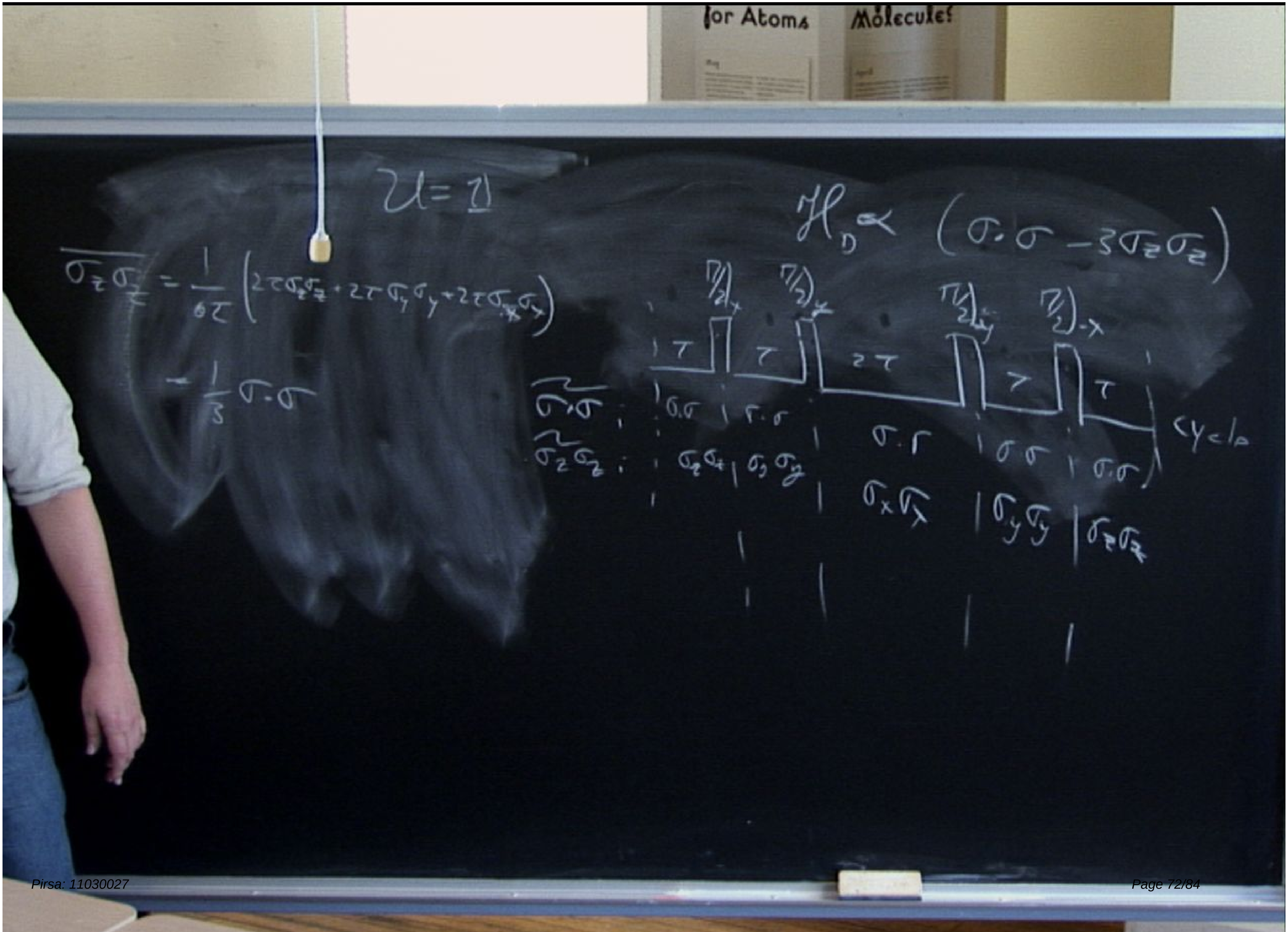

U = 1
$\mathcal{H}_D \propto (\sigma\cdot\sigma - 3\sigma_z\sigma_z)$
cycle


$\mathcal{H}_D \propto (\sigma\cdot\sigma - 3\sigma_z\sigma_z)$
$\pi/2)_x$
$\pi/2)_y$
$\pi/2)_{-y}$
$\pi/2)_{-x}$
τ
τ
2τ
τ
τ
$\widetilde{\sigma\cdot\sigma}$: $\sigma\cdot\sigma$ | $\sigma\cdot\sigma$ | $\sigma\cdot\sigma$ | $\sigma\cdot\sigma$ | $\sigma\cdot\sigma$
$\widetilde{\sigma_z\sigma_z}$: $\sigma_z\sigma_z$ | $\sigma_y\sigma_y$ | | | $\sigma\cdot\sigma$
cycle


U = 1
H_D ∝ (σ·σ − 3σ_z σ_z)
2τ
cycle


U = 1
H_D ∝ (σ·σ − 3σ_zσ_z)
π/2)_x
π/2)_y
π/2)_-y
π/2)_-x
τ
τ
2τ
τ
τ
σ·σ :
σ_zσ_z :
σ·σ
σ·σ
σ·σ
σ·σ
σ·σ
σ_zσ_z
σ_yσ_y
σ_xσ_x
σ_yσ_y
σ_zσ_z
cycle


for Atoms
Molecules
cycle


for Atoms
Molecules
U = 1
H_D ∝ (σ·σ − 3σ_zσ_z)
σ_zσ_z = 1/(6τ) (2τσ_zσ_z + 2τσ_yσ_y + 2τσ_xσ_x)
= 1/3 σ·σ
σ·σ : σ·σ | σ·σ | σ·σ | σ·σ | σ·σ
σ_zσ_z : σ_zσ_z | σ_yσ_y | σ_xσ_x | σ_yσ_y | σ_zσ_z
cycle

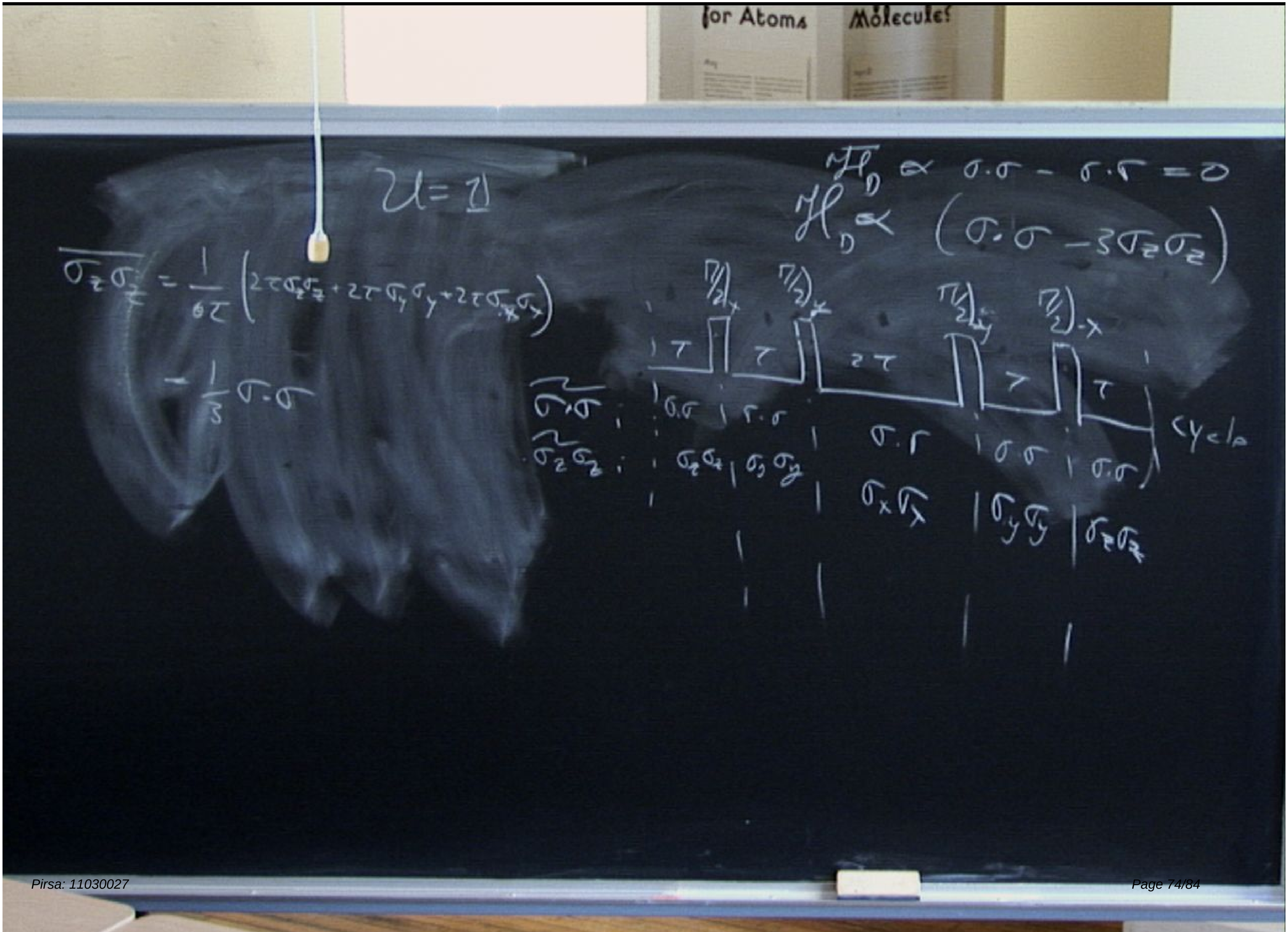
$$\mathcal{H}_D \propto \sigma\cdot\sigma - \sigma\cdot\sigma = 0$$

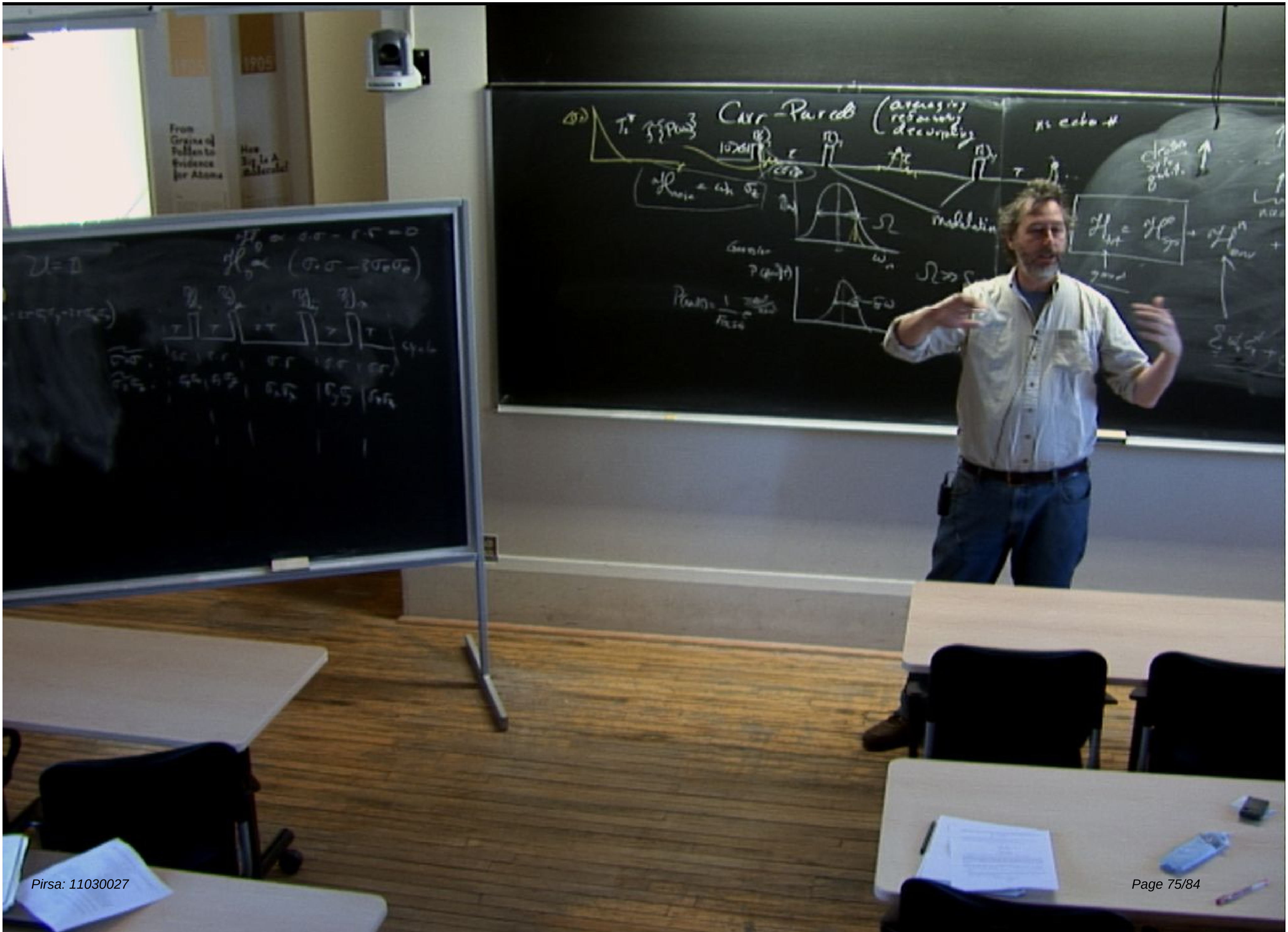
$$\mathcal{H}_D \propto \left(\sigma\cdot\sigma - 3\sigma_z\sigma_z\right)$$

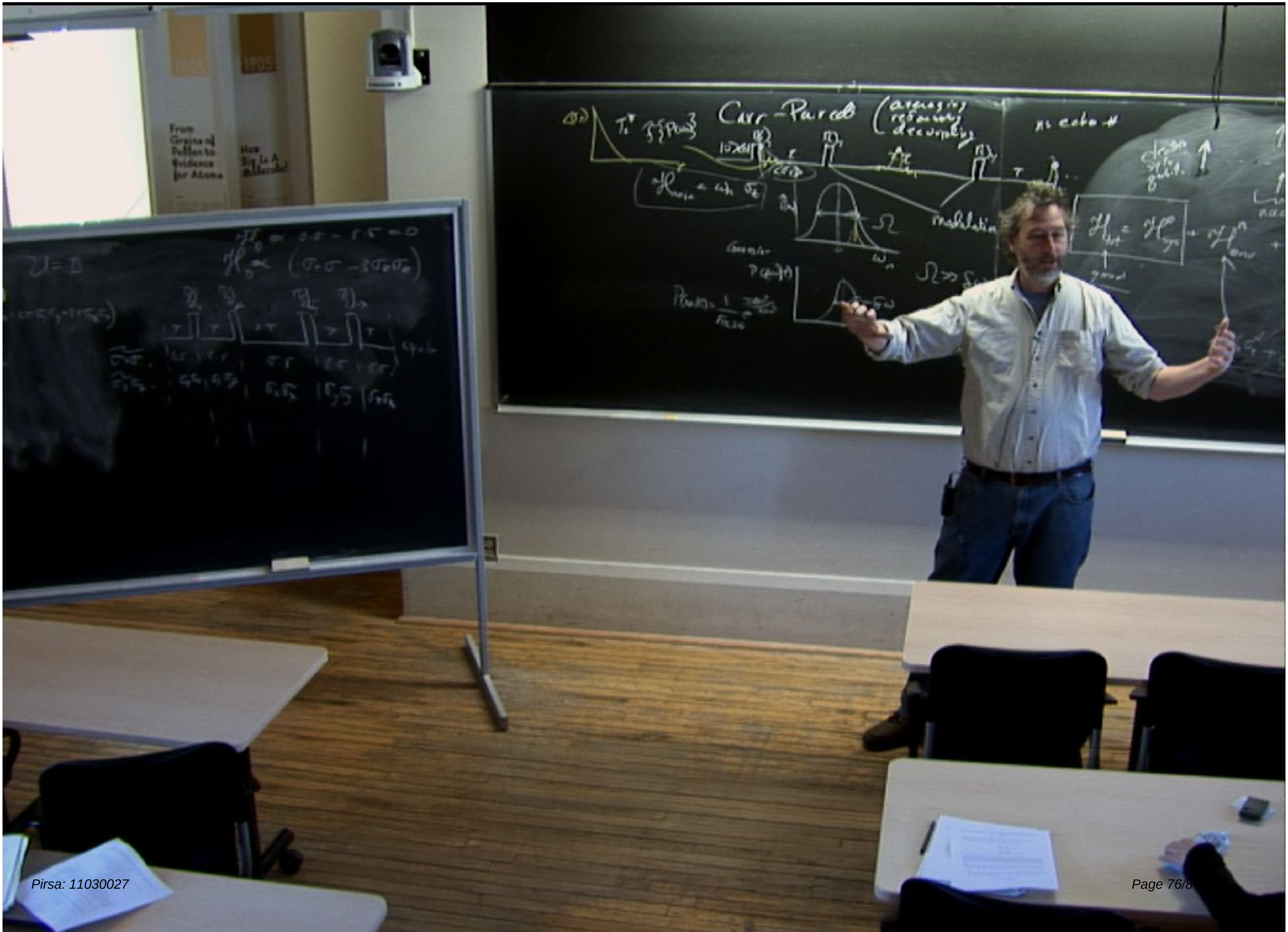
$2\tau\sigma_x\sigma_x)$

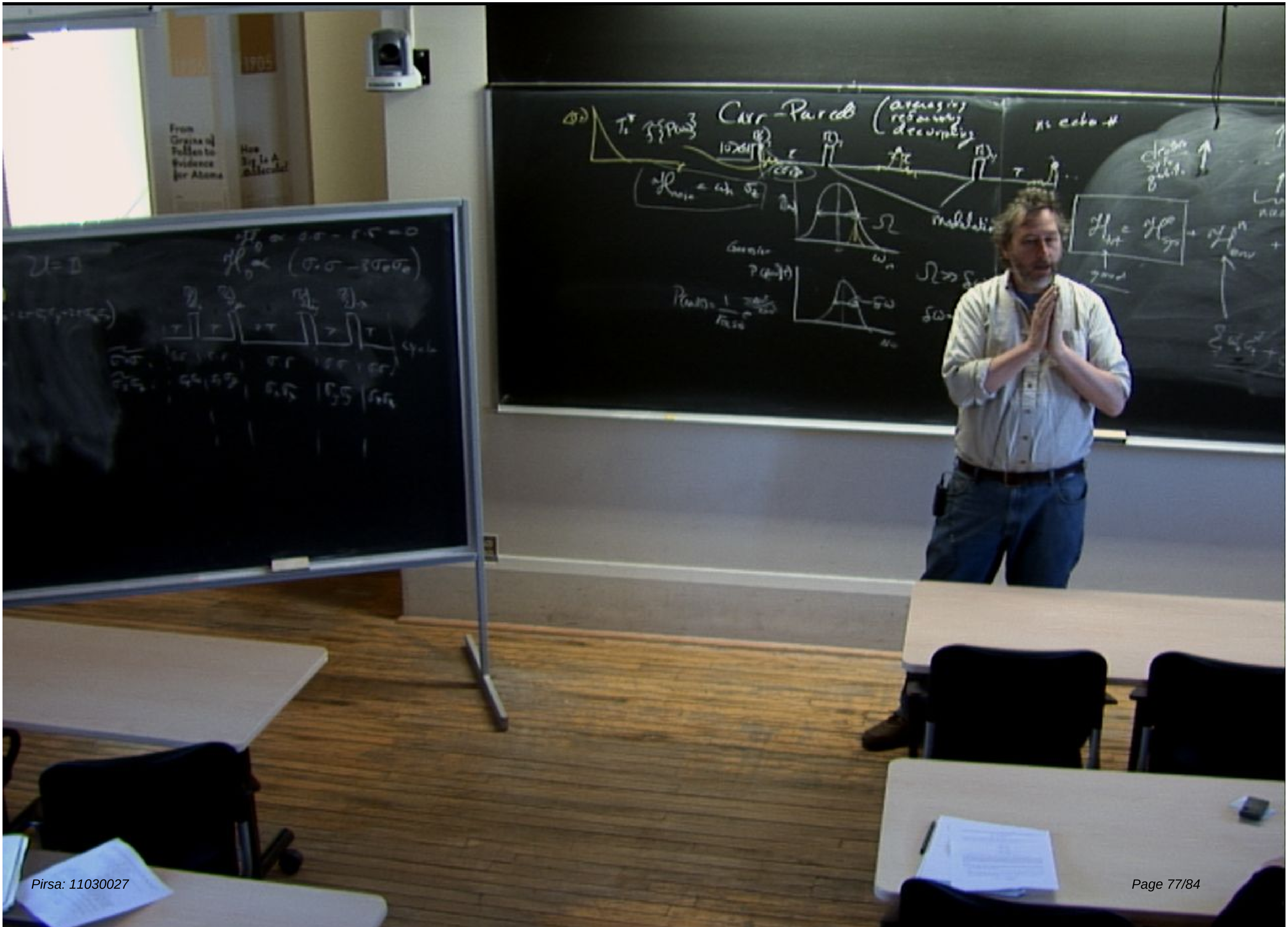
$\tau \;\; \pi/2)_x \;\; \tau \;\; \pi/2)_y \;\; 2\tau \;\; \pi/2)_{-y} \;\; \tau \;\; \pi/2)_{-x} \;\; \tau$ — cycle

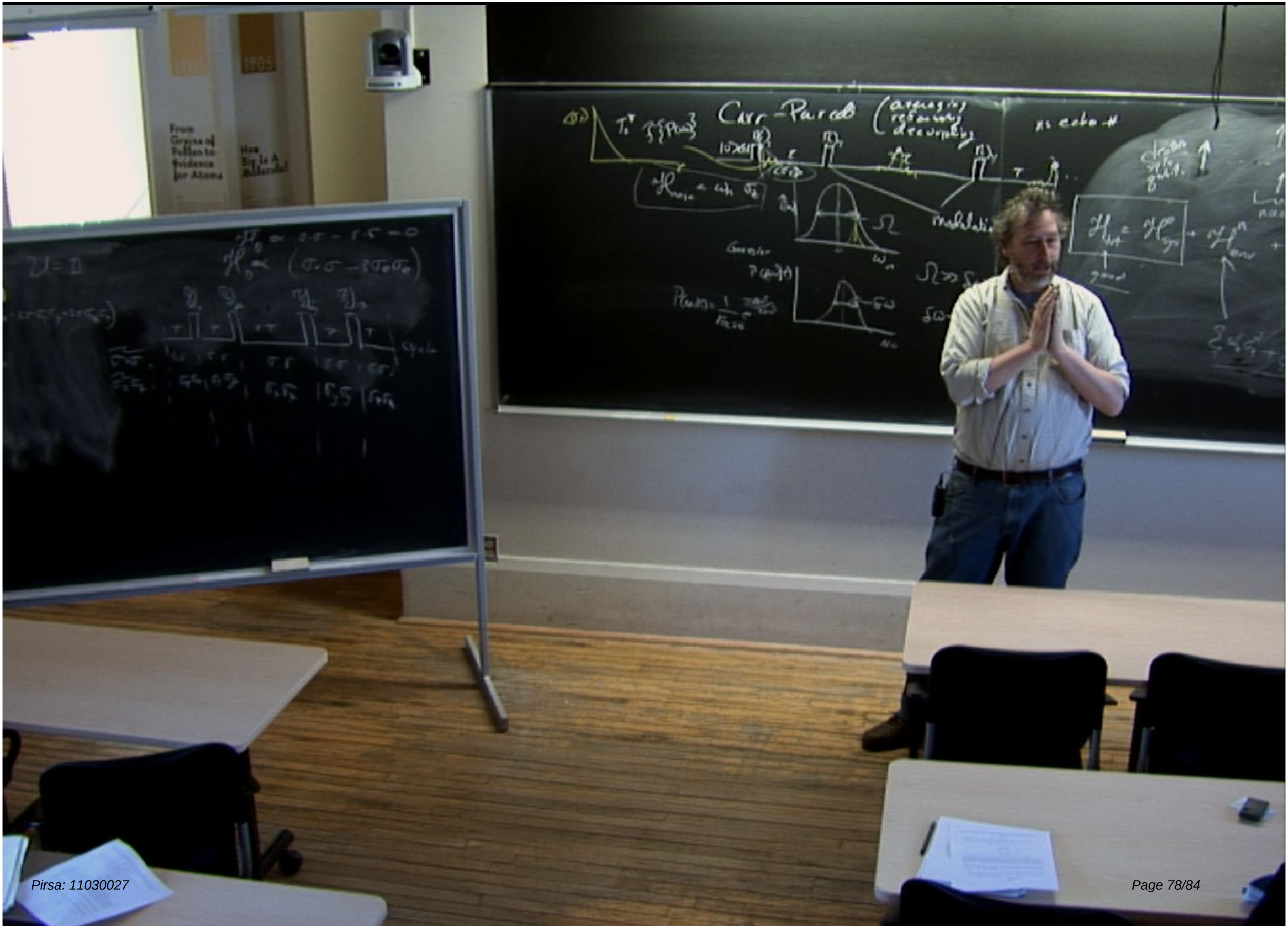
$\widetilde{\sigma\cdot\sigma}$:	$\sigma\cdot\sigma$	$\sigma\cdot\sigma$	$\sigma\cdot\sigma$	$\sigma\cdot\sigma$	$\sigma\cdot\sigma$
$\widetilde{\sigma_z\sigma_z}$:	$\sigma_z\sigma_z$	$\sigma_y\sigma_y$	$\sigma_x\sigma_x$	$\sigma_y\sigma_y$	$\sigma_z\sigma_z$

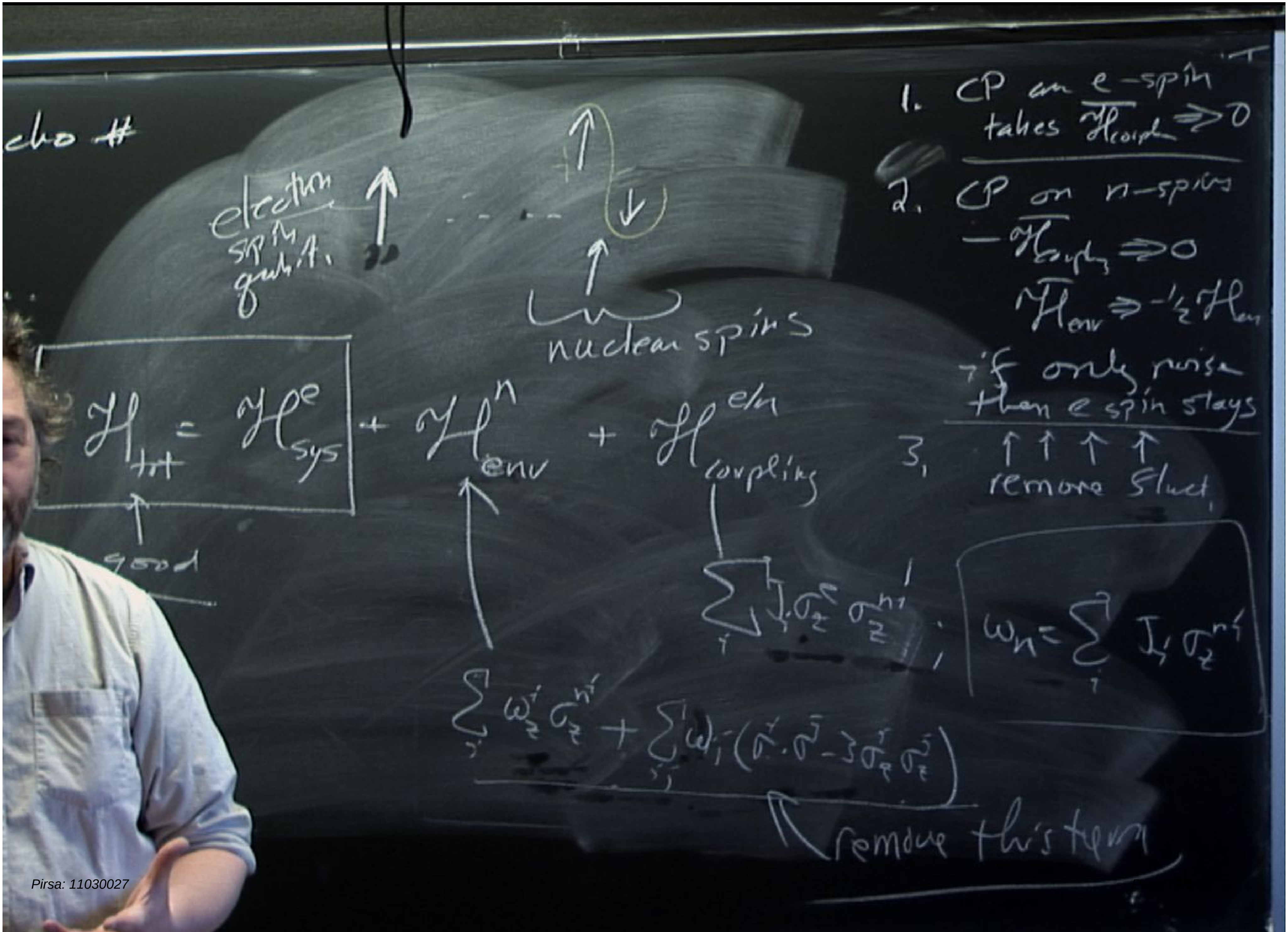

for Atoms
Molecules
U = 1
H_D ∝ σ·σ − σ·σ = 0
H_D ∝ (σ·σ − 3σ_zσ_z)
cycle

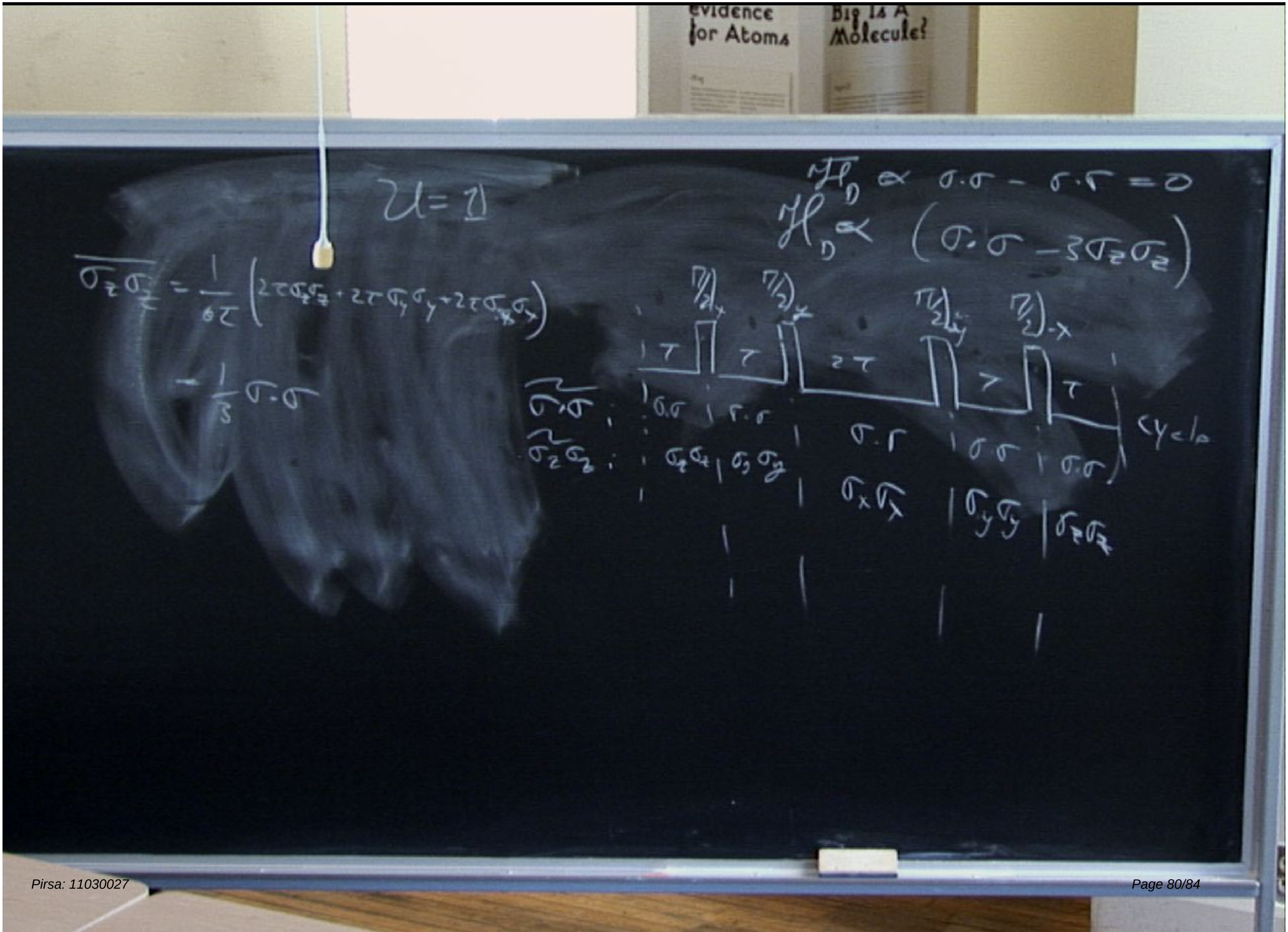

Carr-Purcell
From Grains of Pollen to Evidence for Atoms

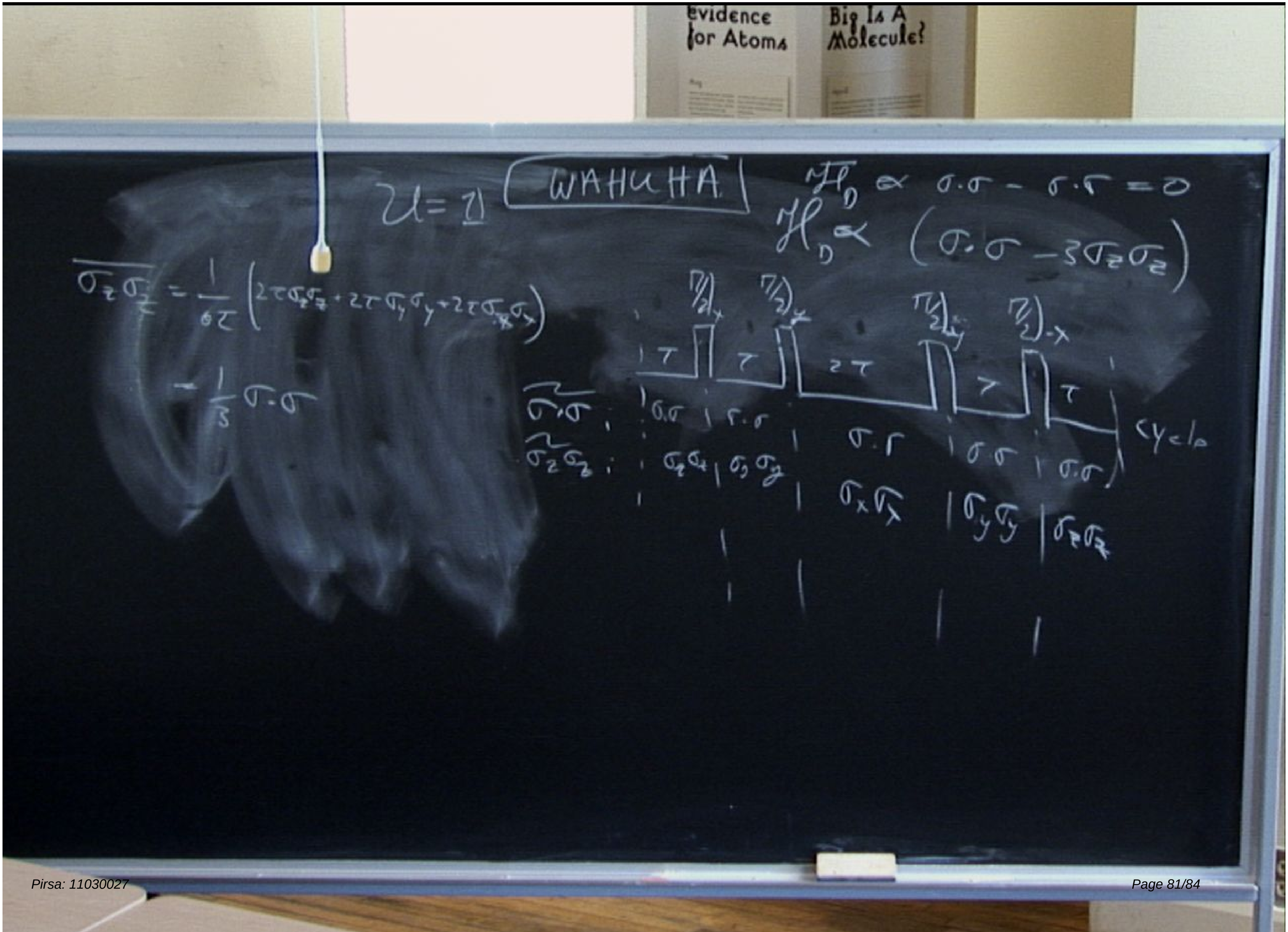

From Grains of Pollen to Evidence for Atoms
Carr-Purcell

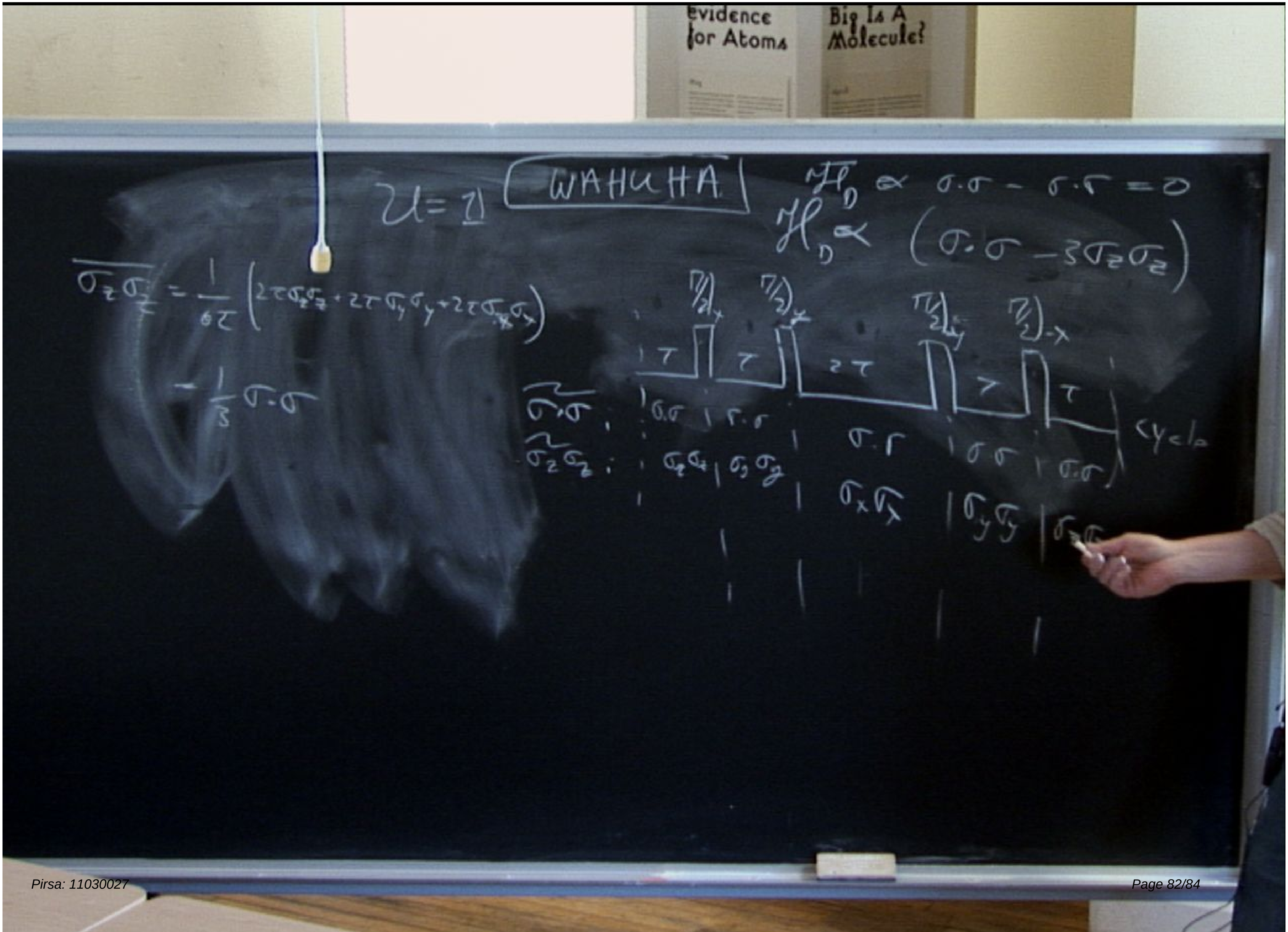

Carr-Purcell

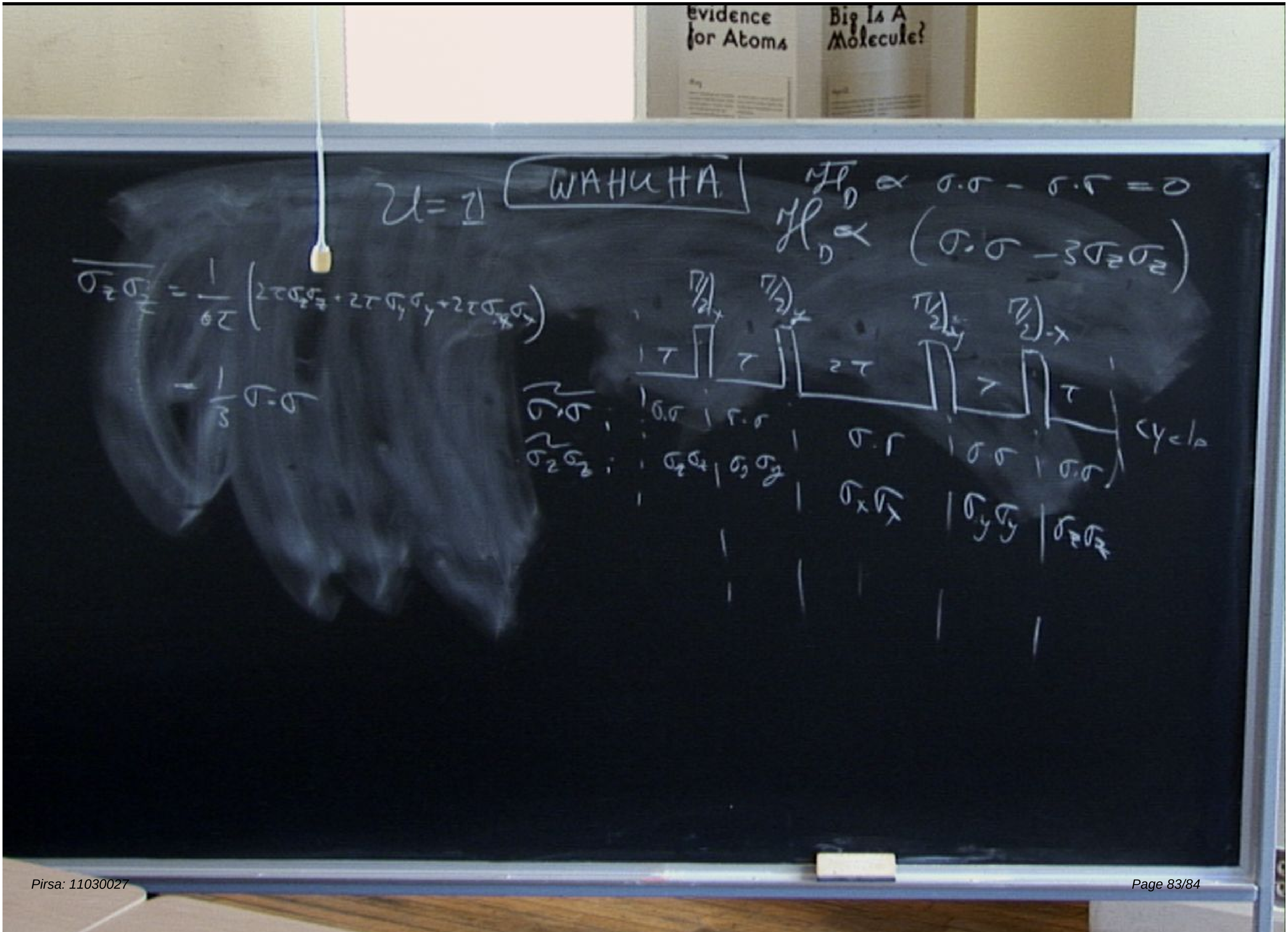

Carr-Purcell

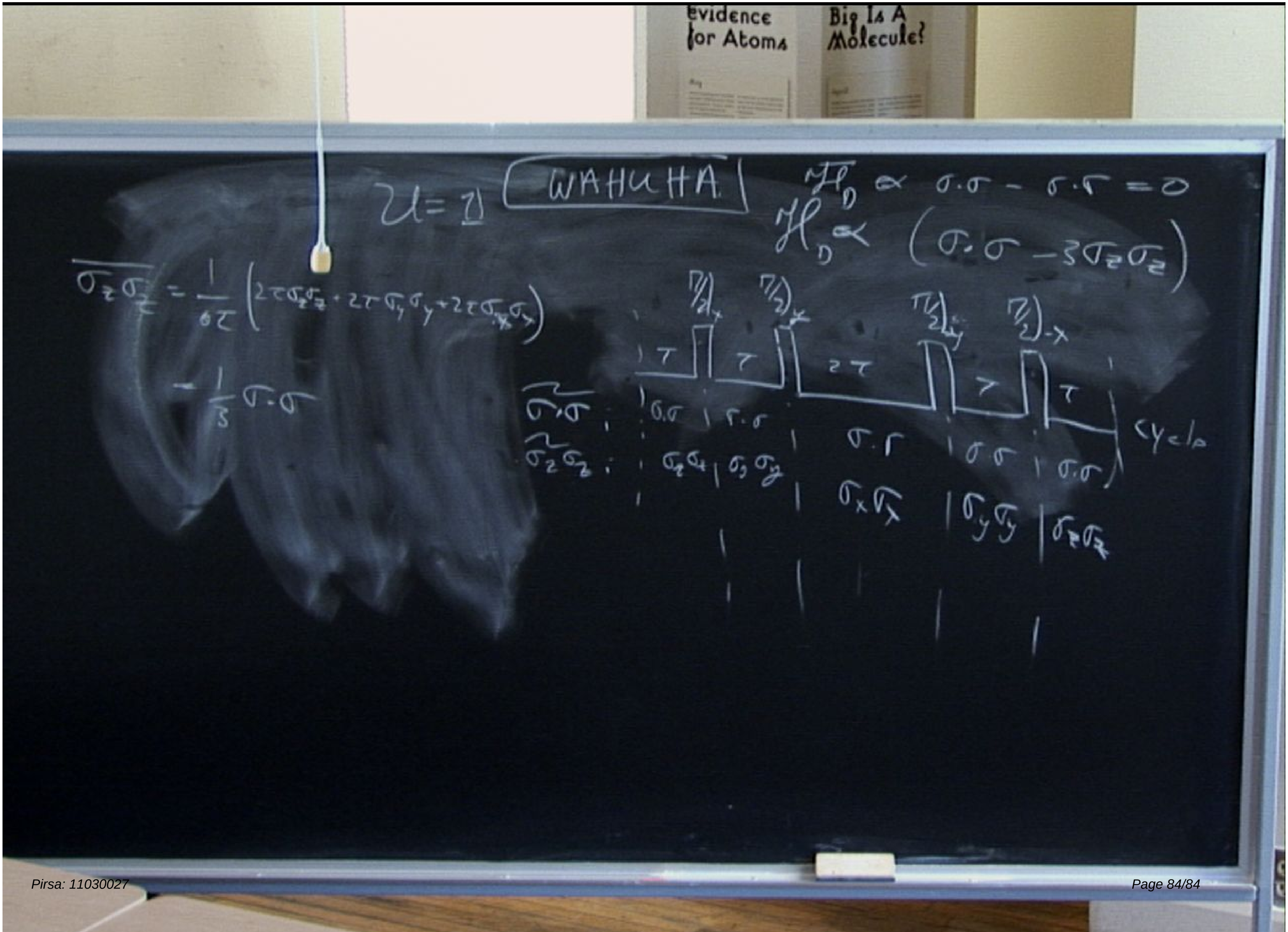

echo #
electron spin guh.t.
nuclear spins
$\mathcal{H}_{tot} = \mathcal{H}^{e}_{sys} + \mathcal{H}^{n}_{env} + \mathcal{H}^{e/n}_{coupling}$
good
$\sum_i J_i \sigma_z^e \sigma_z^{ni}$;
$\sum_i \omega_z^i \sigma_z^{ni} + \sum_{ij} \omega_{ij} (\vec{\sigma}^i \cdot \vec{\sigma}^j - 3\sigma_z^i \sigma_z^j)$
remove this term
1. CP on e-spin
takes $\overline{\mathcal{H}}_{coupl} \Rightarrow 0$
2. CP on n-spins
$- \overline{\mathcal{H}}_{coupling} \Rightarrow 0$
$\overline{\mathcal{H}}_{env} \Rightarrow -\frac{1}{2}\mathcal{H}_{env}$
if only noise
then e spin stays
3. remove fluct.
$\omega_n = \sum_i J_i \sigma_z^{ni}$


evidence
for Atoms
Big Is A
Molecule?


Evidence for Atoms
Big Is A Molecule?
WAHUHA
cycle


Evidence for Atoms
Big Is A Molecule?
WAHUHA


Evidence for Atoms
Big Is A Molecule?
WAHUHA


Evidence for Atoms
Big Is A Molecule?
WAHUHA
cycle