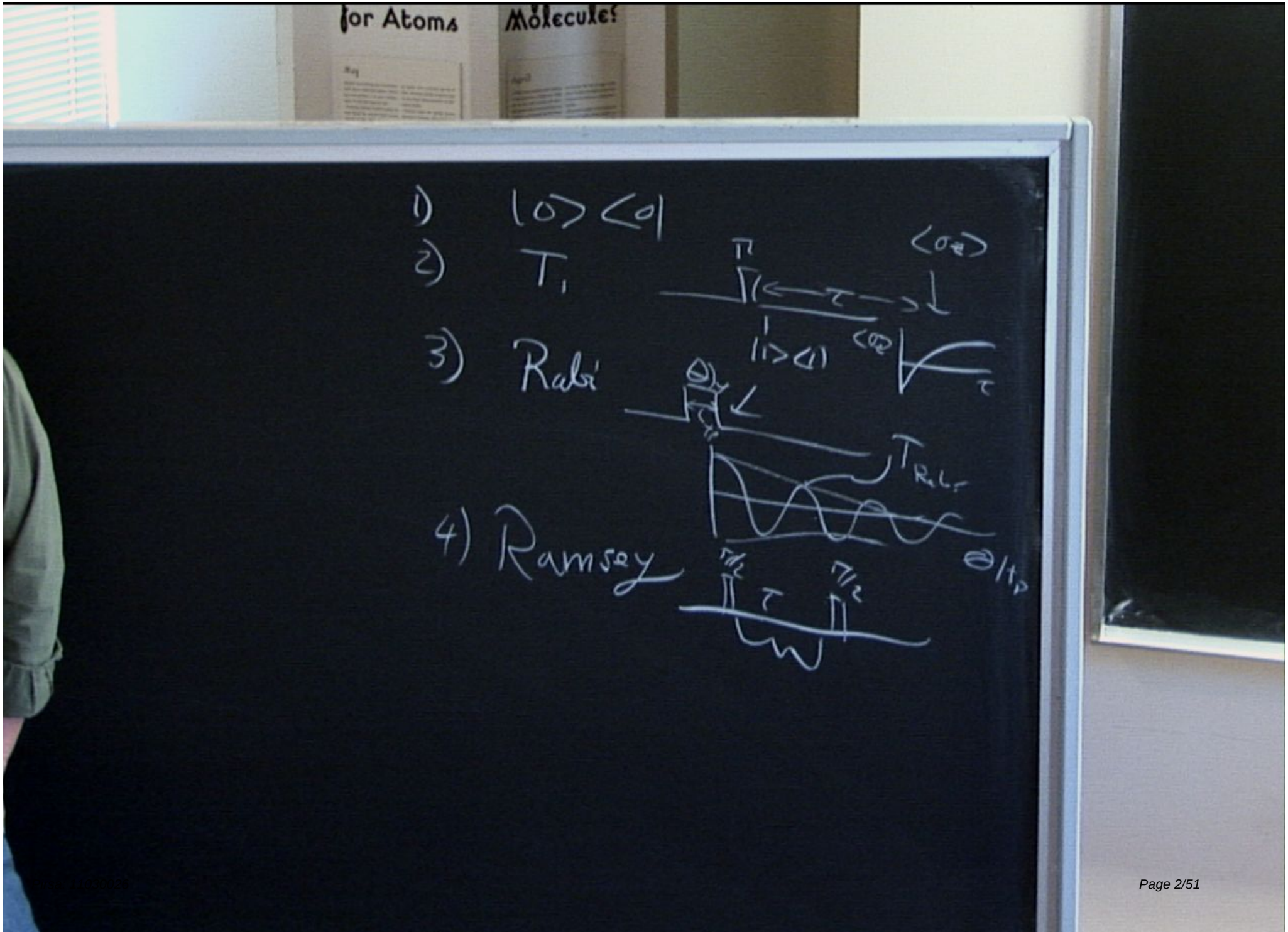
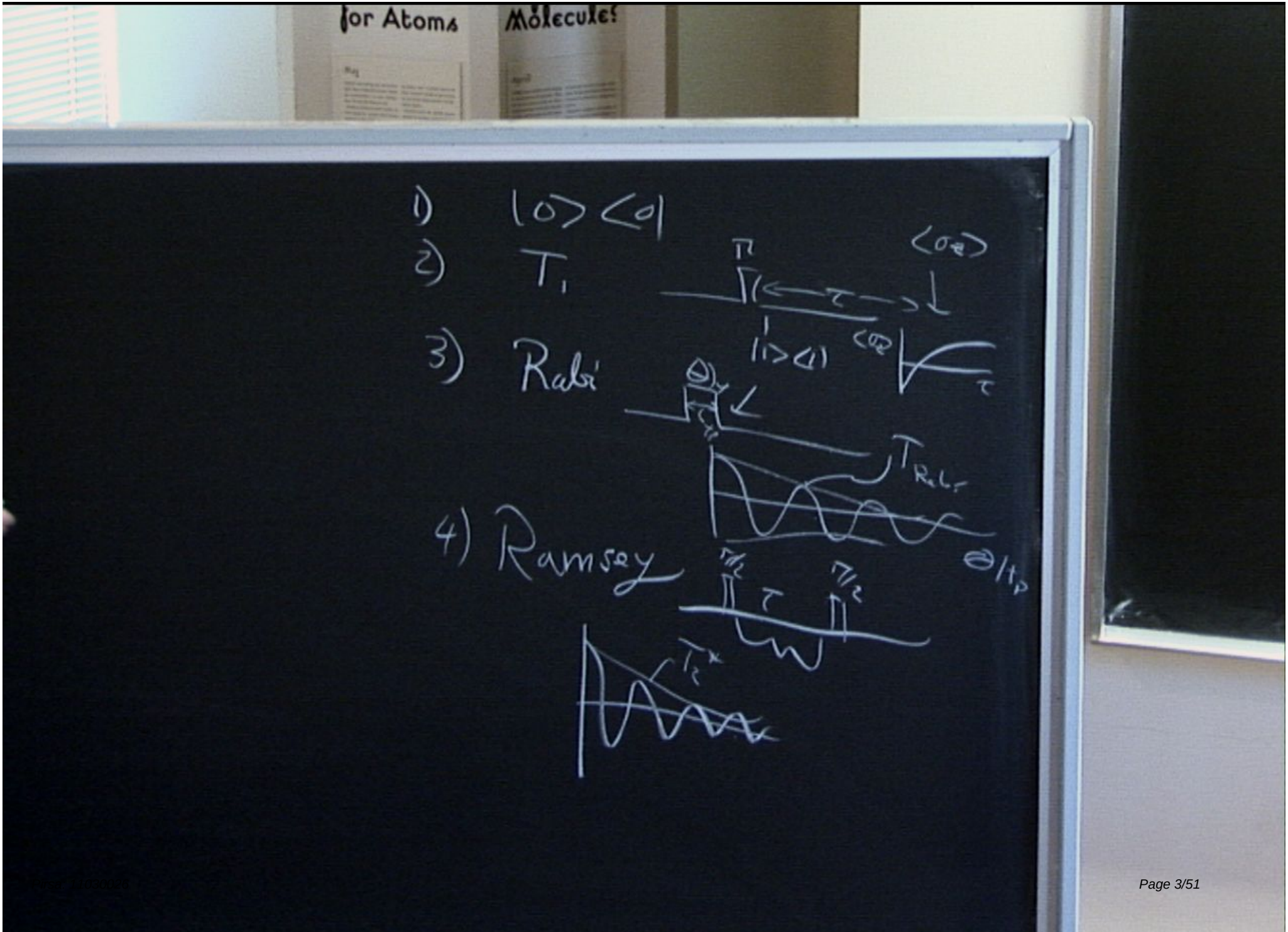
Title: Explorations in Quantum Information - Lecture 11

Date: Mar 29, 2011 09:00 AM

URL: http://pirsa.org/11030026

Abstract:


for Atoms
Molecule?
1) |0><0|
2) T1
3) Rabi
4) Ramsey


for Atoms
Molecule?
1) |0><0|
2) T1
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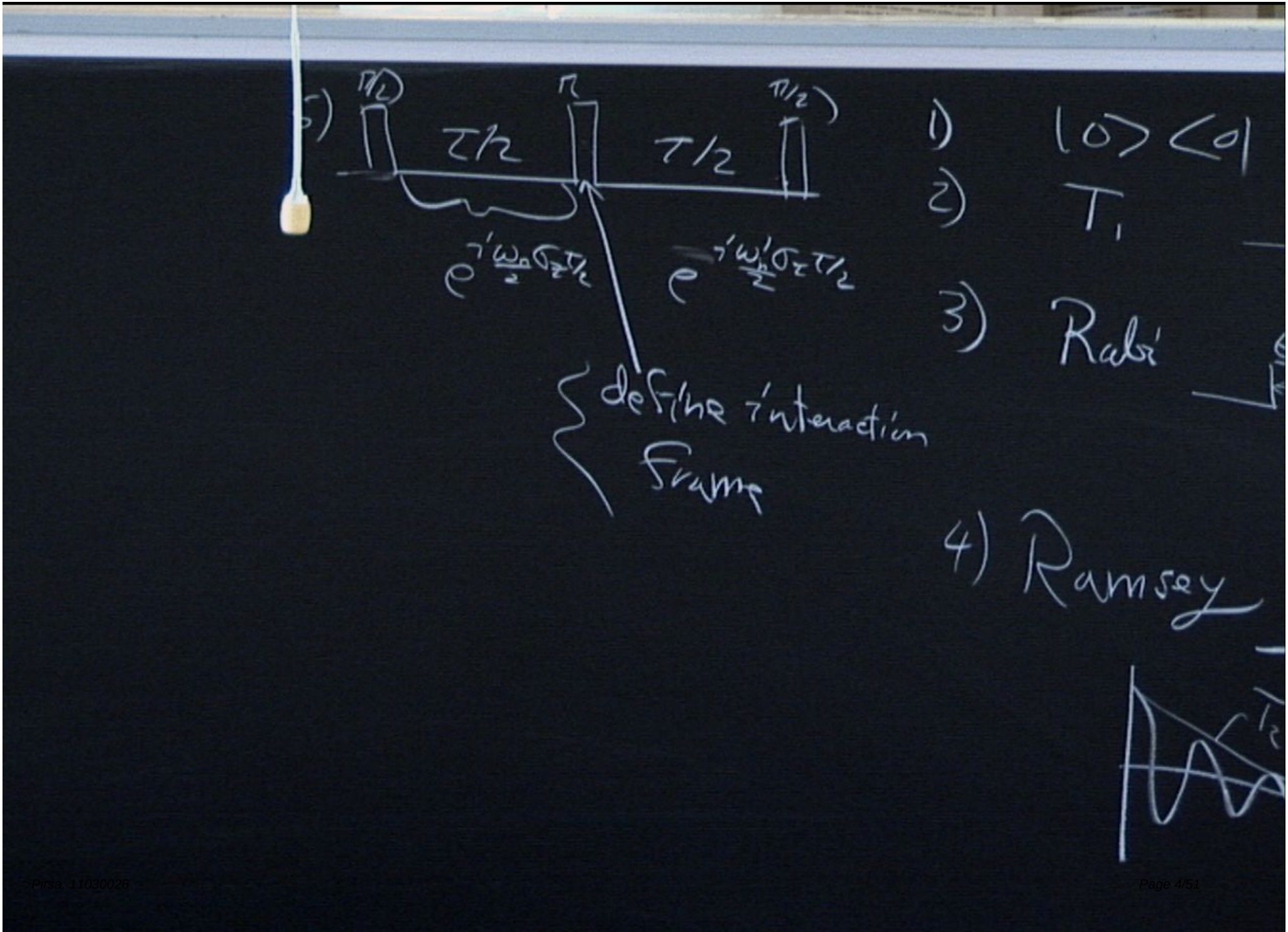
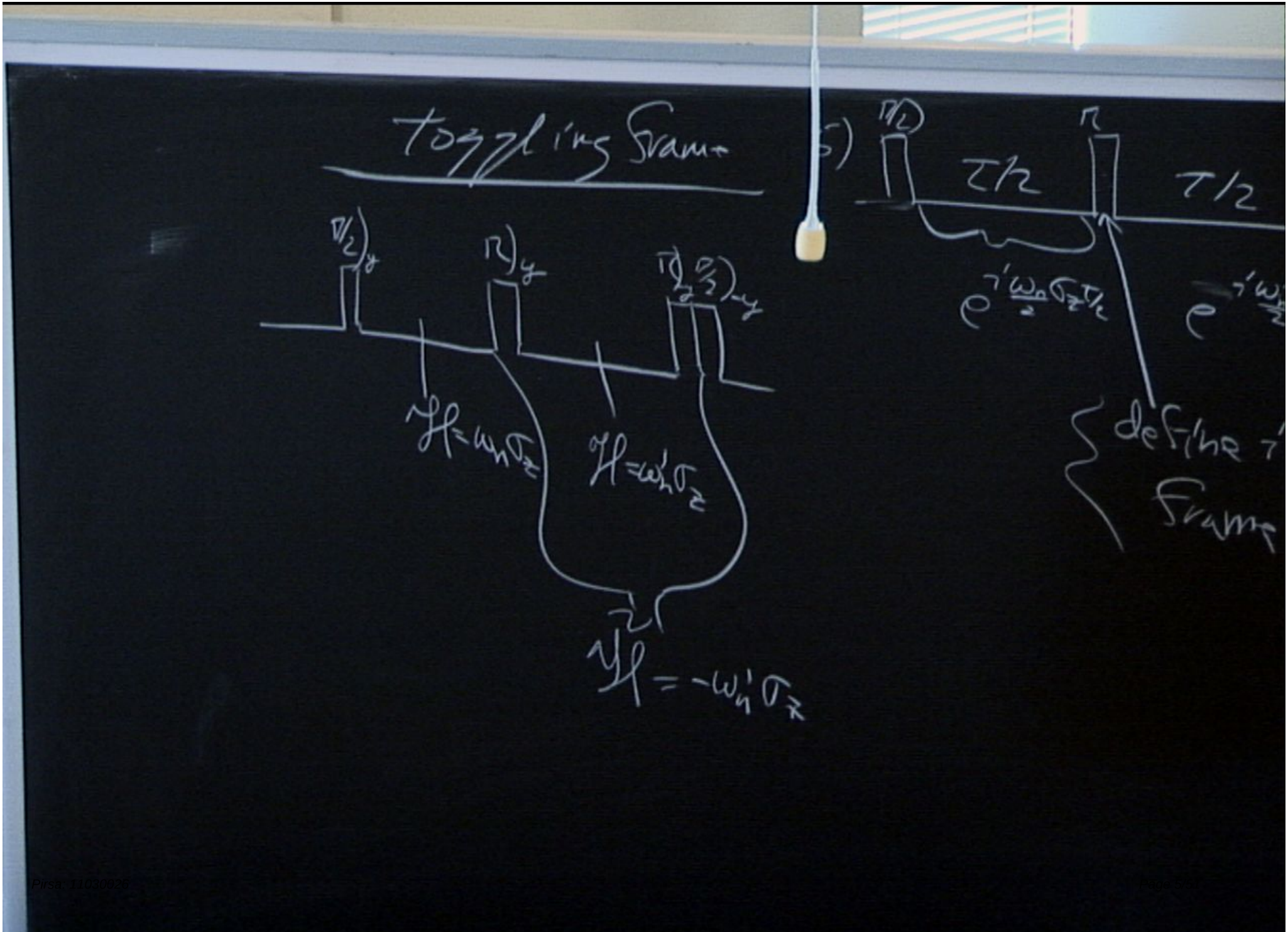
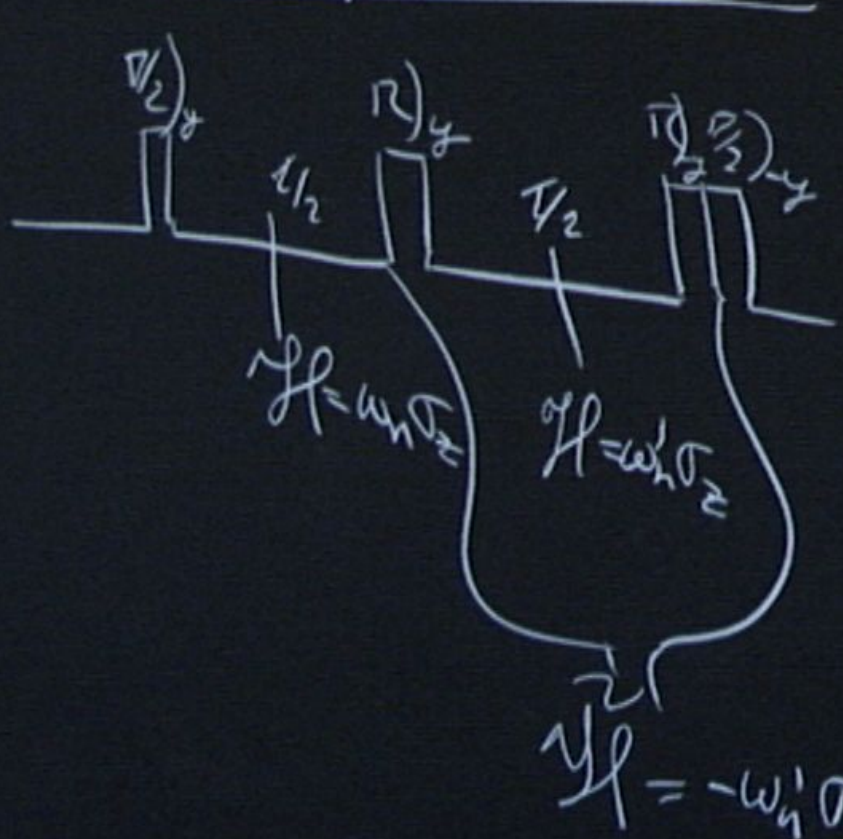
4) Ramsey


π/2
τ/2
π
τ/2
π/2
1) |0><0|
2) T1
3) Rabi
4) Ramsey
define interaction frame


Toggling Frame
π/2
τ/2
τ/2
define τ'
Frame

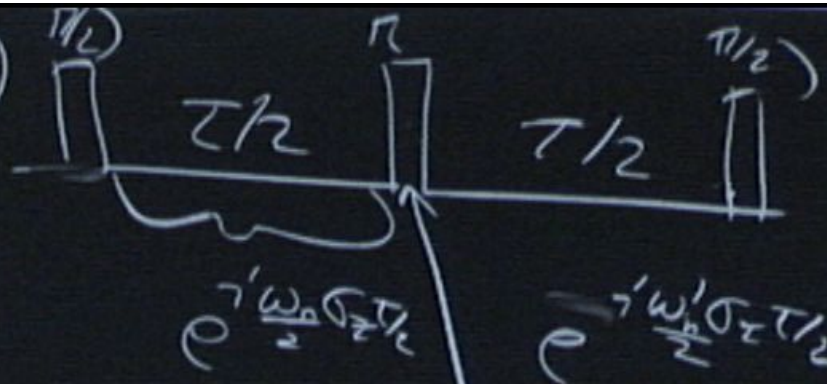
Toggling Frame



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

$\mathcal{H} = \omega_n' \sigma_z$

$\bar{\mathcal{H}} = -\omega_n' \sigma_z$



$e^{-i\frac{\omega_n}{2}\sigma_z \tau/2}$

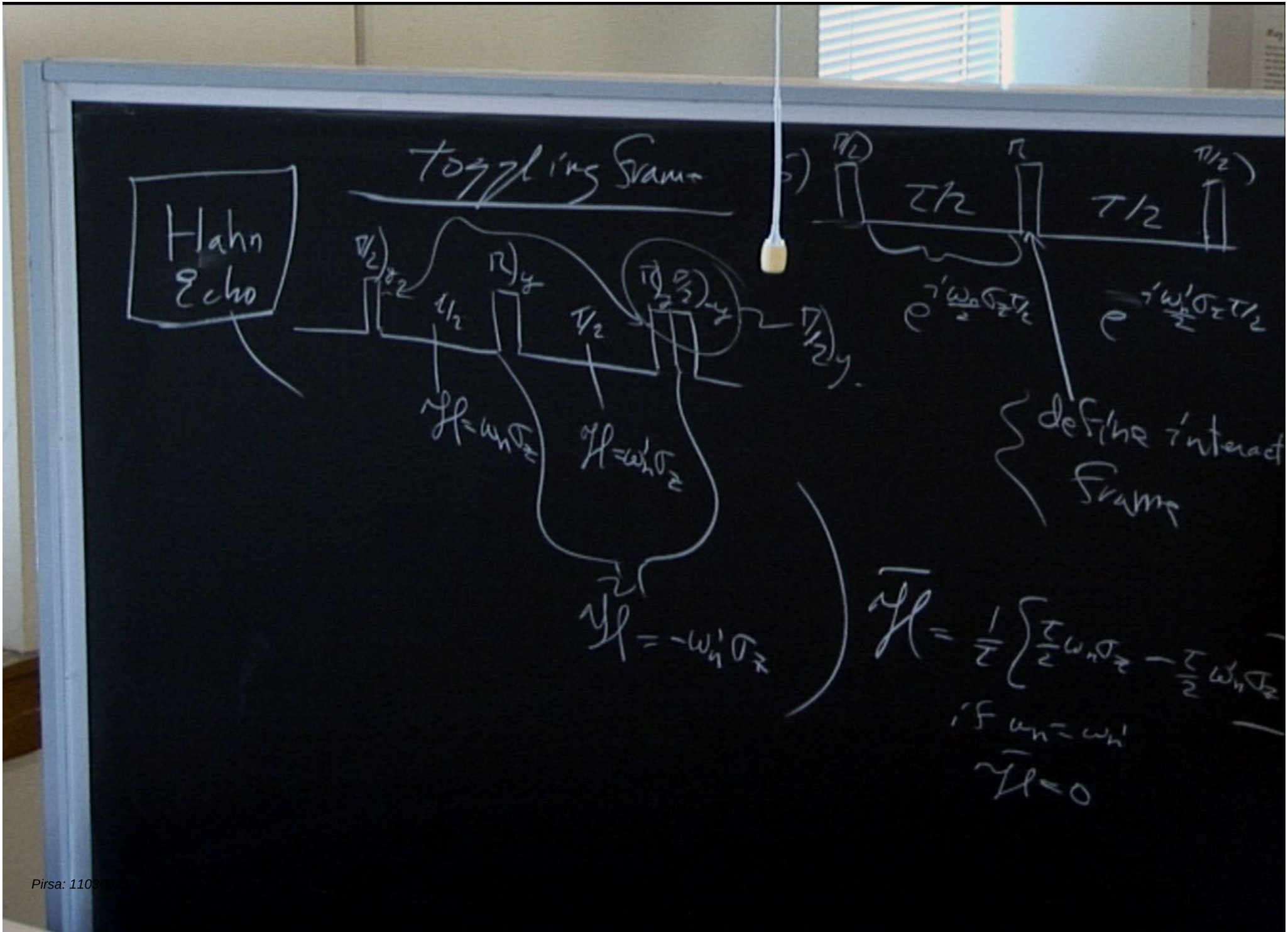
$e^{-i\frac{\omega_n'}{2}\sigma_z \tau/2}$

define interaction frame

$$\bar{\mathcal{H}} = \frac{1}{\tau}\left\{\frac{\tau}{2}\omega_n \sigma_z - \frac{\tau}{2}\omega_n \sigma_z\right\}$$

if $\omega_n = \omega_n'$

$\bar{\mathcal{H}} = 0$



$$\mathcal{H}_{int} = \omega_0 \sigma_z$$

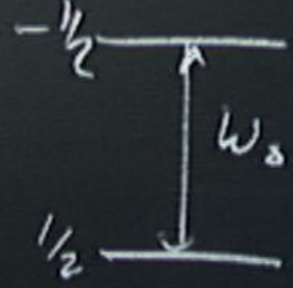
ω_0: 3 GHz

most important

$\mathcal{H}_{int} = \omega_0 \sigma_z$

ω_0

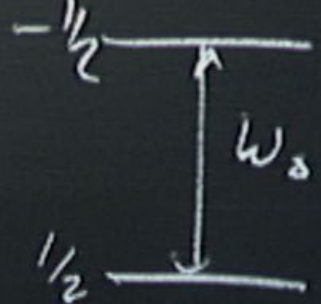
3 GHz



most important

$\mathcal{H}_{int} = \omega_0 \sigma_z$

3GHz

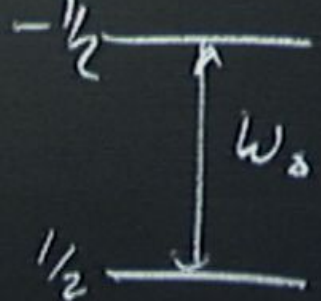


$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$

most important

$\mathcal{H}_{int} = \omega_0 \sigma_z$

3GHz



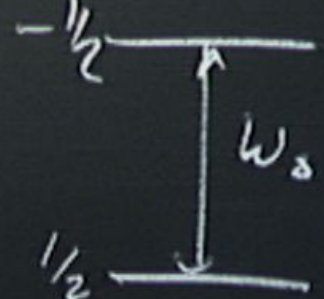
$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$

$e^{i\omega_0/2 t}$

most important

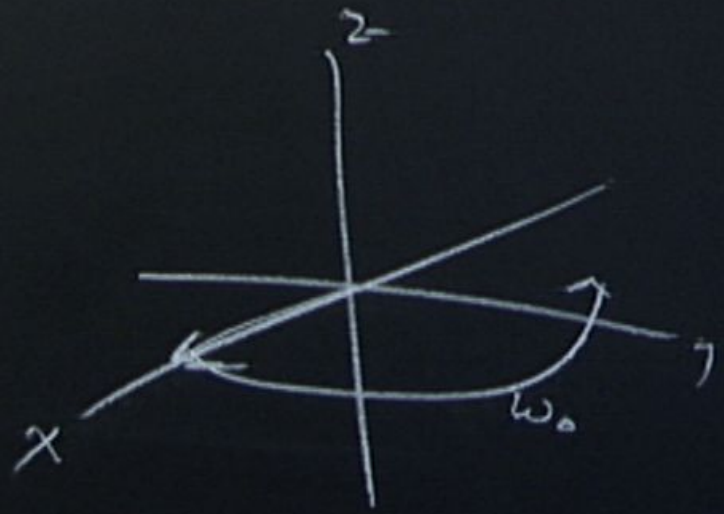
$\mathcal{H}_{int} = \omega_0 \sigma_z$

3GHz



$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$

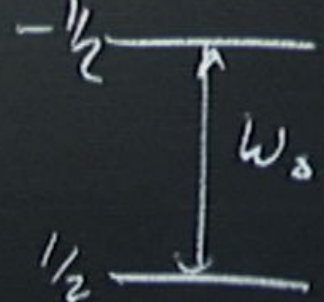
$e^{i\omega_0/2 t}$



most important

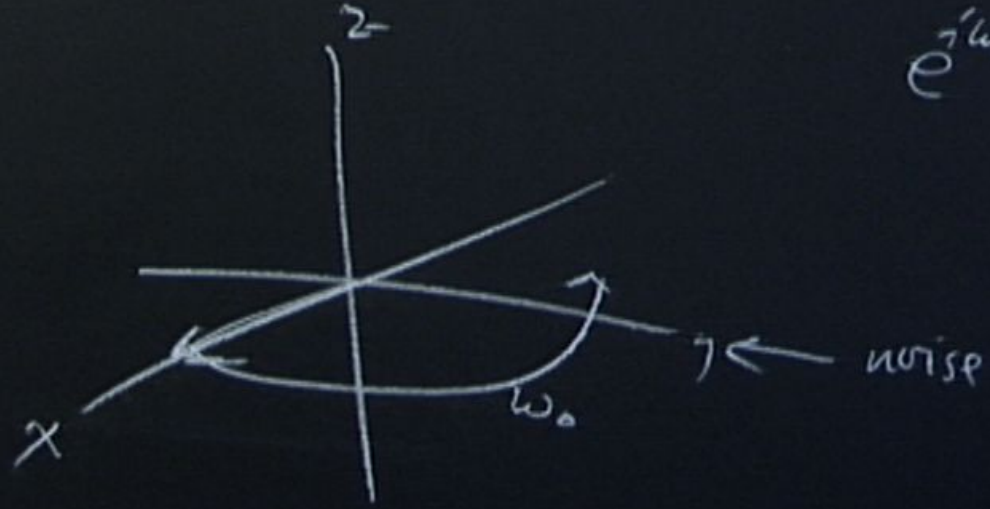
$\mathcal{H}_{int} = \omega_0 \sigma_z$

3GHz



$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$

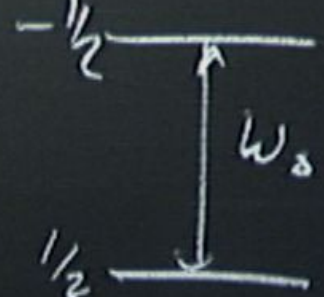
$e^{i\omega_0/2 t}$



most important

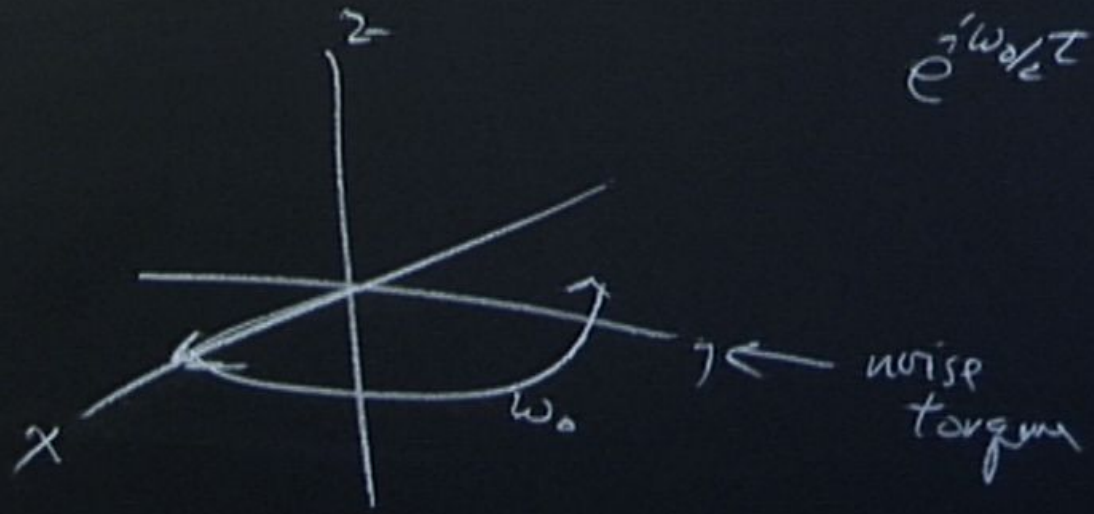
$\mathcal{H}_{int} = \omega_0 \sigma_z$

3GHz



$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$

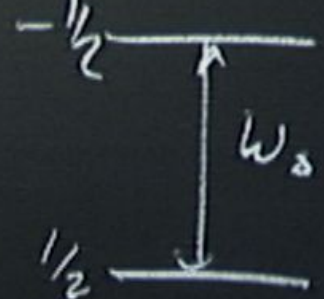
$e^{i\omega_0/2 t}$



most important

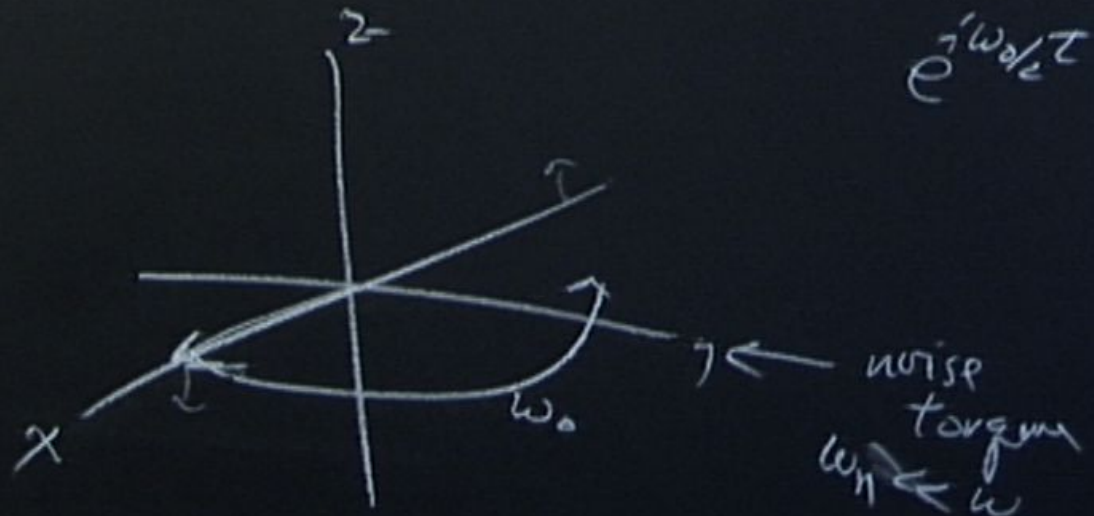
$\mathcal{H}_{int} = \omega_0 \sigma_z$

3GHz



$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$

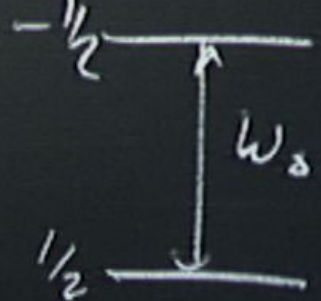
$e^{i\omega_0/2 t}$



most important

$\mathcal{H}_{int} = \omega_0 \sigma_z$

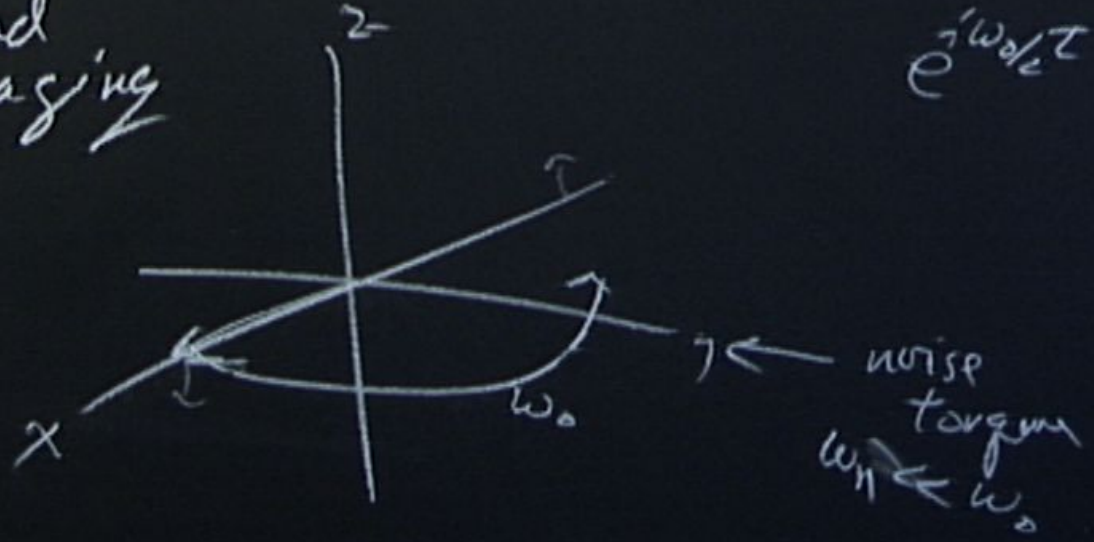
3GHz



$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$

$e^{i\omega_0/2 \tau}$

second averaging



noise

1) noise is DC along $\hat{z}$

most important

$\mathcal{H}_{int} = \omega_0 \sigma_z$

3GHz

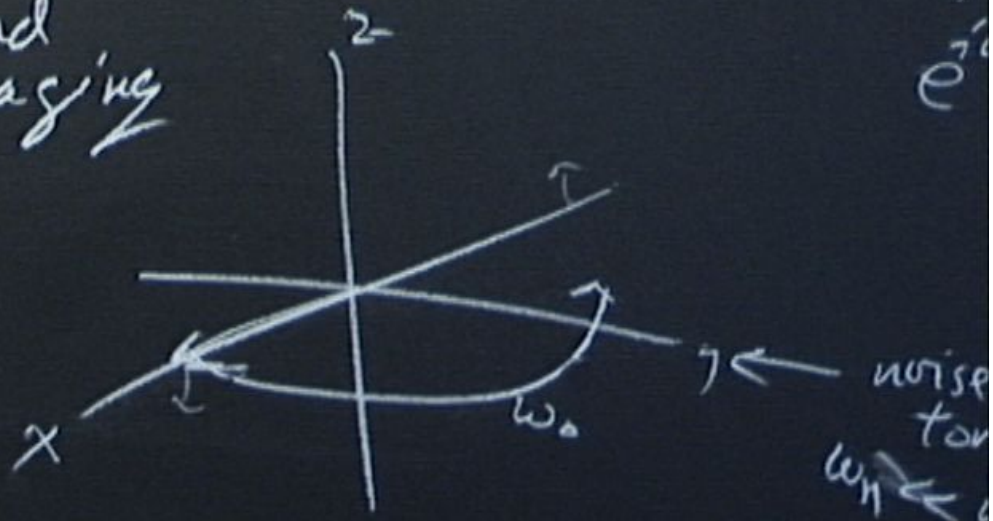
$-1/2$

ω_0

$1/2$

$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |$

second averaging



noise to

$\omega_n \ll$

noise

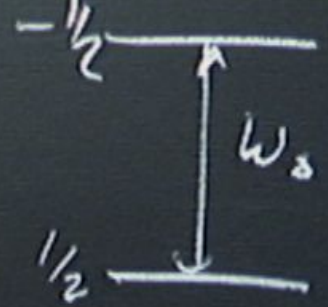
1) noise is DC along z

2) noise in xy plane @ freq. ω_0

most important

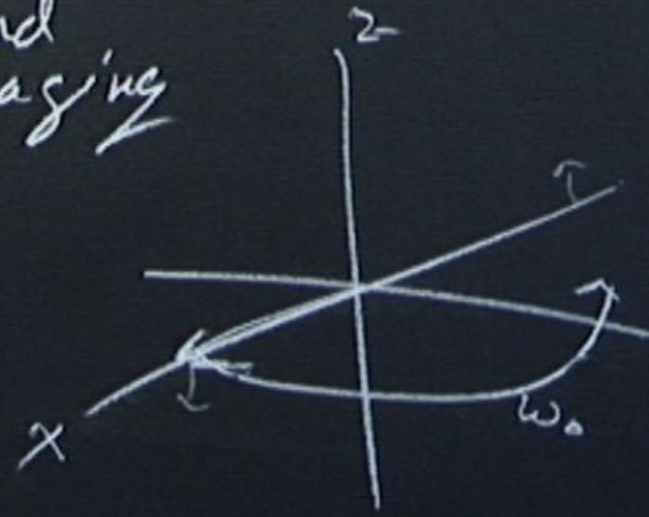
$\mathcal{H}_{int} = \omega_0 \sigma_z$

3GHz



$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |$

second averaging



noise

noise

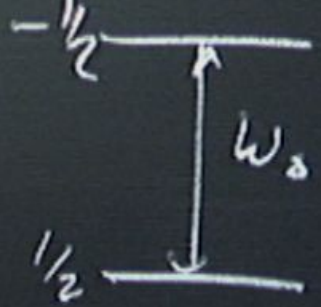
1) noise is DC along $\hat{z}$

2) noise in xy plane @ freq. ω_0

most important

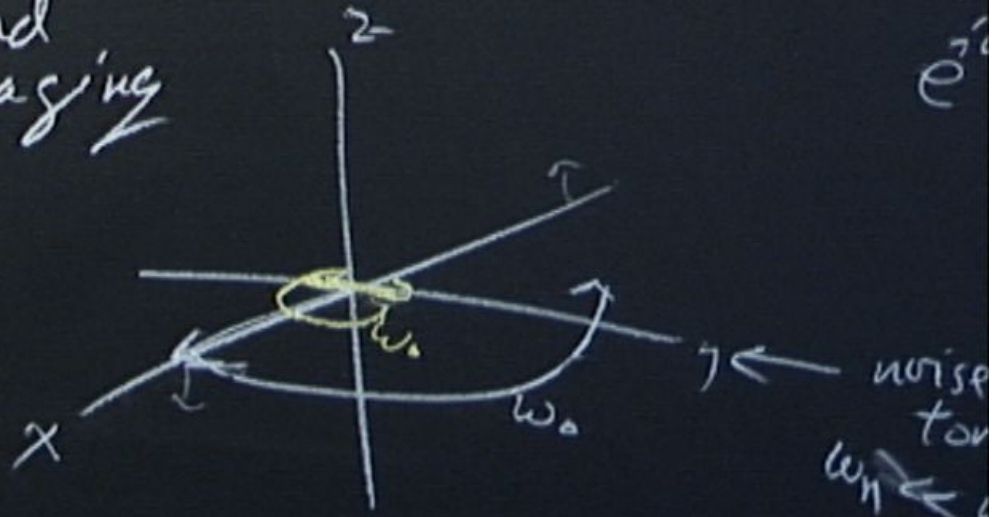
$\mathcal{H}_{int} = \omega_0 \sigma_z$

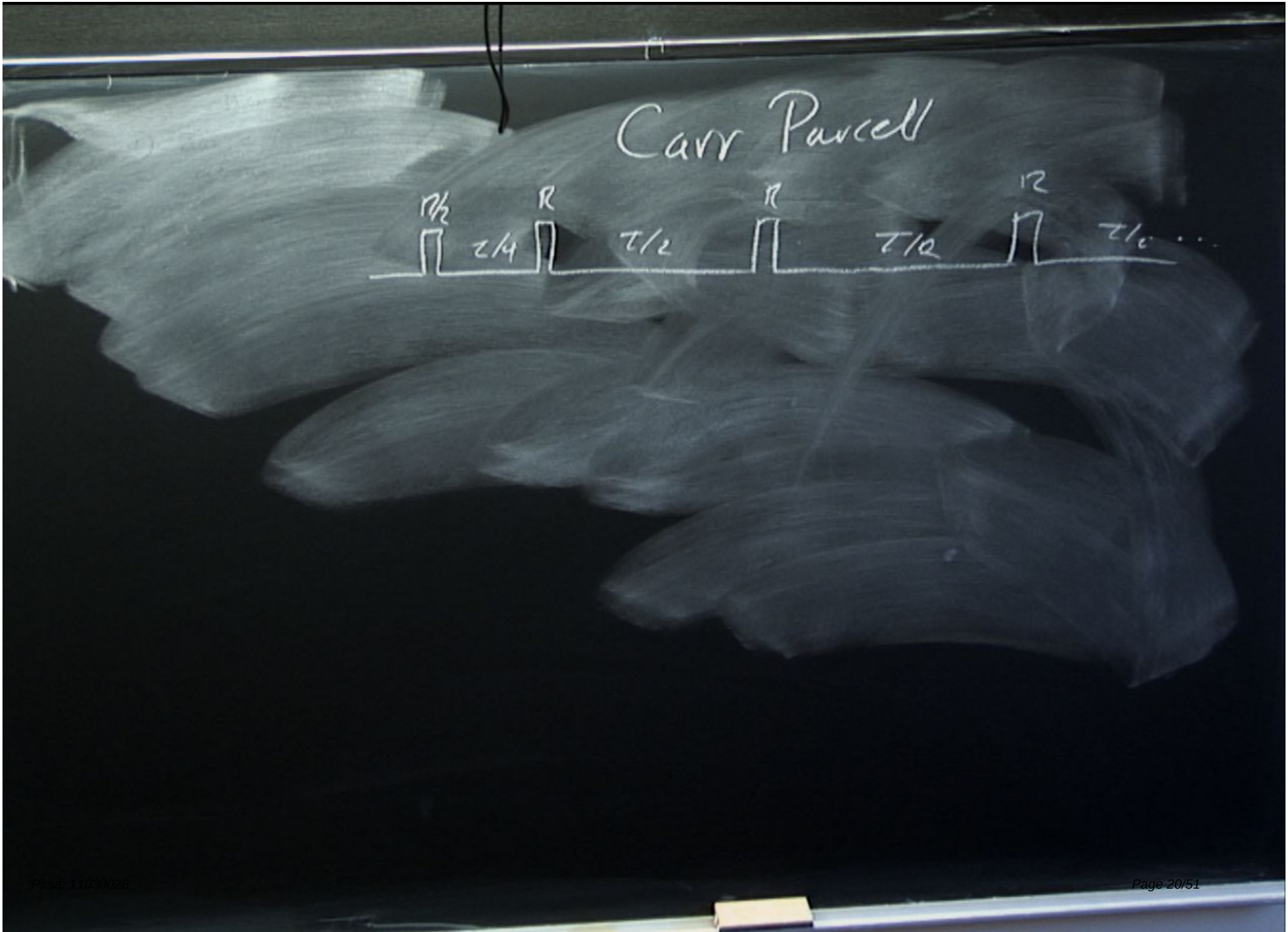
3GHz

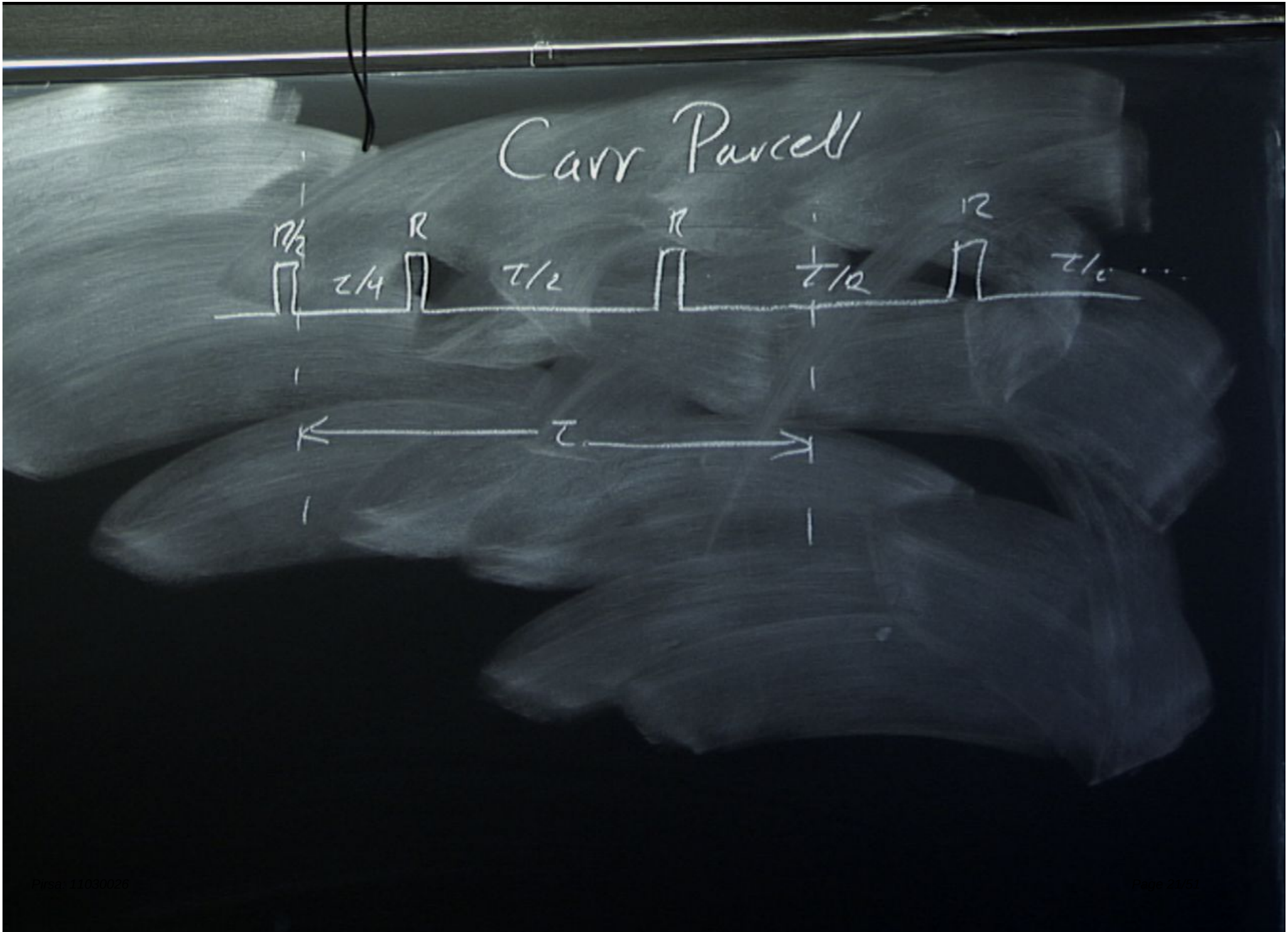


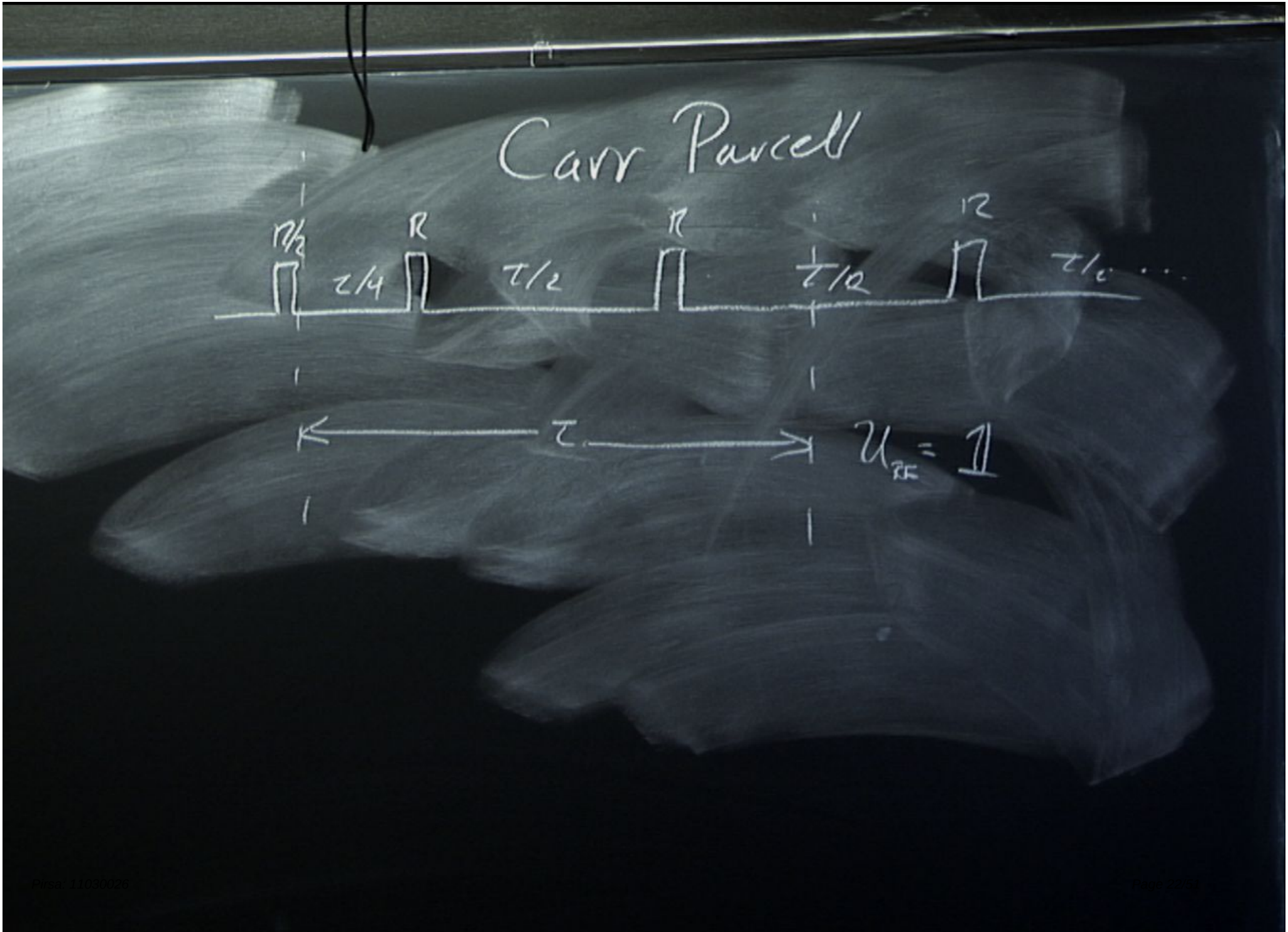
$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle +$

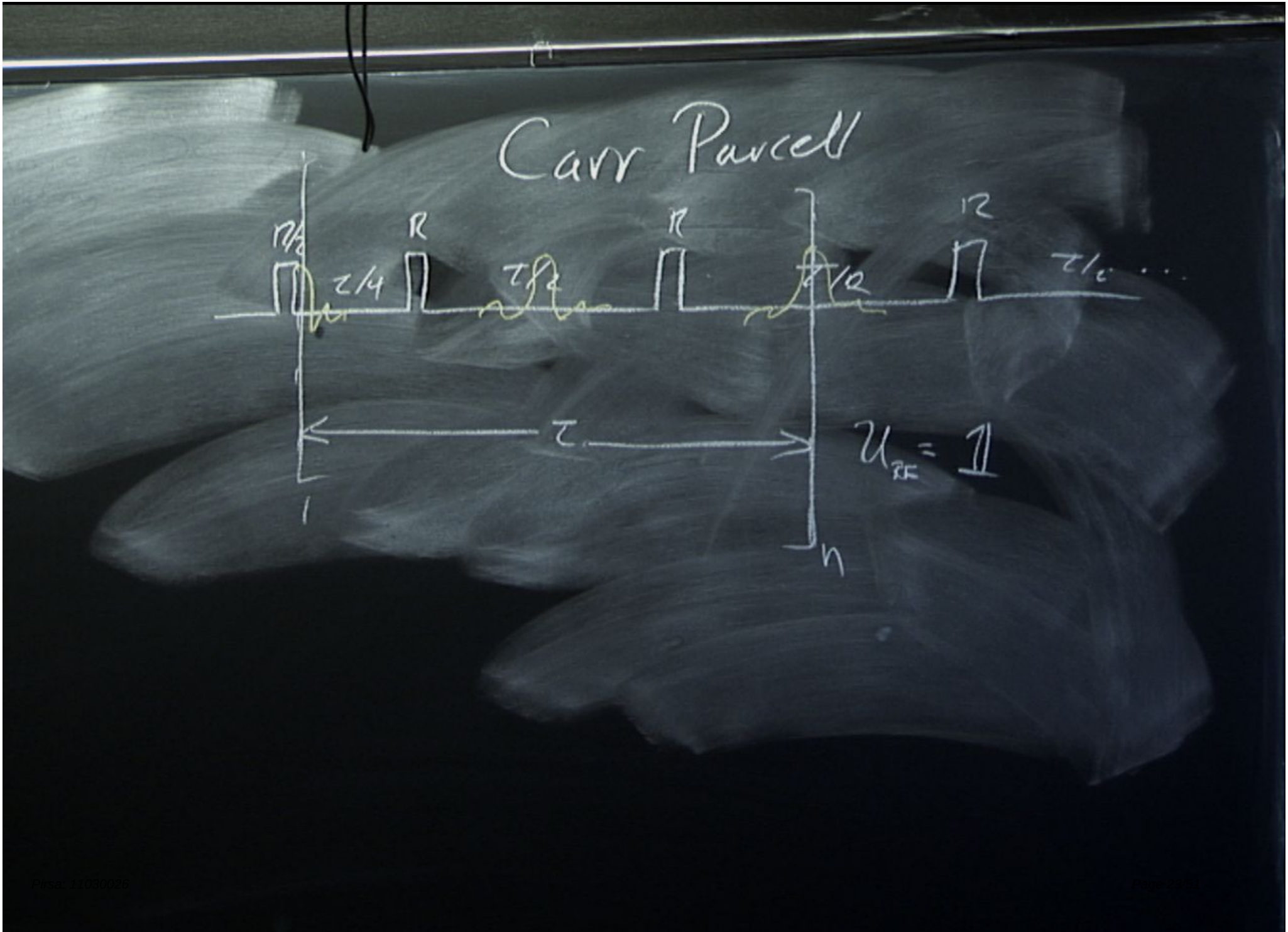
second averaging

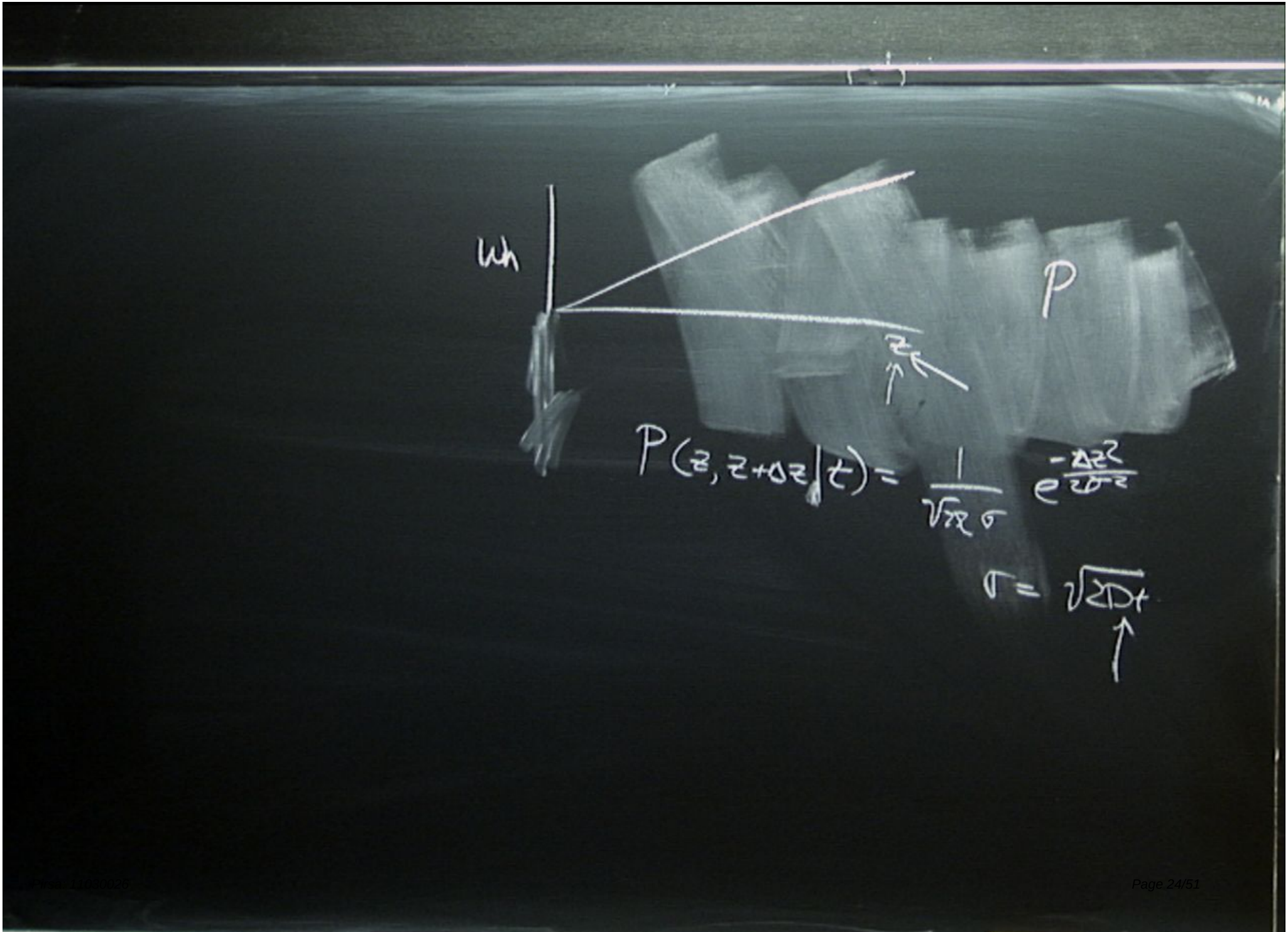


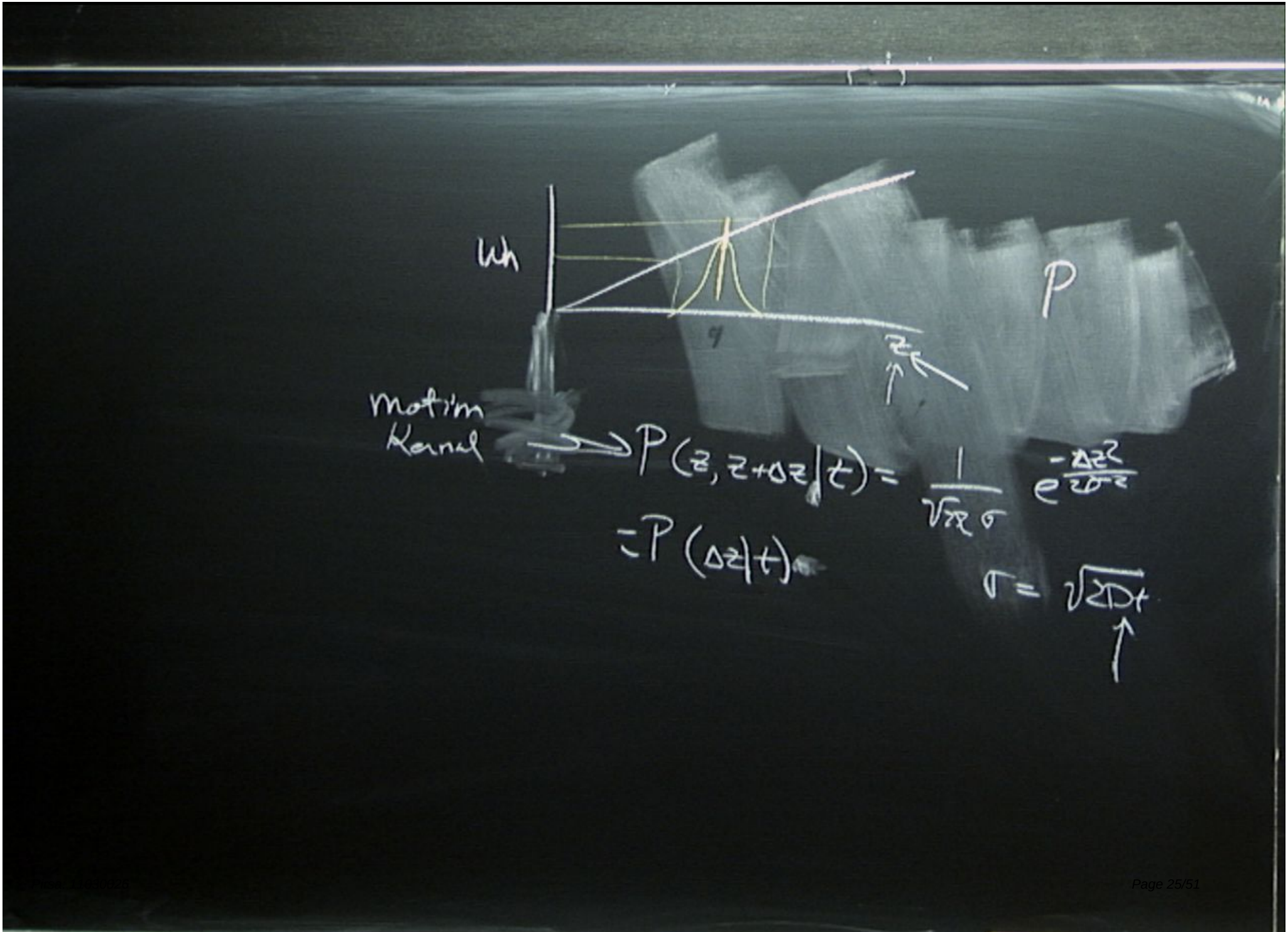

Carr Purcell
π/2
π
π
2π
τ/4
τ/2
τ/2
τ/2 ...

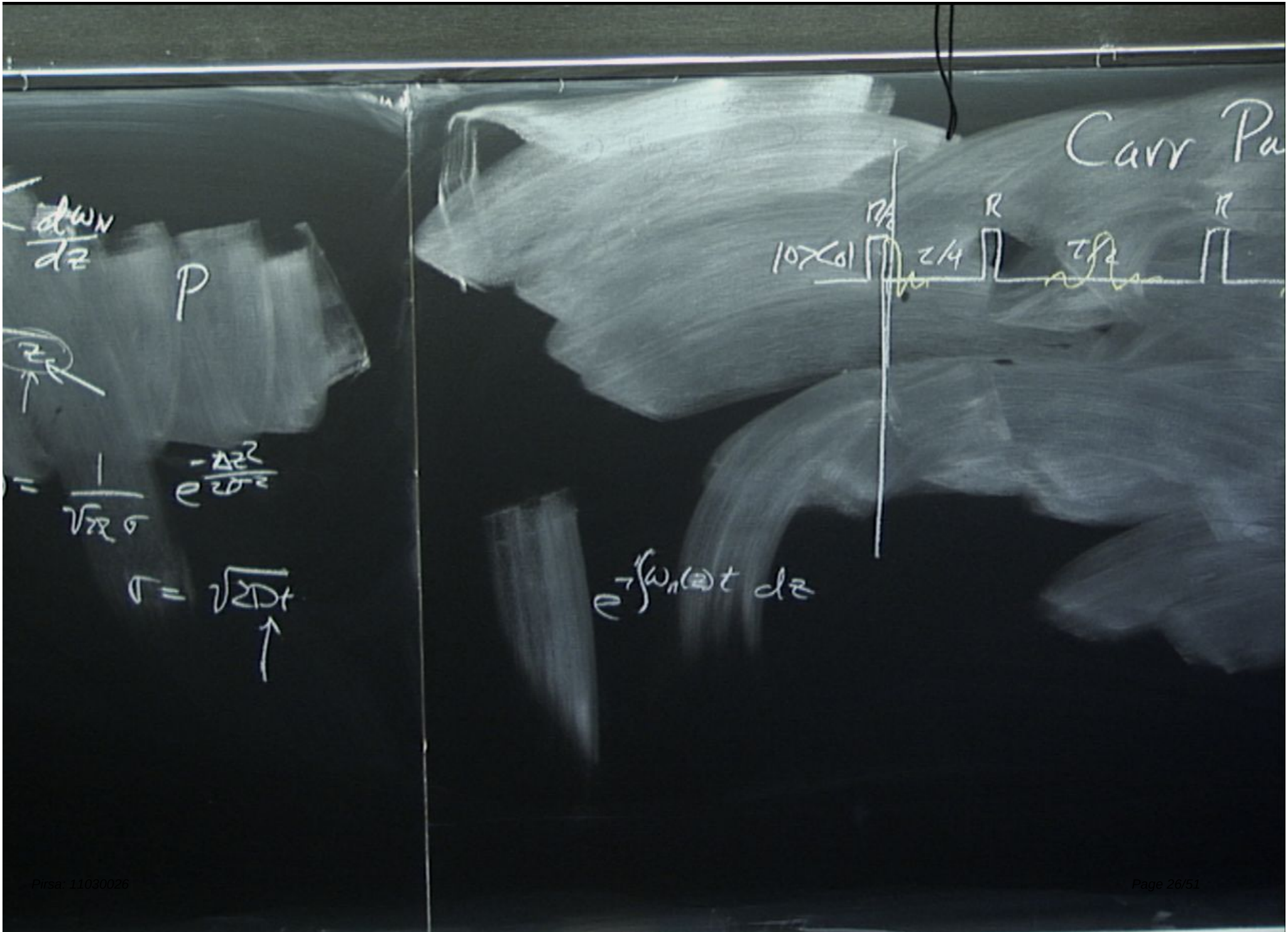

Carr Purcell
π/2
π
π
π
τ/4
τ/2
τ/2
τ/2
τ
τ

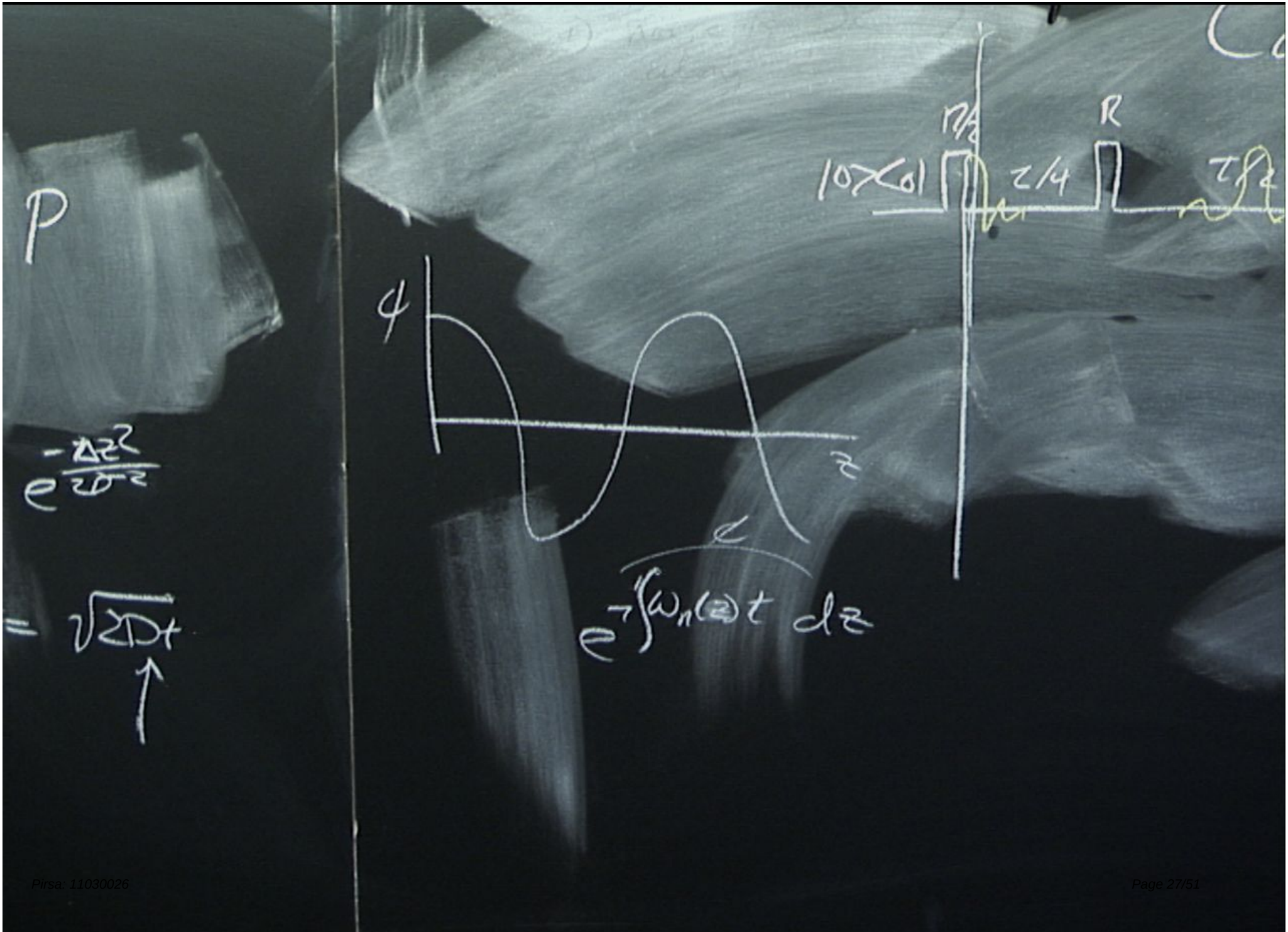

Carr Purcell
π/2
τ/4
π
τ/2
π
τ/2
π
τ/2 ...
τ
$U_{\pi} = \mathbb{1}$

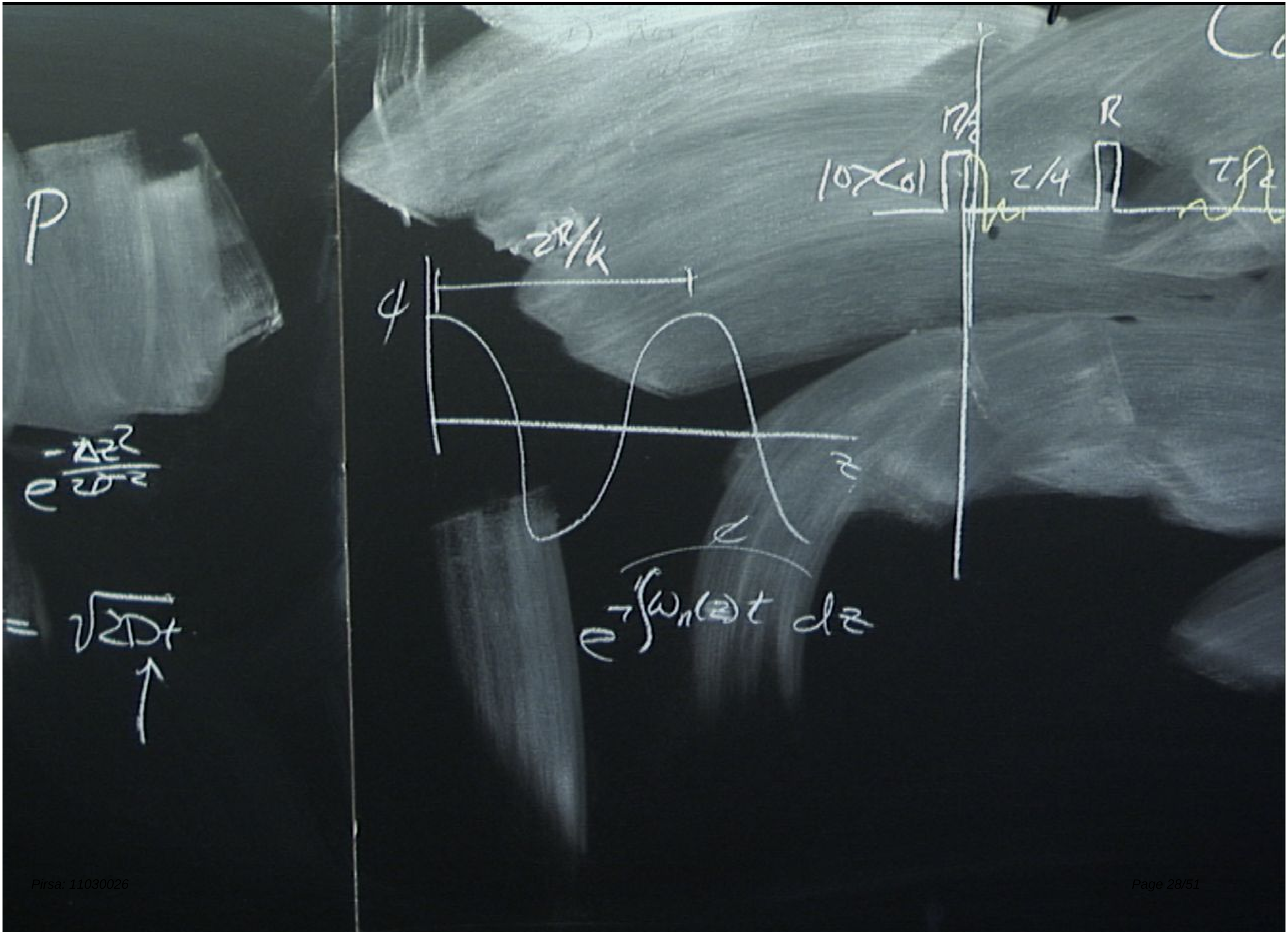

Carr Purcell
π/2
τ/4
π
τ
π
τ/2
π
τ/2
τ
$M_{z'} = 1$
1
n

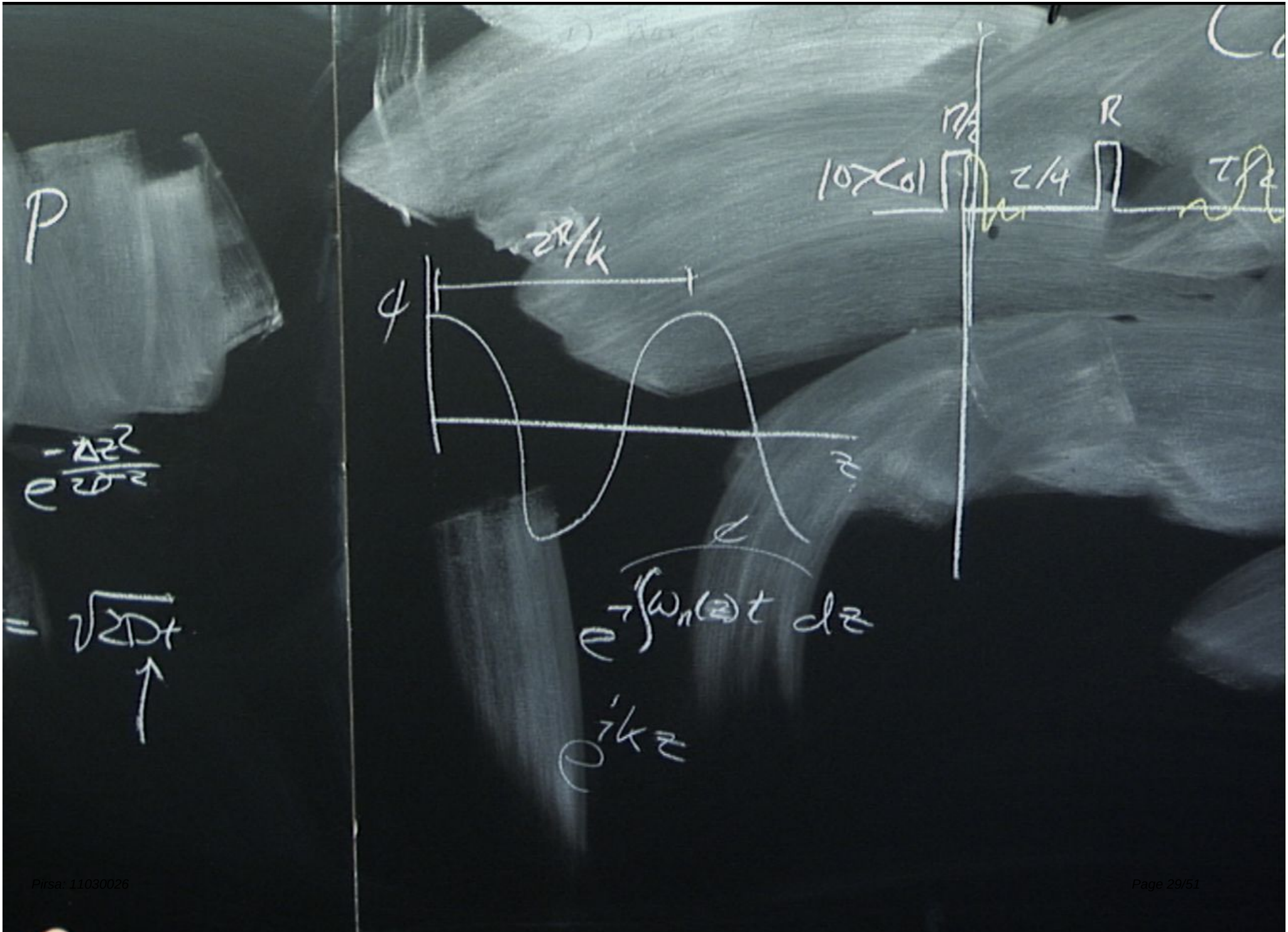

wh
P
z
P(z, z+Δz | t) = 1/√(2π) σ e^(-Δz²/2σ²)
σ = √(2Dt)

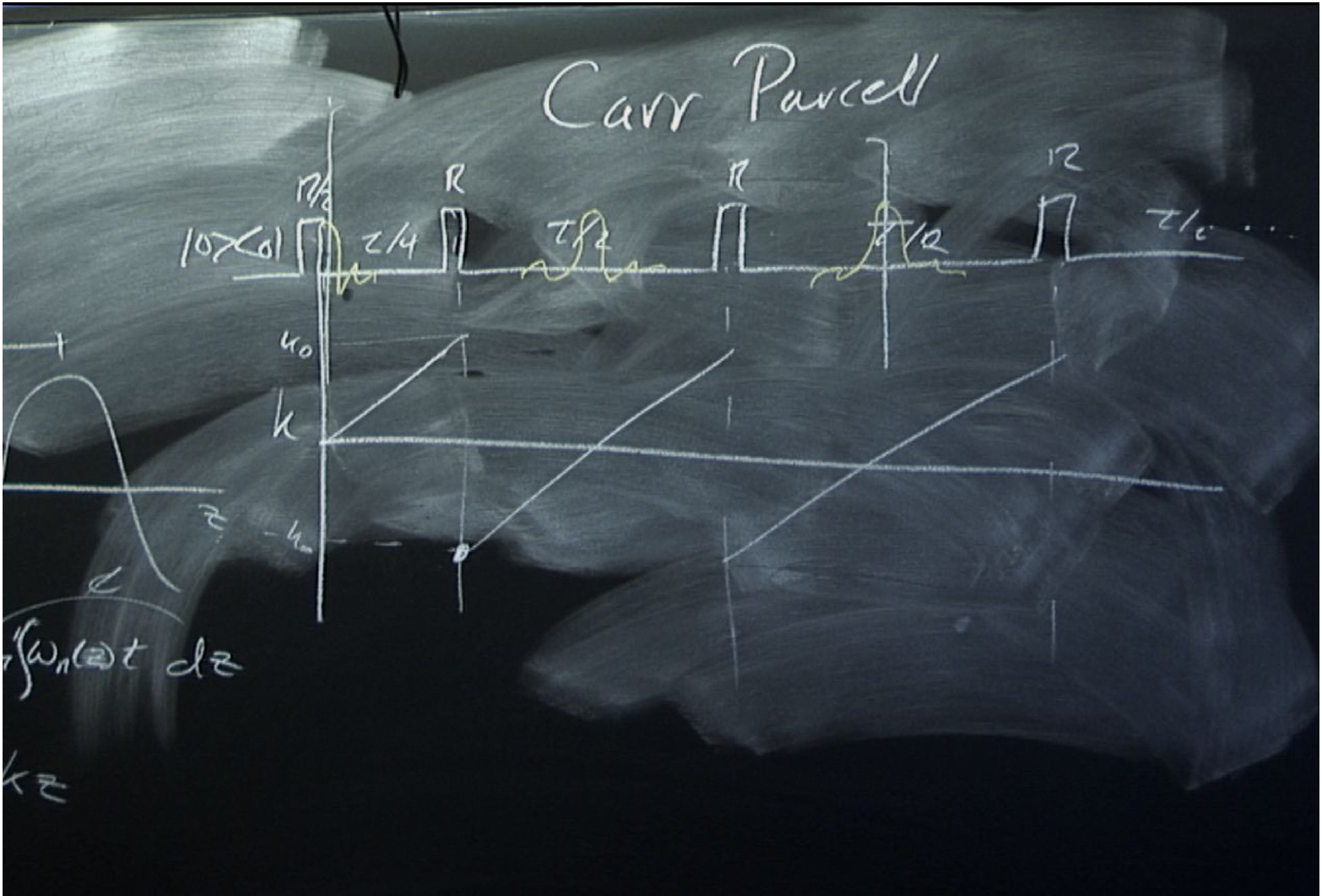

Wh
P
q
z
Motion
Kernel
$P(z, z+\Delta z \mid t) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-\Delta z^2}{2\sigma^2}}$
$= P(\Delta z \mid t)$
$\sigma = \sqrt{2Dt}$

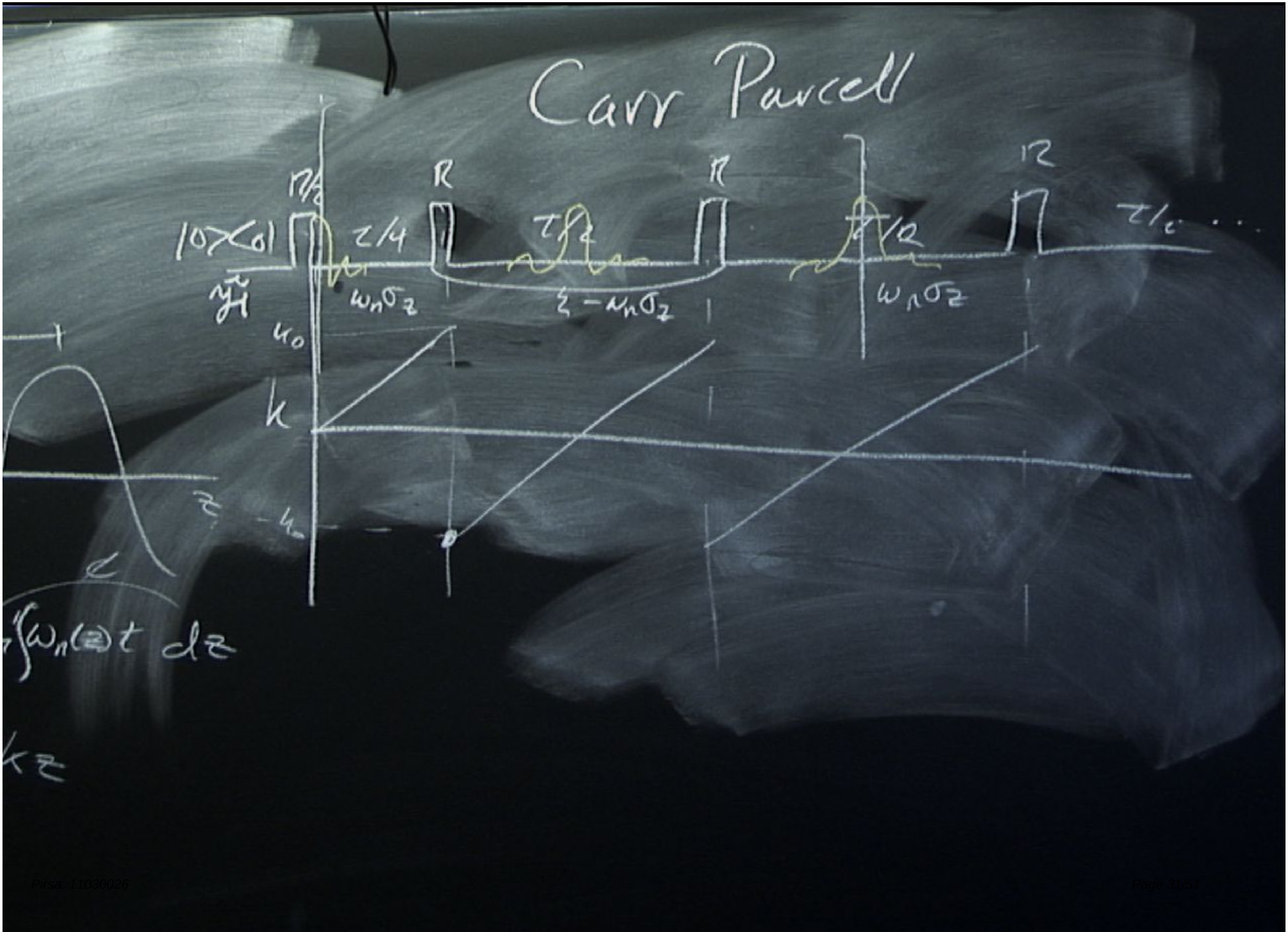

Carr Pu
π/2
π
π
10×01
τ/4
τ/2
P
$\frac{dw_N}{dz}$
$= \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-\Delta z^2}{2\sigma^2}}$
$\sigma = \sqrt{2Dt}$
$e^{-\gamma \int \omega_n(z) t \, dz}$


P
$e^{\frac{-\Delta z^2}{2\sigma^2}}$
$= \sqrt{2Dt}$
ψ
z
$e^{-\int \omega_n(z)\, t\, dz}$
R
z/4

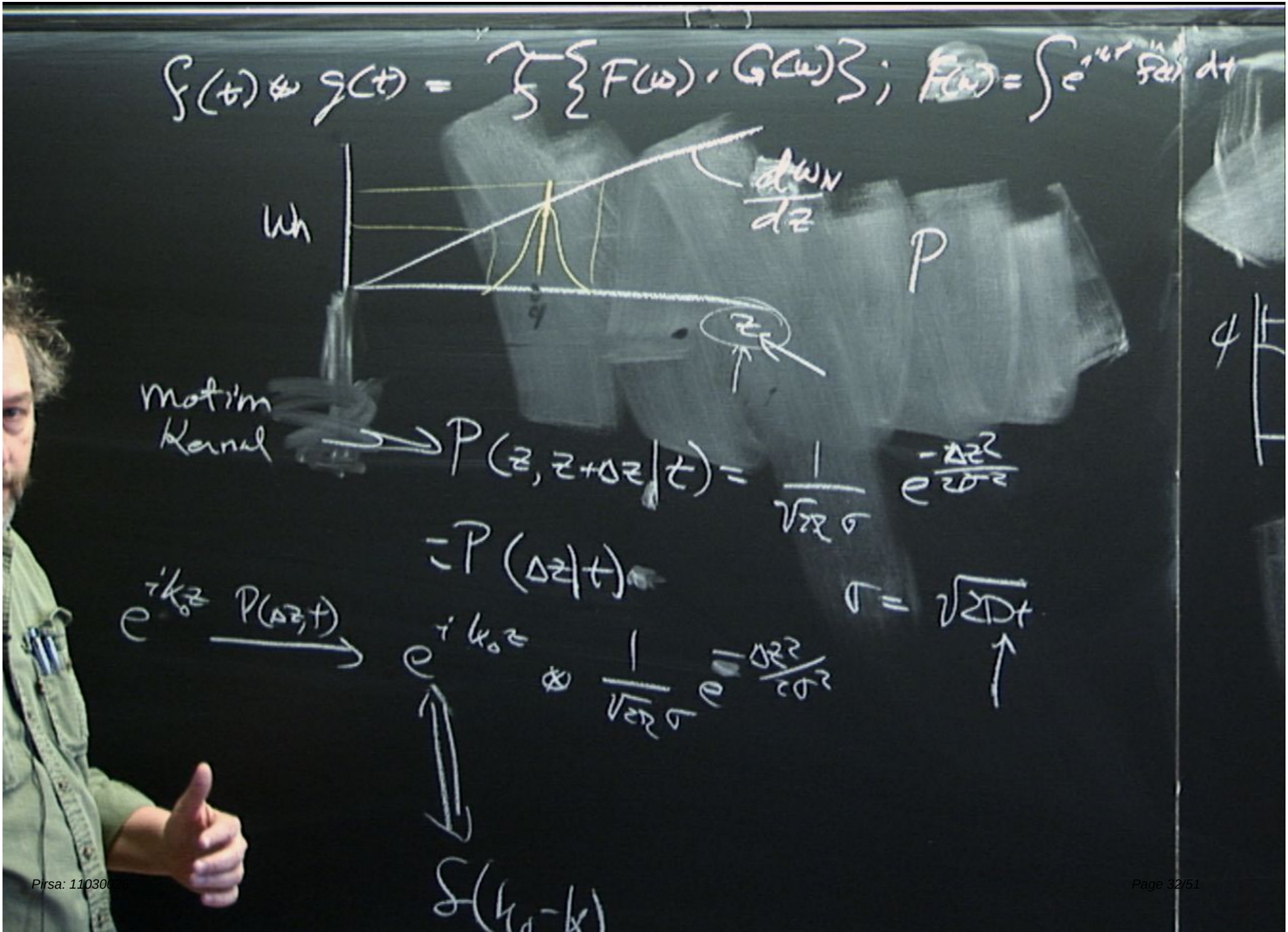

P
= √2Dt
10><01
τ/4
R
2π/k
z
e^{-∫ω_n(z) t dz}


P
$e^{\frac{-\Delta z^2}{2\sigma^2 z}}$
$= \sqrt{2Dt}$
$2\pi/k$
ψ
z
$e^{-\int \omega_n(z) t \, dz}$
e^{ikz}
R
$2\pi/k$

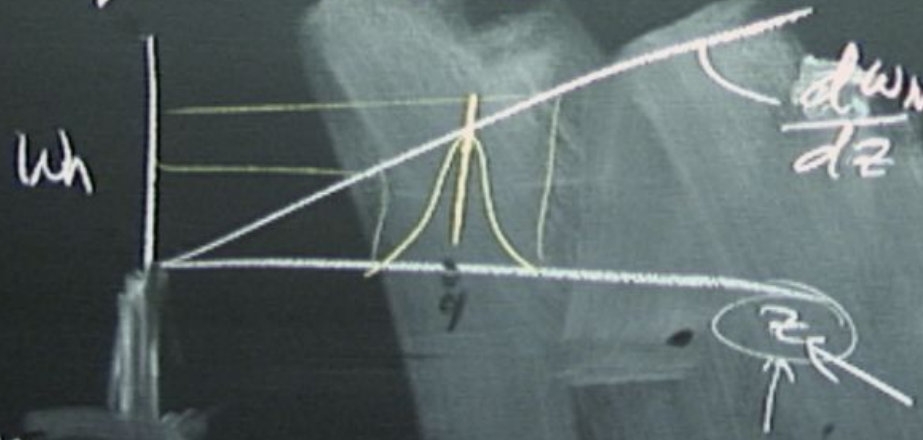

Carr Purcell
R
R
R



Carr Purcell
π/2
π
π
π
|0⟩⟨0|
τ/4
τ/2
τ/2
τ/2
ω_n σ_z
-ω_n σ_z
ω_n σ_z
k_0
k
z
-k_0
∫ω_n(z)t dz
kz


$f(t) \otimes g(t) = \mathcal{F}^{-1}\{F(\omega) \cdot G(\omega)\}$; $F(\omega) = \int e^{-i\omega t} f(t)\, dt$
$\frac{dw_N}{dz}$
w_h
P
z_r
Motim Kanul
$P(z, z+\Delta z \mid t) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-\Delta z^2}{2\sigma^2}}$
$= P(\Delta z \mid t)$
$\sigma = \sqrt{2Dt}$
$e^{-ik_0 z}$ $P(\Delta z, t)$
$e^{-ik_0 z} \otimes \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-\Delta z^2}{2\sigma^2}}$
$\delta(k_0 - k)$

$f(t) * g(t) = \mathcal{F}^{-1}\{F(\omega) \cdot G(\omega)\}$; $F(\omega) = \int e^{-i\omega t} f(t)\, dt$



Motion Kernel $\Rightarrow P(z, z+\Delta z \mid t) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-\Delta z^2}{2\sigma^2}}$

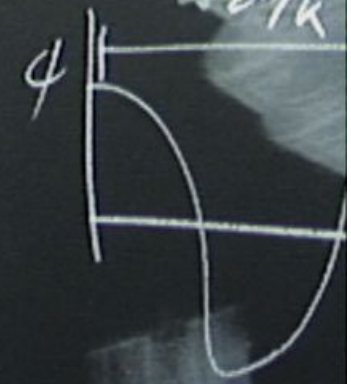
$= P(\Delta z \mid t)$

$\sigma = \sqrt{2Dt}$

$e^{ik_0 z}\ P(\Delta z, t) \longrightarrow e^{ik_0 z} * \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-\Delta z^2}{2\sigma^2}}$

$\delta(k_0 - k)\ e^{-\frac{k_0^2 \sigma^2}{2}}$

$f(t) * g(t) = \mathcal{F}^{-1}\{F(\omega) \cdot G(\omega)\}$; $F(\omega) = \int e^{-i\omega t} f(t)\, dt$



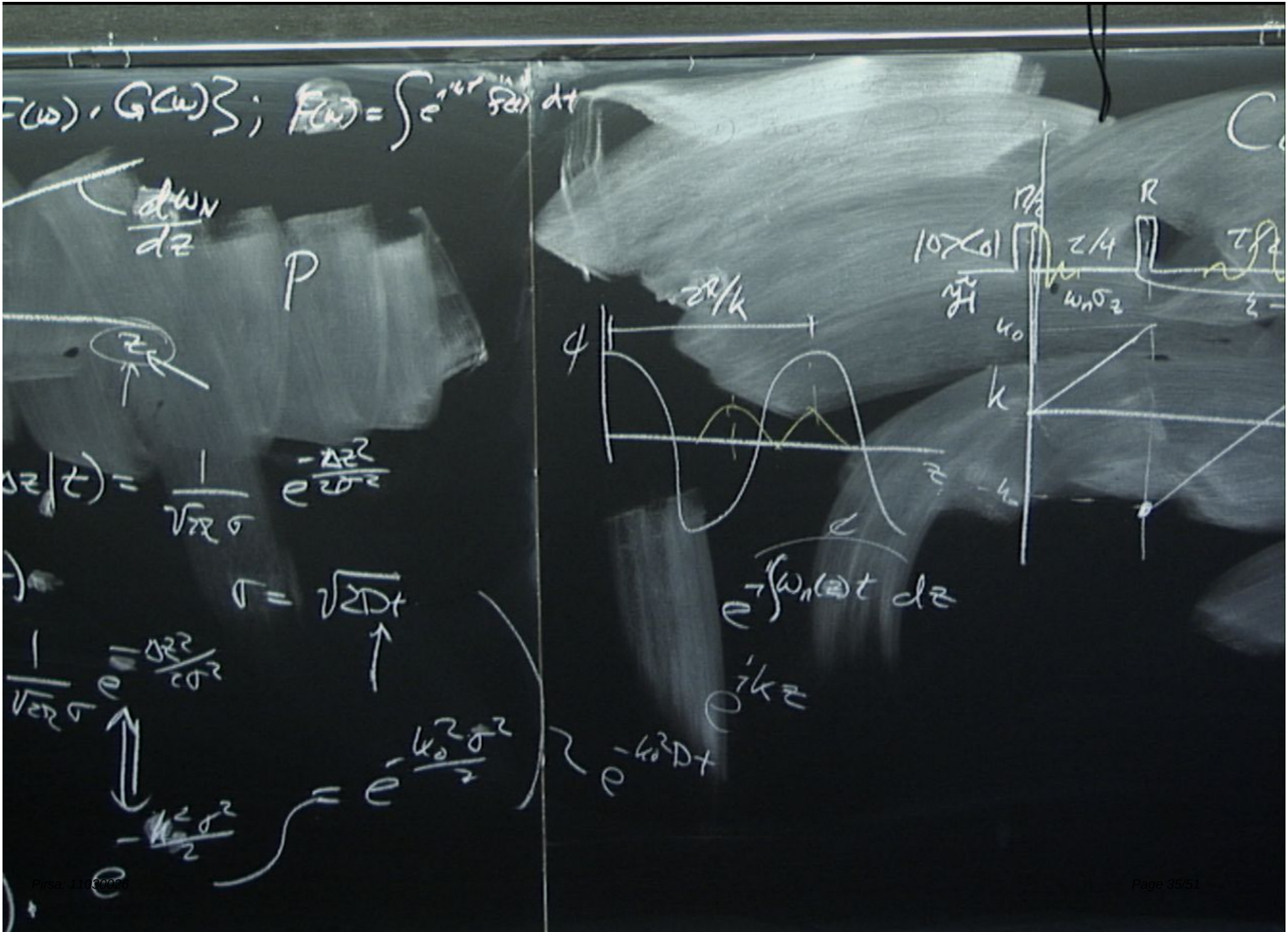
Motion Kernel $\Rightarrow P(z, z+\Delta z \mid t) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-\Delta z^2}{2\sigma^2}}$

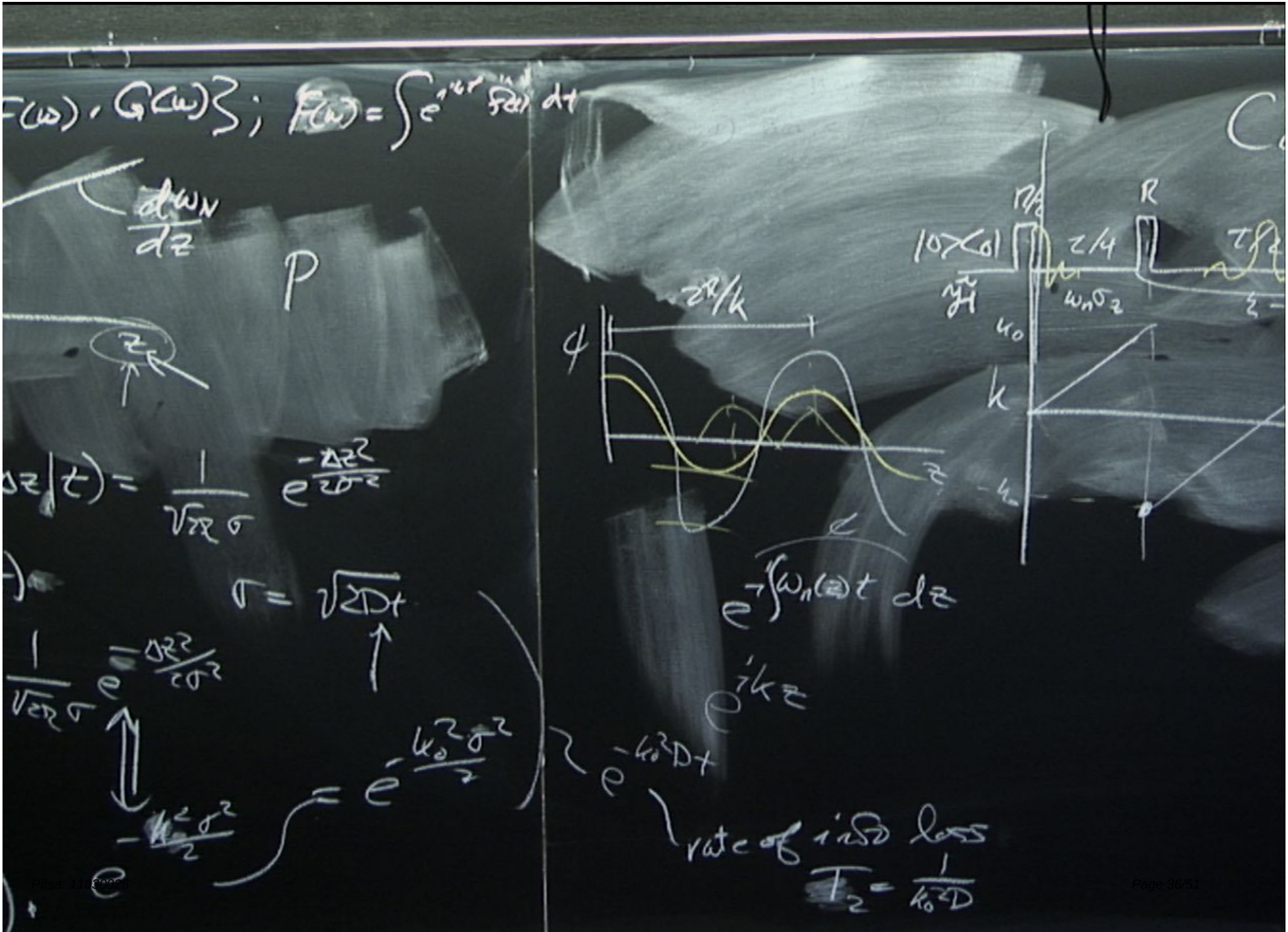
$= P(\Delta z \mid t)$

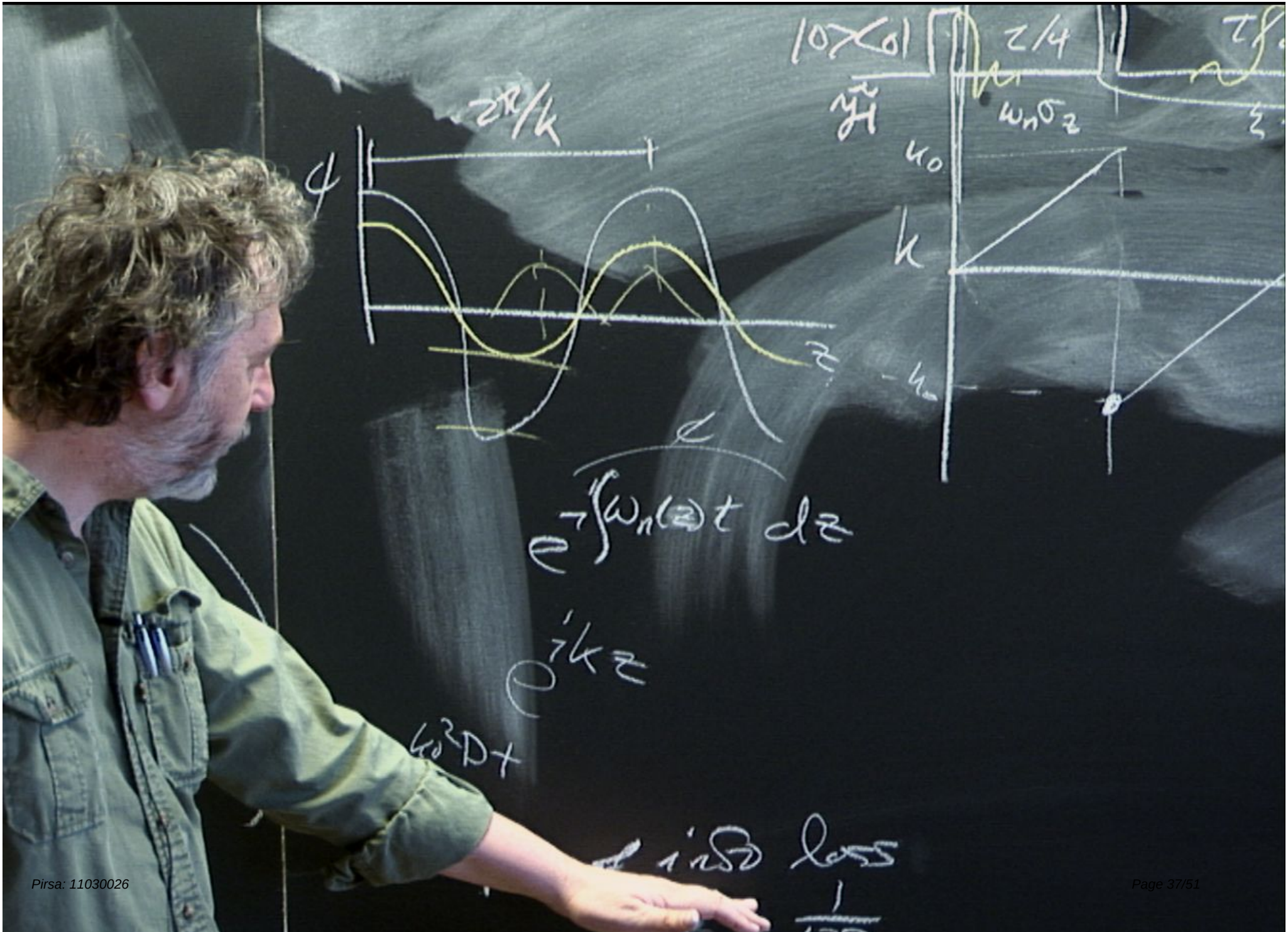
$\sigma = \sqrt{2Dt}$

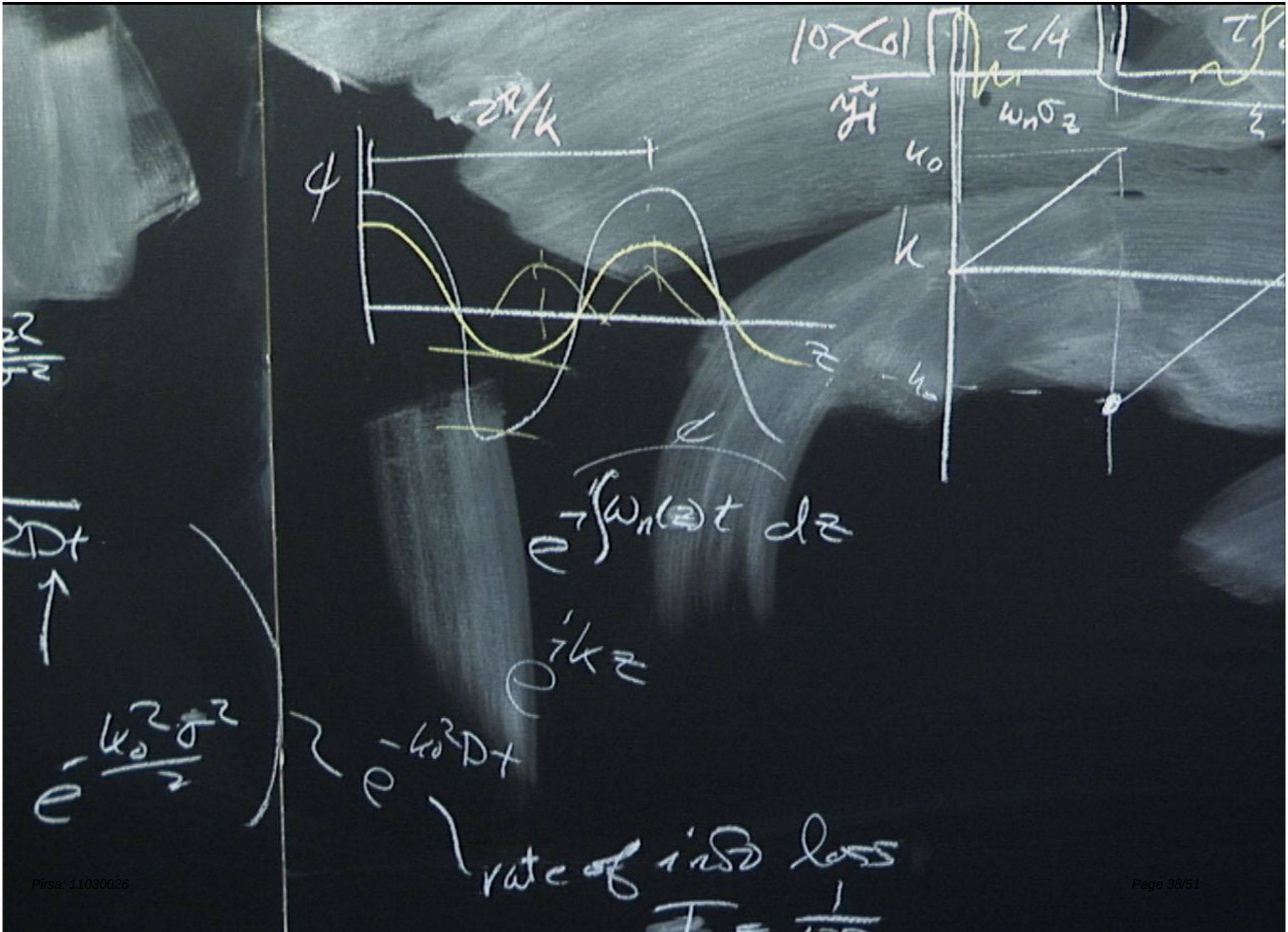
$e^{ik_0 z} \xrightarrow{P(\Delta z, t)} e^{ik_0 z} * \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-\Delta z^2}{2\sigma^2}} = e^{-\frac{k_0^2\sigma^2}{2}} \sim e^{-k_0^2 Dt}$

$\delta(k_0 - k) \cdot e^{-\frac{k_0^2\sigma^2}{2}}$


$\mathcal{F}(\omega) \cdot G(\omega)\}$; $F(\omega) = \int e^{-i\omega t} f(t)\, dt$
$\frac{d\omega_N}{dz}$
P
z
$\Delta z | t) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-\Delta z^2}{2\sigma^2}}$
$\sigma = \sqrt{2Dt}$
$\frac{1}{\sqrt{2\pi}\sigma} e^{-\Delta z^2/2\sigma^2}$
$e^{-\frac{k_0^2\sigma^2}{2}} = e^{-\frac{k_0^2\sigma^2}{2}}$
$\sim e^{-k_0^2 D t}$
$2\pi/k$
q
z
$e^{-\int \omega_n(z)\, t\, dz}$
e^{ikz}
$10^{<01}$
$\pi/2$
$z/4$
R
$\omega_n \sigma_z$
k_0
k
k_-


$\mathcal{F}(\omega) \cdot G(\omega)\}$; $F(\omega) = \int e^{i\omega t} f(t)\, dt$
$\frac{d\omega_N}{dz}$
P
z
$\Delta z|t) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-\Delta z^2}{2\sigma^2}}$
$\sigma = \sqrt{2Dt}$
$\frac{1}{\sqrt{2\pi}\sigma} e^{-\Delta z^2/2\sigma^2}$
$e^{-\frac{k_0^2\sigma^2}{2}} = e^{-\frac{k_0^2 D t}{2}}$
$-\frac{k_0^2\sigma^2}{2}$
$2\pi/k$
q
z
$e^{-\int \omega_n(z)\, t\, dz}$
e^{ikz}
$e^{-k_0^2 D t}$
rate of loss
$T_2 = \frac{1}{k_0^2 D}$
10^{-6}
$\pi/2$
π
$z/4$
R
$\omega_n \sigma_z$
k_0
k
$-k_0$


2π/k
z
$e^{-i\int \omega_n(z)\,t\,dz}$
e^{ikz}
$\omega^2 D +$

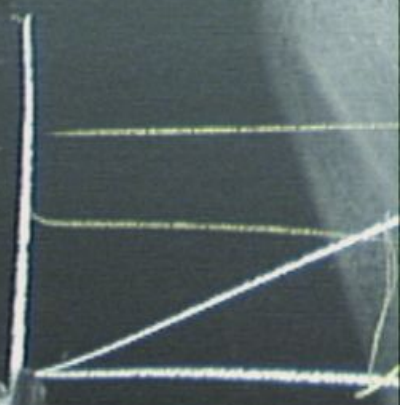

$2\pi/k$
$\omega_n \sigma_z$
k_0
$-k_0$
k
z
ξ
$e^{-\int \omega_n(z) t \, dz}$
e^{ikz}
$e^{-k^2 D t}$
$e^{-\frac{k_0^2 \sigma^2}{2}}$
$2Dt$
rate of loss

$\int c \frac{d\omega_N}{dt}$

$f(t) * g(t) =$

$k(t) = \frac{dk}{dt} t$

$\int k(t) D \, dt$



Matrix Kernel

$= P$

$\int c \frac{d\omega_N}{dz}$

$f(t) \otimes g(t) =$

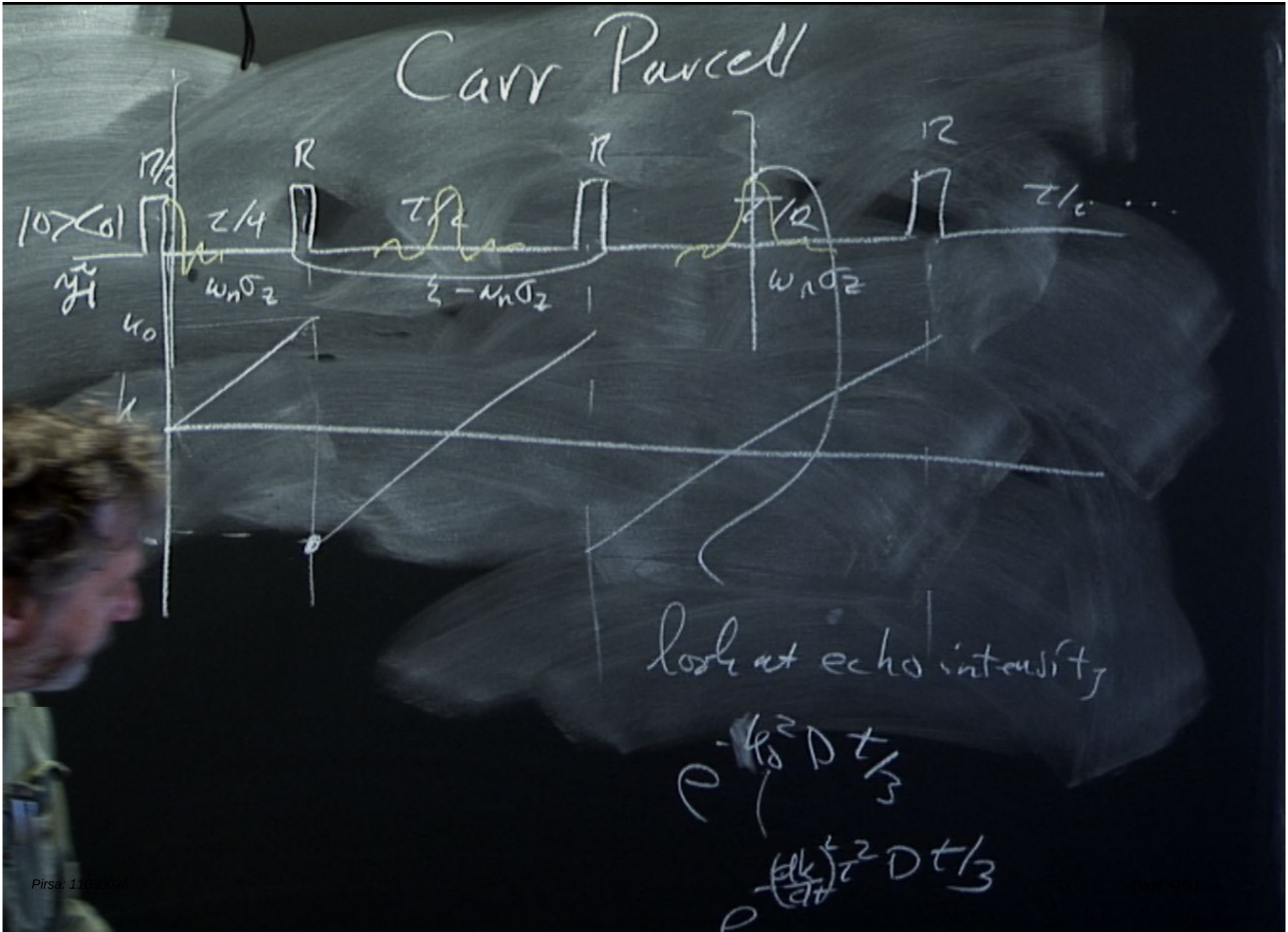
$k(t) = \frac{dk}{dt} t$

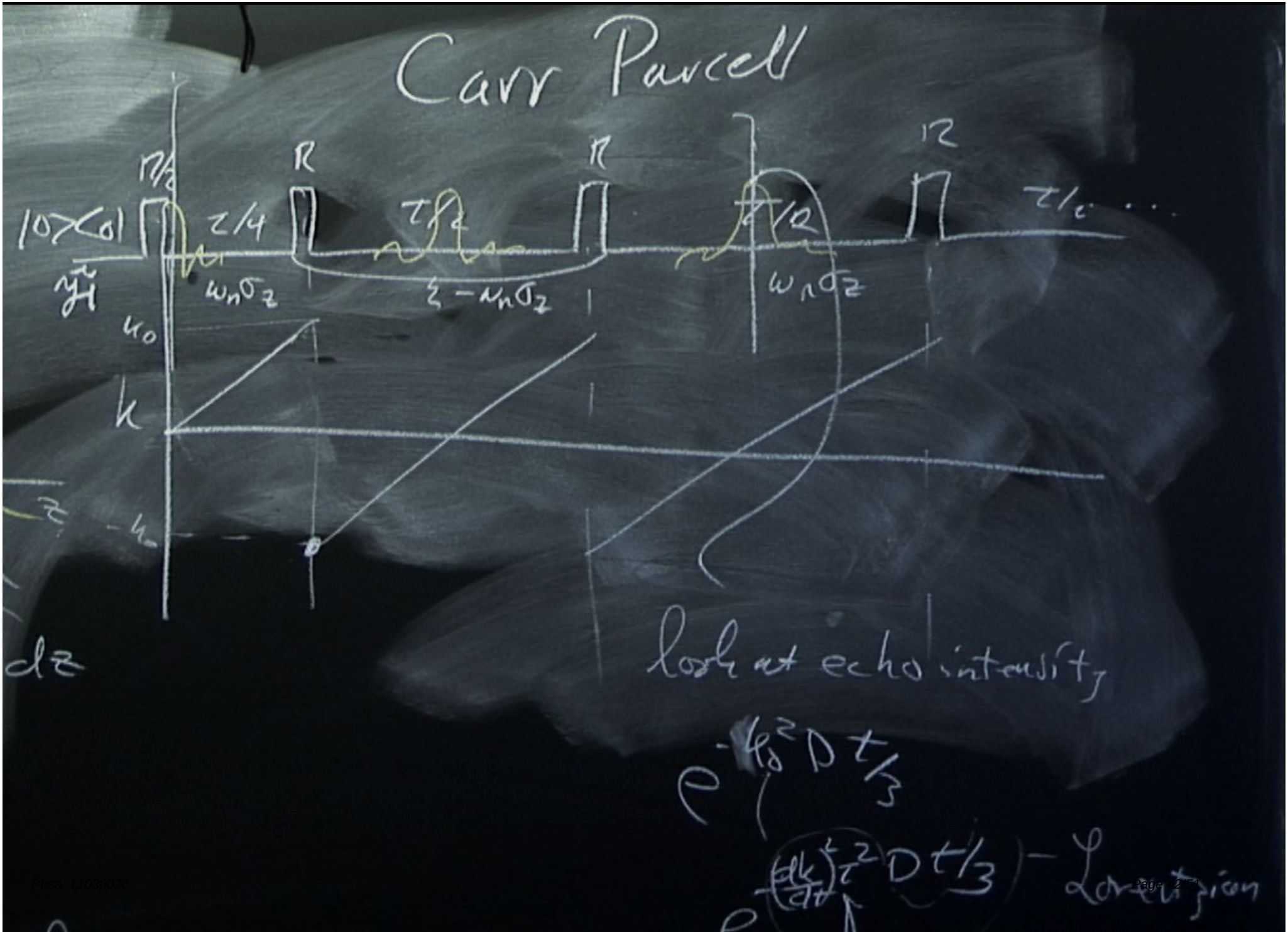
$\int k^2(t) D \, dt$

$e^{-k_0^2 D t/3}$

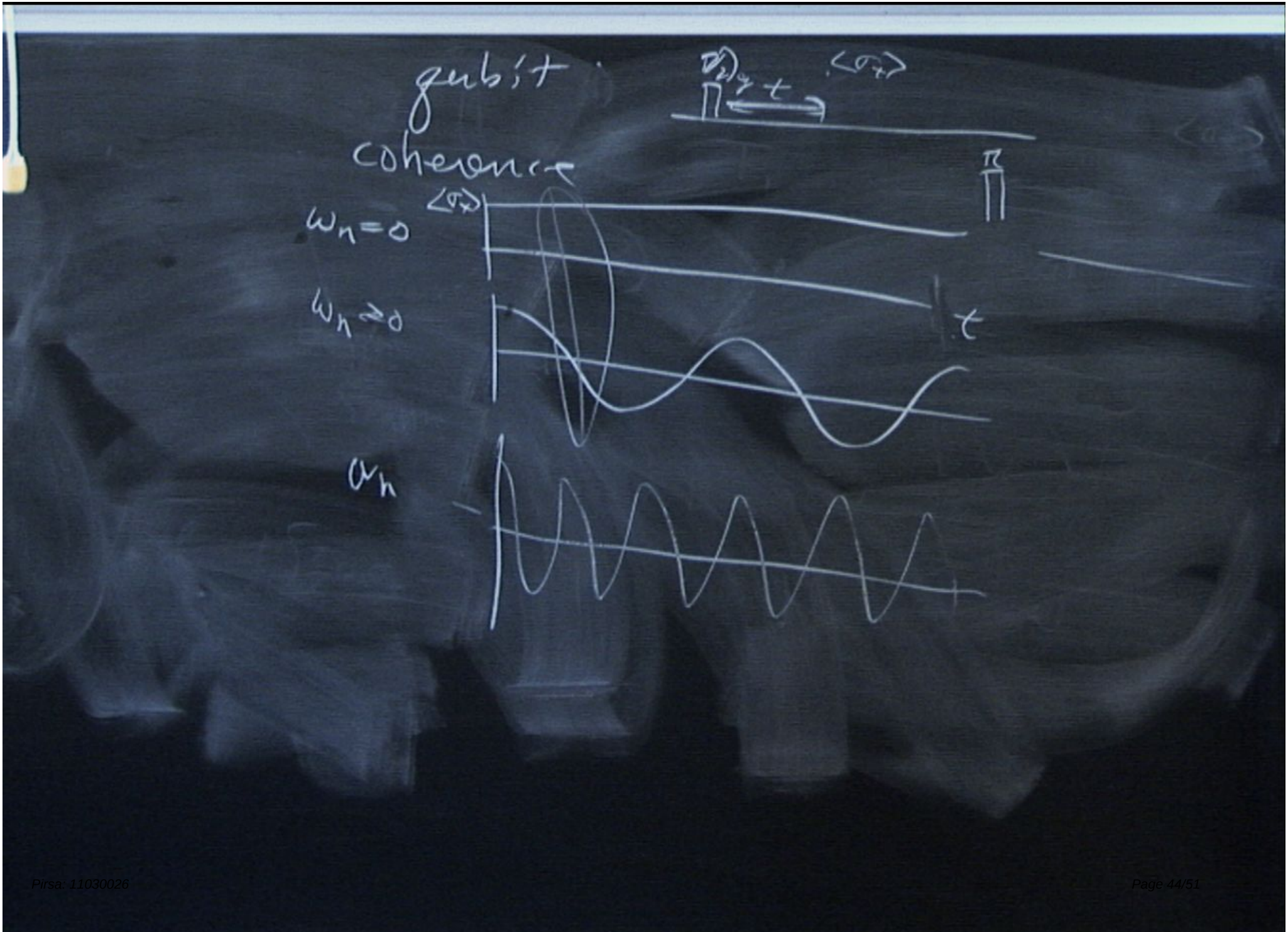
With

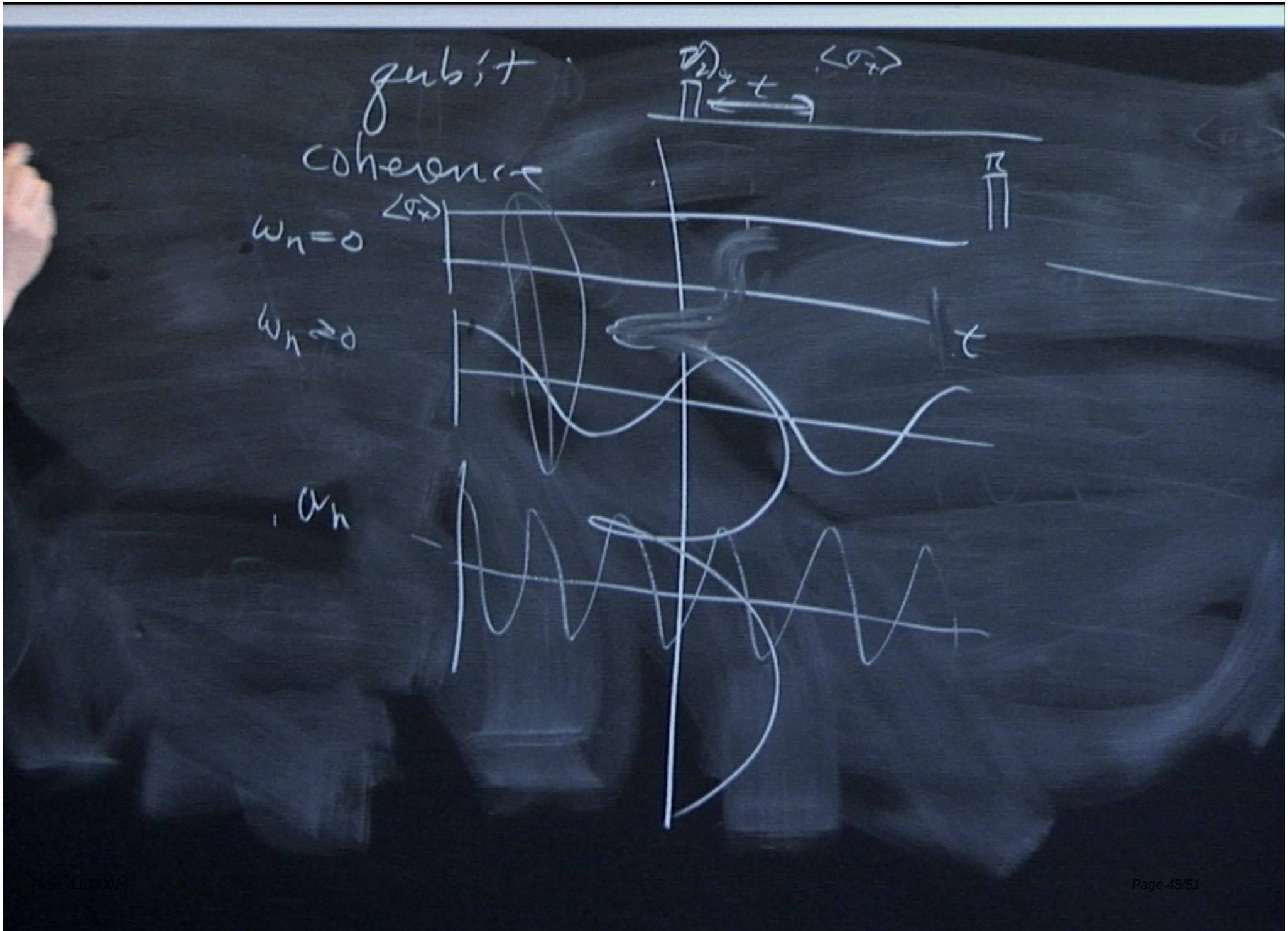
Motion Kernel

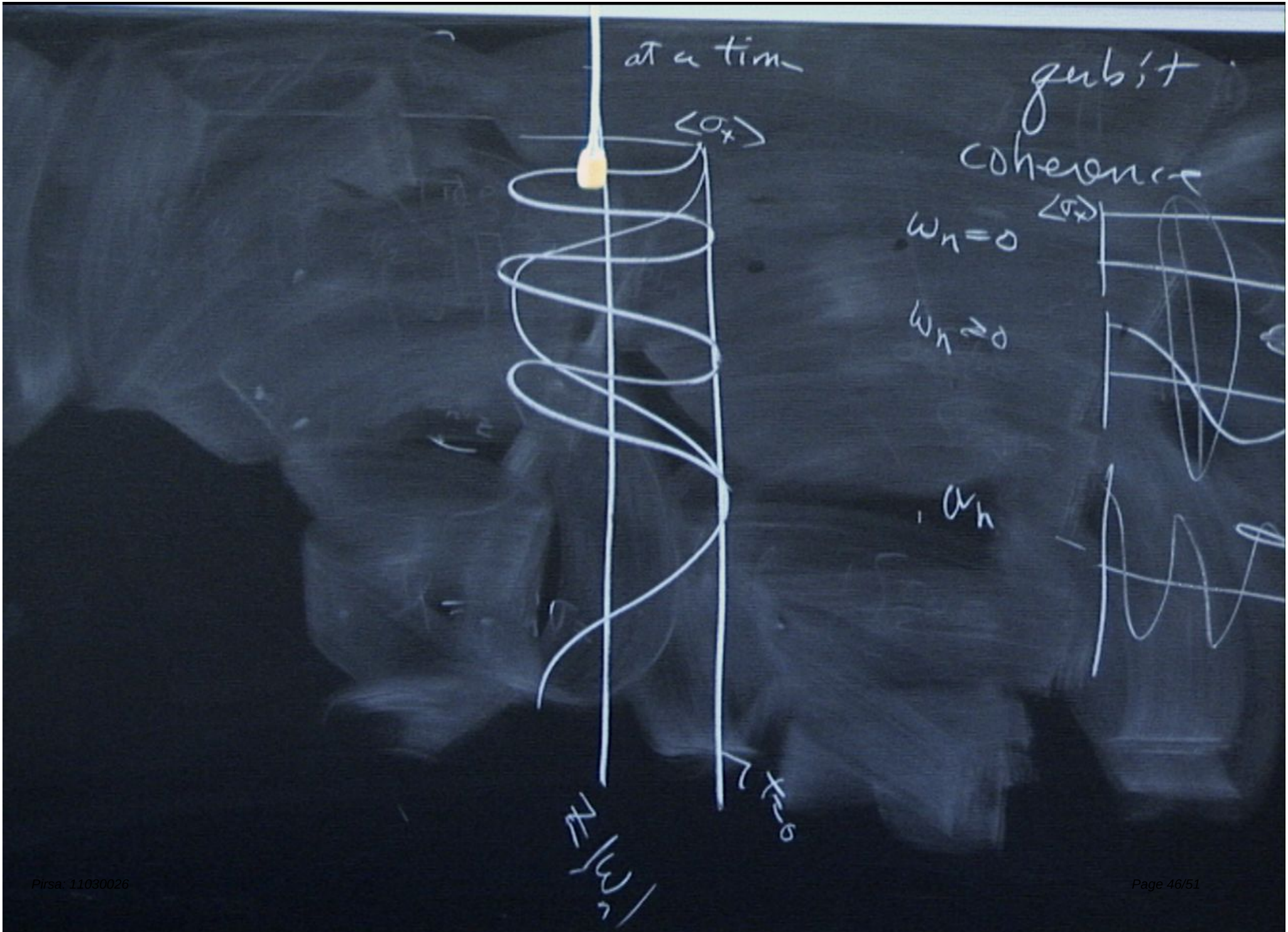

Carr Purcell
π/2
π
π
π
τ/4
τ/2
τ/2
τ/2
τ
$\omega_n \sigma_z$
$\xi - \omega_n \sigma_z$
$\omega_n \sigma_z$
k_0
k
look at echo intensity
$e^{-k_0^2 D t/3}$
$e^{-(\frac{dk}{dt})^2 \tau^2 D t/3}$

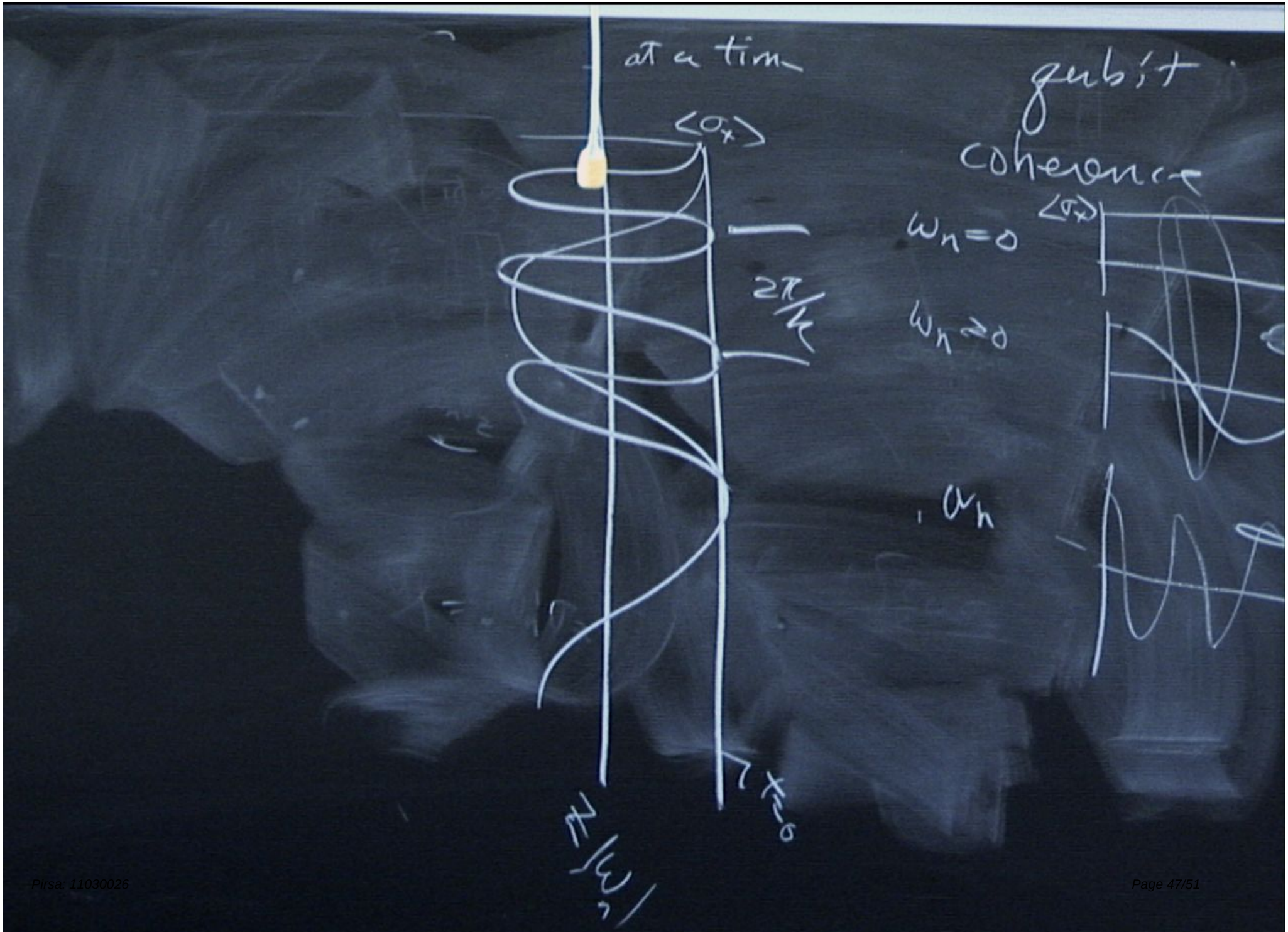

Carr Purcell
π/2
π
π
π
|0><0|
τ/4
τ/2
τ/2
τ/2
τ/2 ...
$\omega_n \sigma_z$
$\xi - \omega_n \sigma_z$
$\omega_n \sigma_z$
u_0
k
dz
look at echo intensity
$e^{-k_0^2 D t/3}$
$e^{-\left(\frac{dk}{dt}\right)^2 \tau^2 D t/3}$
Localization

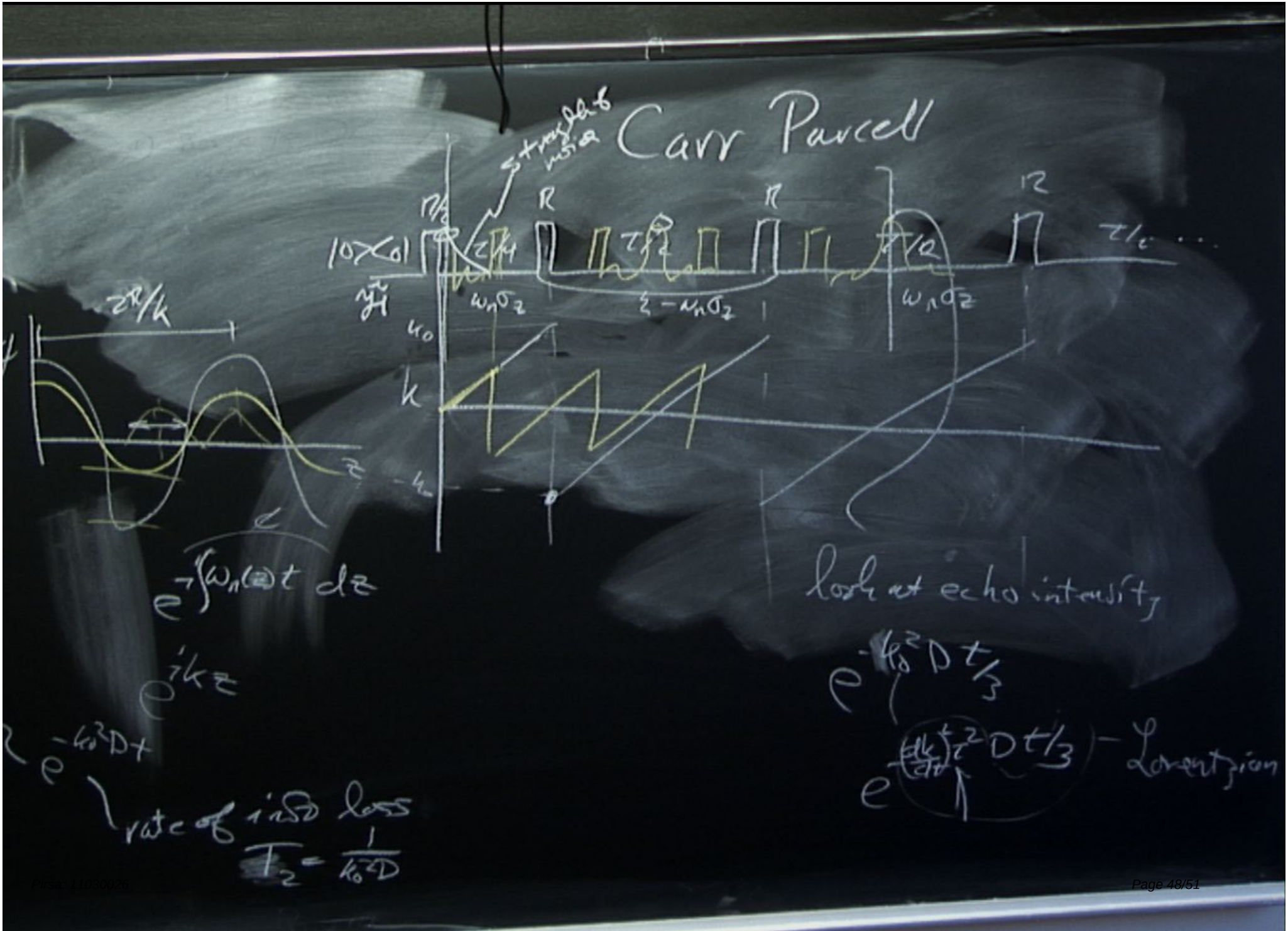

qubit
coherence
$\omega_n = 0$
$\omega_n \neq 0$
$\langle \sigma_x \rangle$
$\langle \sigma_z \rangle$
$\pi/2$
t
α_n

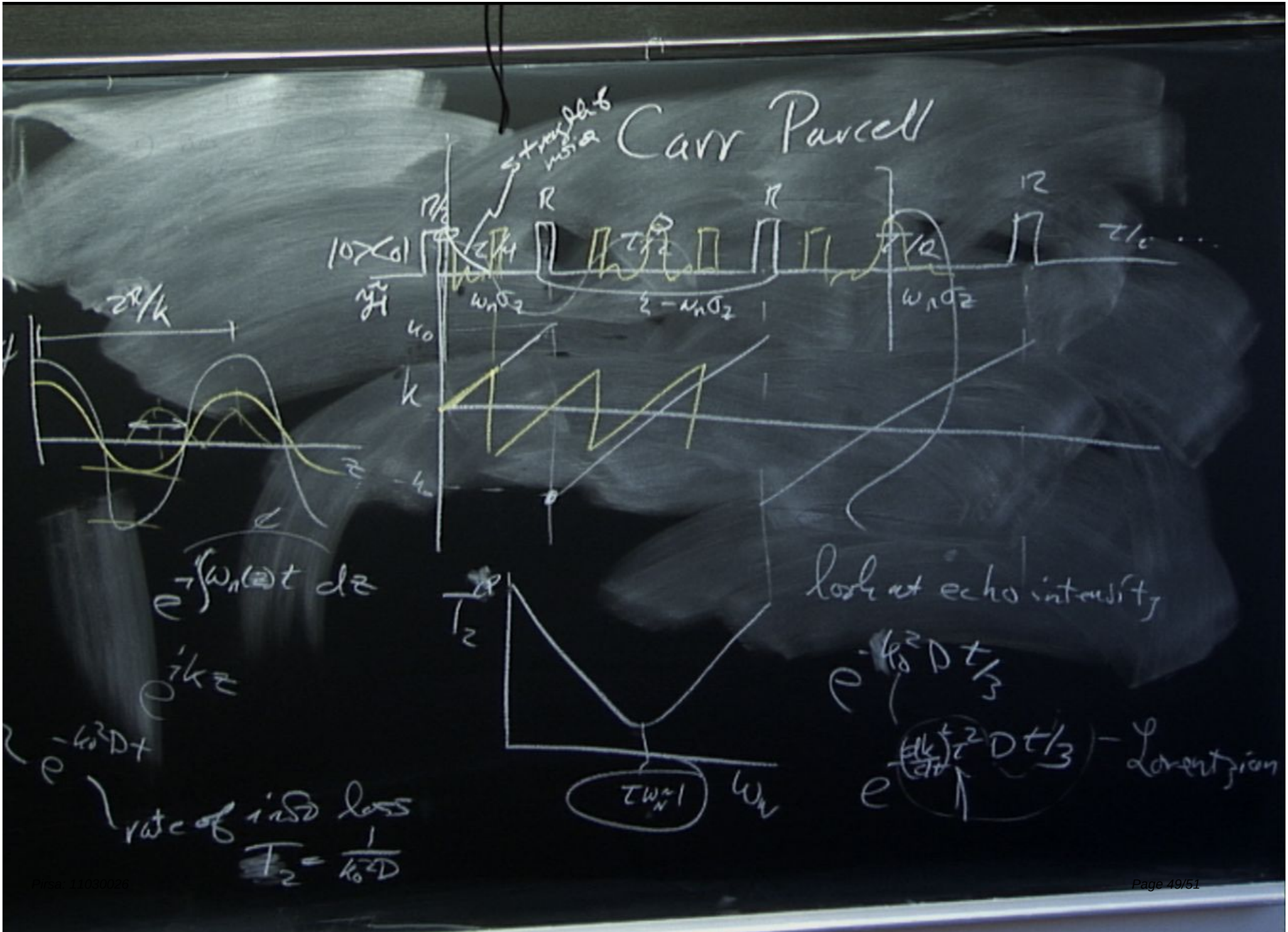

qubit
coherence
$\omega_n = 0$
$\omega_n \neq 0$
α_n
$\langle \sigma_x \rangle$
$\pi/2$
τ
π
t

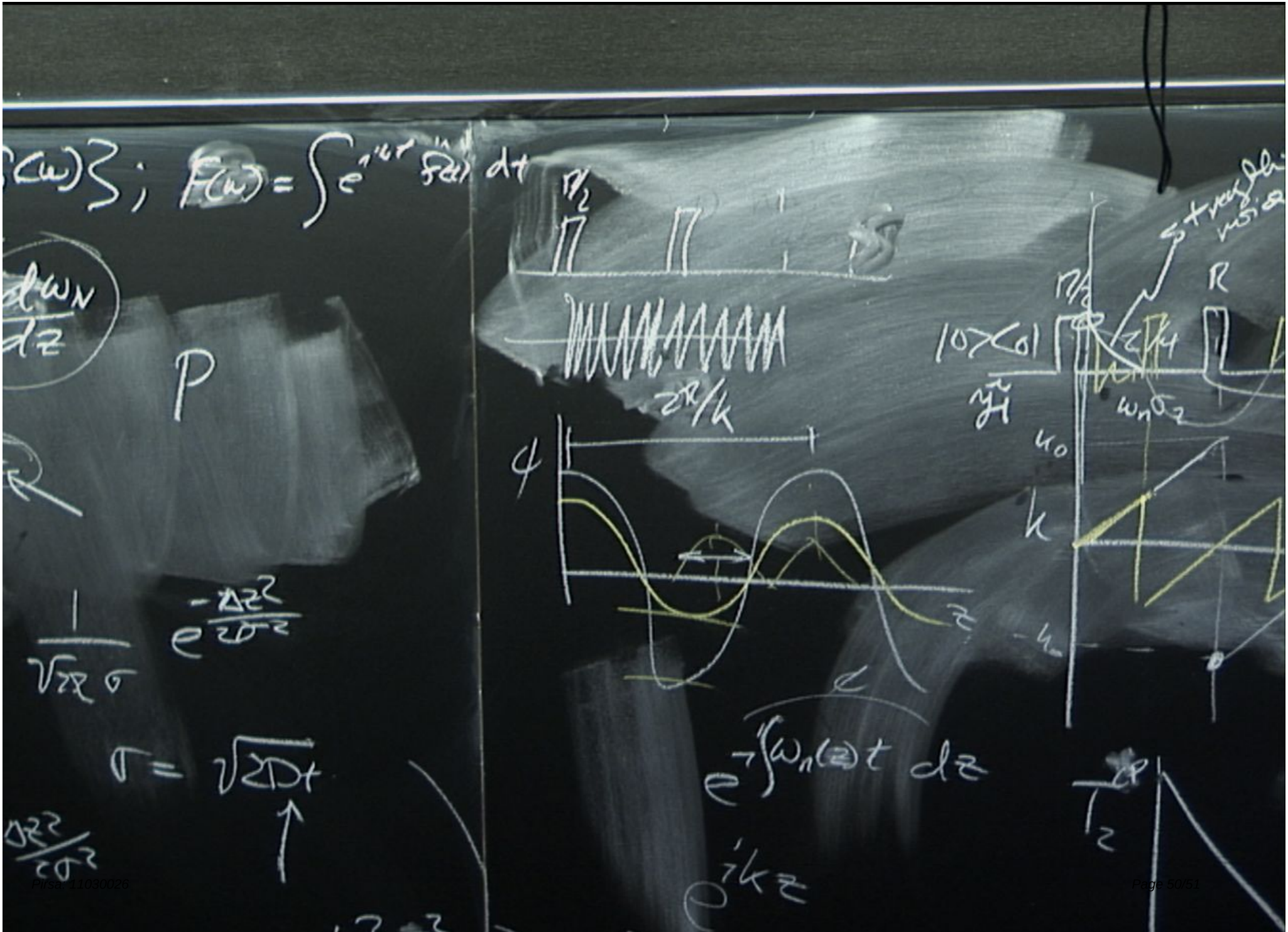

qubit
coherence
$\pi/2$
τ
π
$\langle\sigma_x\rangle$
$\omega_n = 0$
$\omega_n \neq 0$
t
a_n

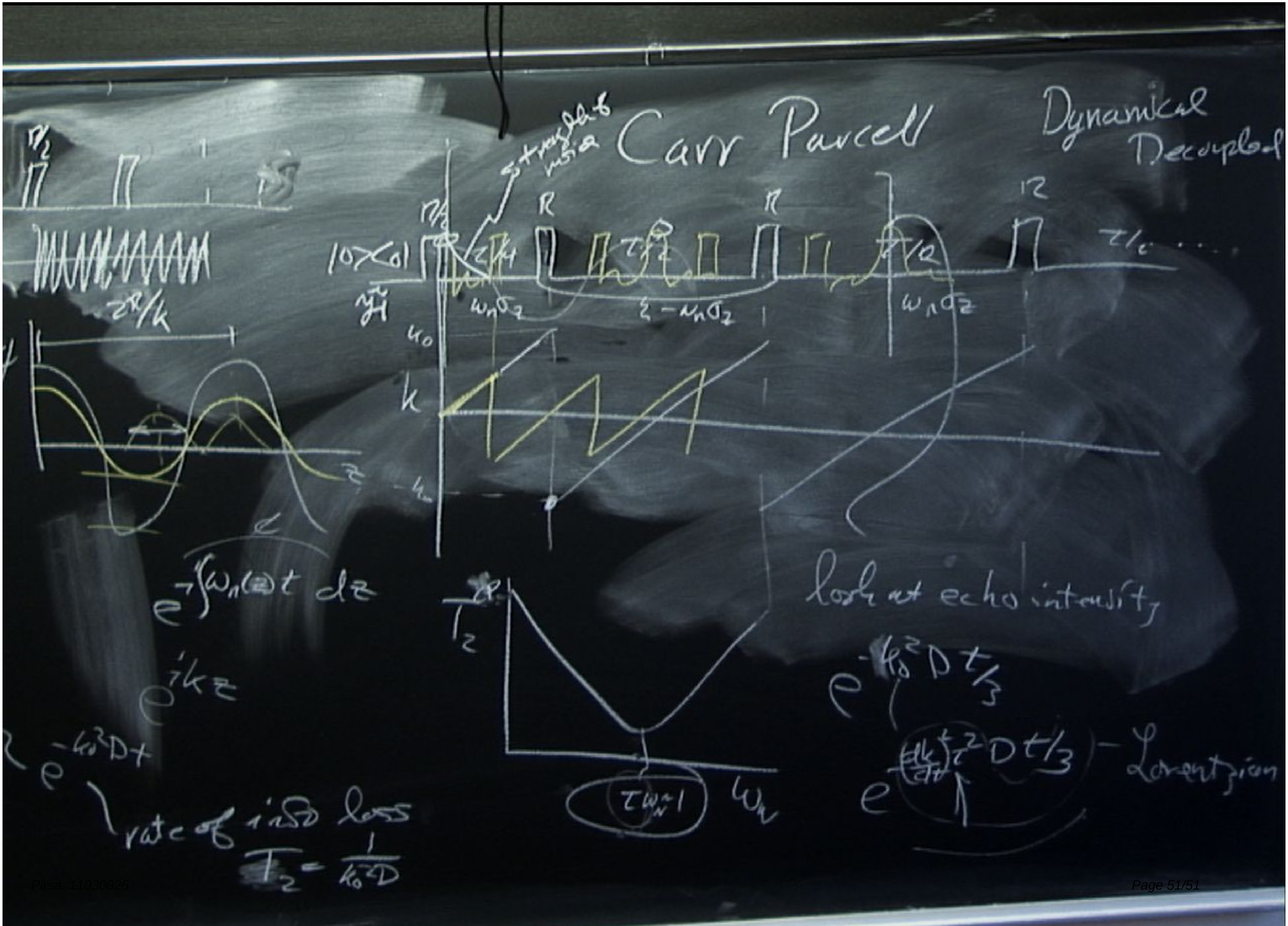

at a time
$\langle \sigma_x \rangle$
$x=0$
qubit
coherence
$\langle \sigma_x \rangle$
$\omega_n = 0$
$\omega_n \neq 0$
α_n


at a time
$\langle \sigma_x \rangle$
$2\pi/k$
$z = f(\omega_n)$
$x=0$
qubit
coherence
$\langle \sigma_x \rangle$
$\omega_n = 0$
$\omega_n \neq 0$
α_n


Carr Purcell
$\pi/2$
π
π
2π
$\tau/4$
$\tau/2$
$\tau/2$
$\tau/4$
τ_c ...
$\omega_n\sigma_z$
$\xi - \omega_n\sigma_z$
$\omega_n\sigma_z$
k_0
k
$-k_0$
$2\pi/k$
z
L
$e^{-i\int\omega_n(z)t\,dz}$
e^{ikz}
$e^{-k_0^2Dt}$
rate of inhomo loss
$\frac{1}{T_2} = \frac{1}{k_0^2D}$
look at echo intensity
$e^{-k_0^2Dt/3}$
$e^{-\frac{(\pm k)}{2\pi}\tau_c^2Dt/3}$
Lorentzian


Carr Purcell
$\pi/2$
π
π
$\pi/2$
τ_c ...
$\omega_n\sigma_z$
$\xi - \omega_n\sigma_z$
$\omega_n\sigma_z$
$2\pi/k$
k_0
k
$-k_0$
z
ϵ
$e^{-i\int\omega_n(z)t\,dz}$
e^{ikz}
$e^{-k_0^2Dt}$
rate of inst loss
$T_2 = \frac{1}{k_0^2D}$
2π
T_2
$\tau\omega_n \ll 1$
ω_n
look at echo intensity
$e^{-k_0^2Dt/3}$
$e^{-\left(\frac{k}{dt}\right)^2 t^2 Dt/3}$
Lorentzian


$F(\omega) = \int e^{-i\omega t} f(t)\, dt$
P
$\frac{1}{\sqrt{2\pi}\sigma}\, e^{\frac{-\Delta z^2}{2\sigma^2}}$
$\sigma = \sqrt{2Dt}$
$\frac{\Delta z^2}{2\sigma^2}$
$2\pi/k$
$e^{-i\int \omega_n(z)\, t\, dz}$
e^{ikz}
$\omega_n \sigma_z$
k_0
k
$-k_0$
R
T_z


Carr Purcell
Dynamical Decoupled
look at echo intensity
Lorentzian
rate of info loss