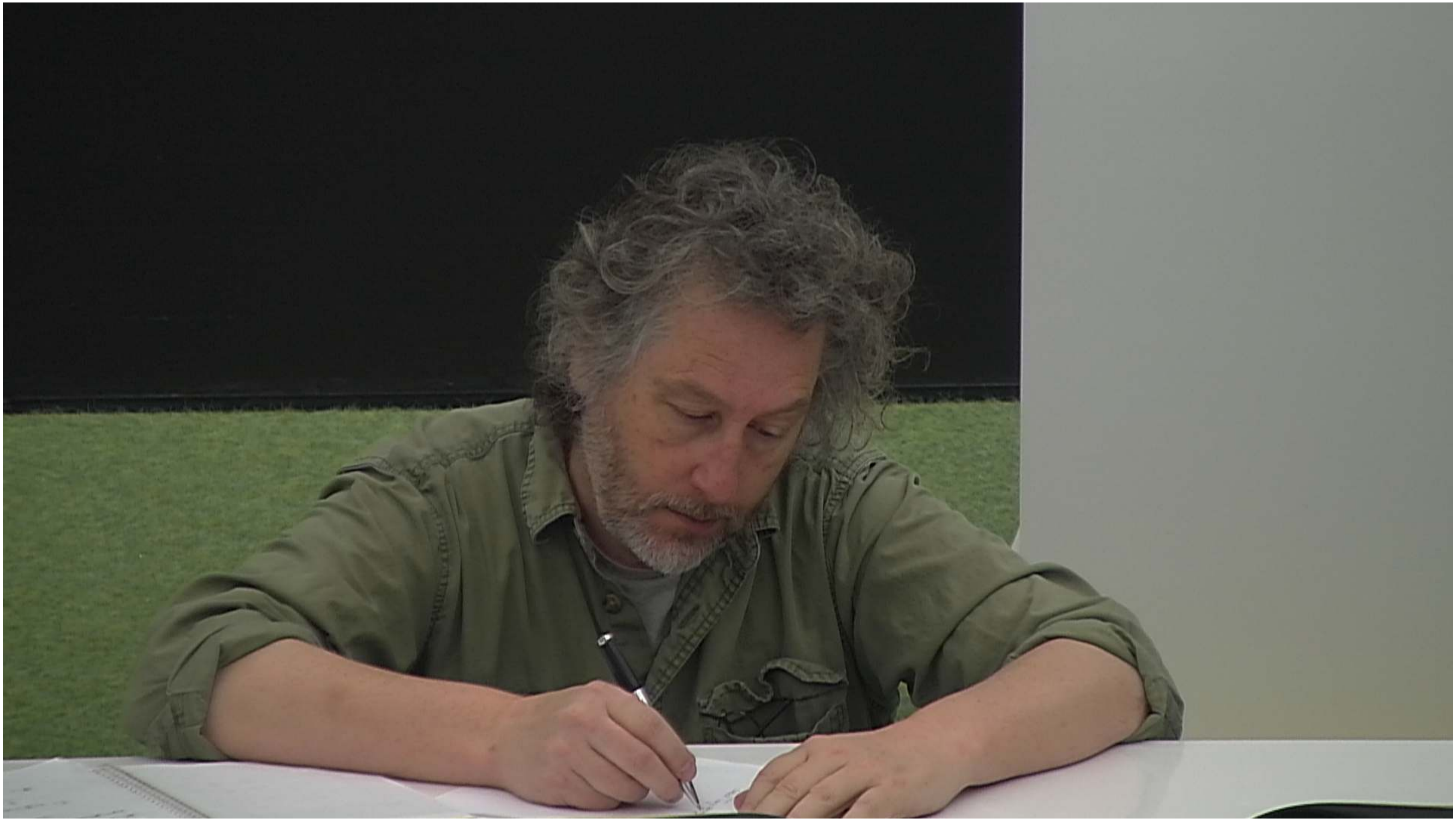
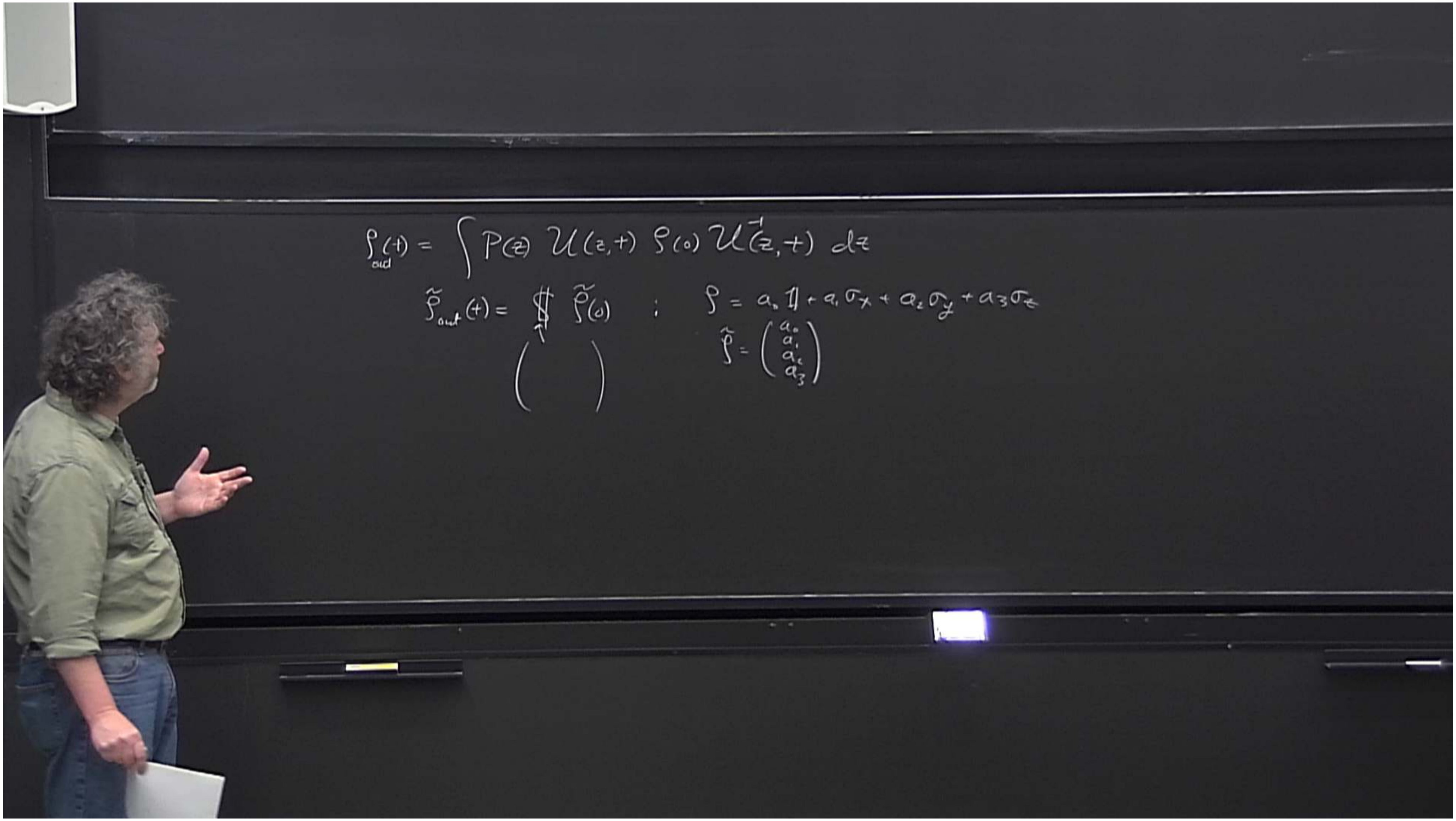
Title: Explorations in Quantum Information - Lecture 3

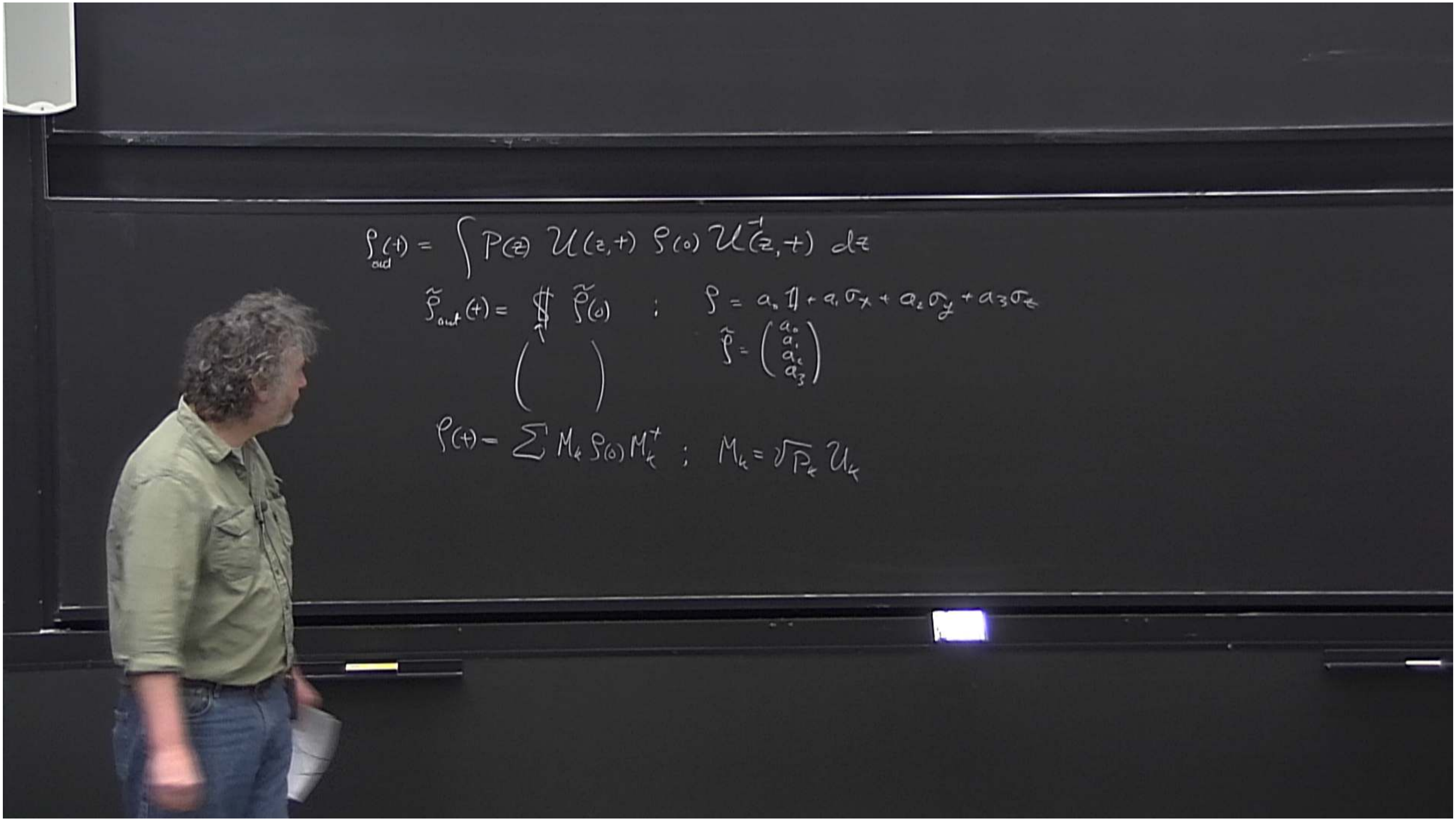
Date: Mar 14, 2012 09:00 AM

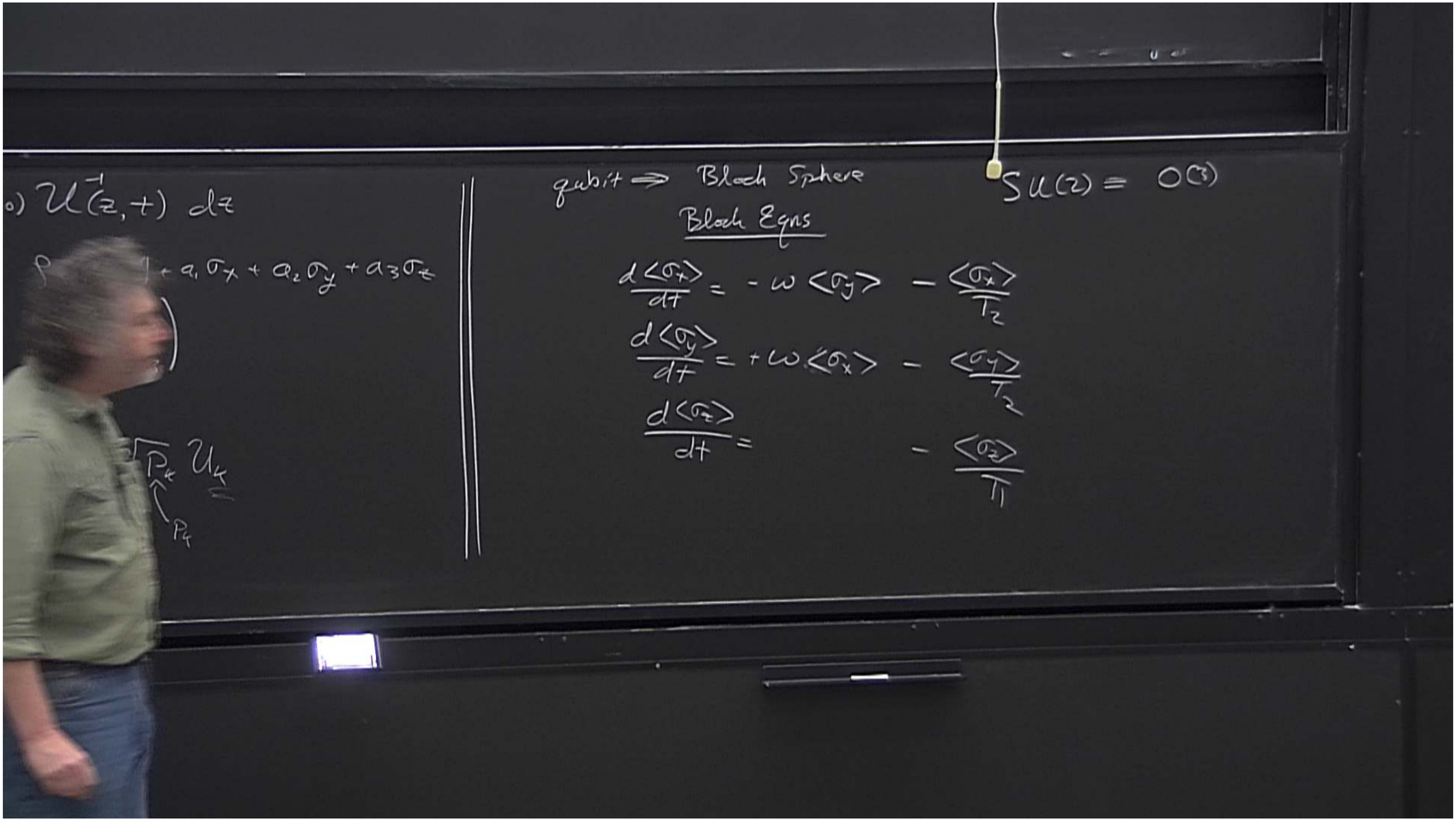
URL: http://pirsa.org/12030006

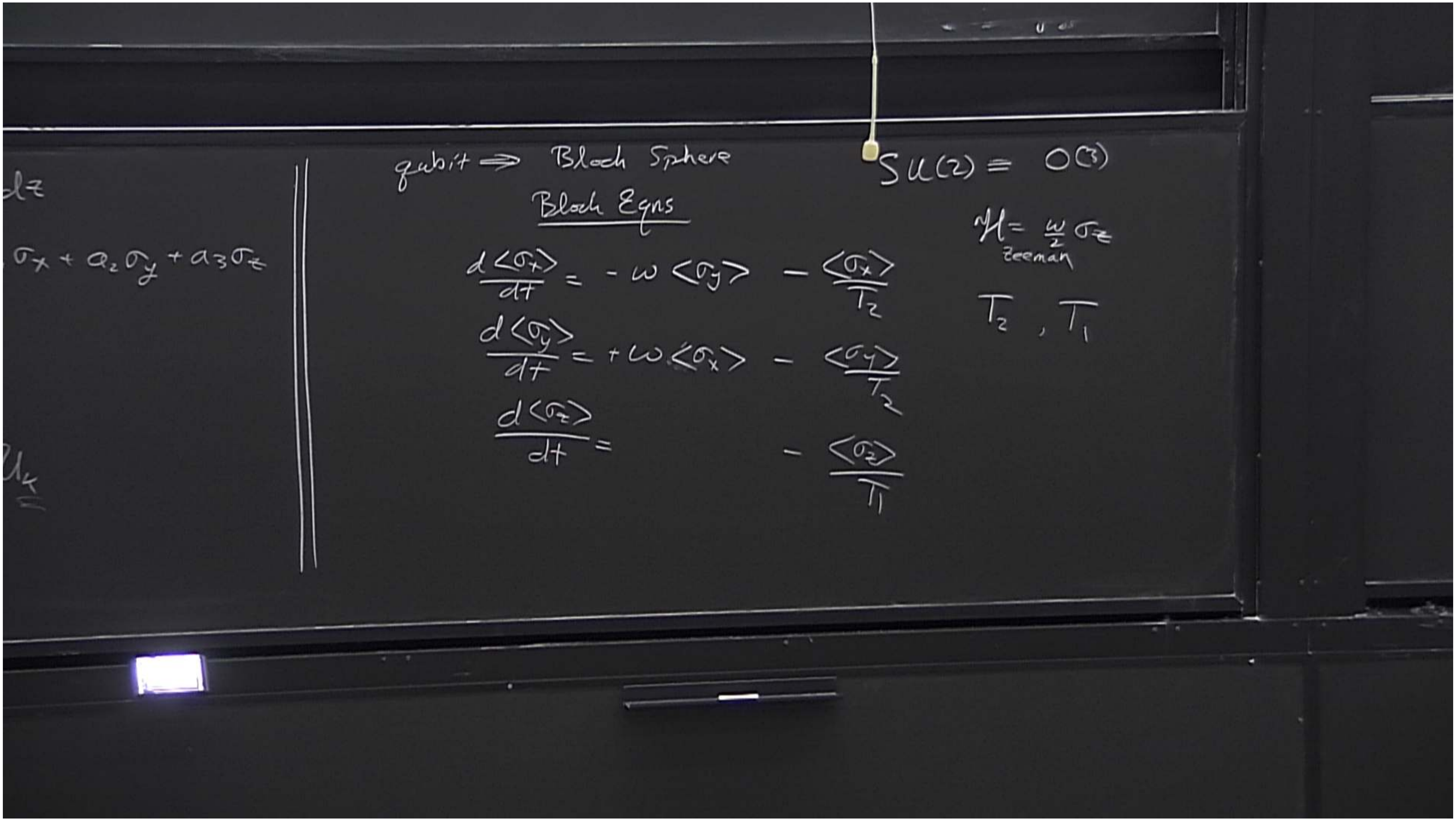
Abstract:

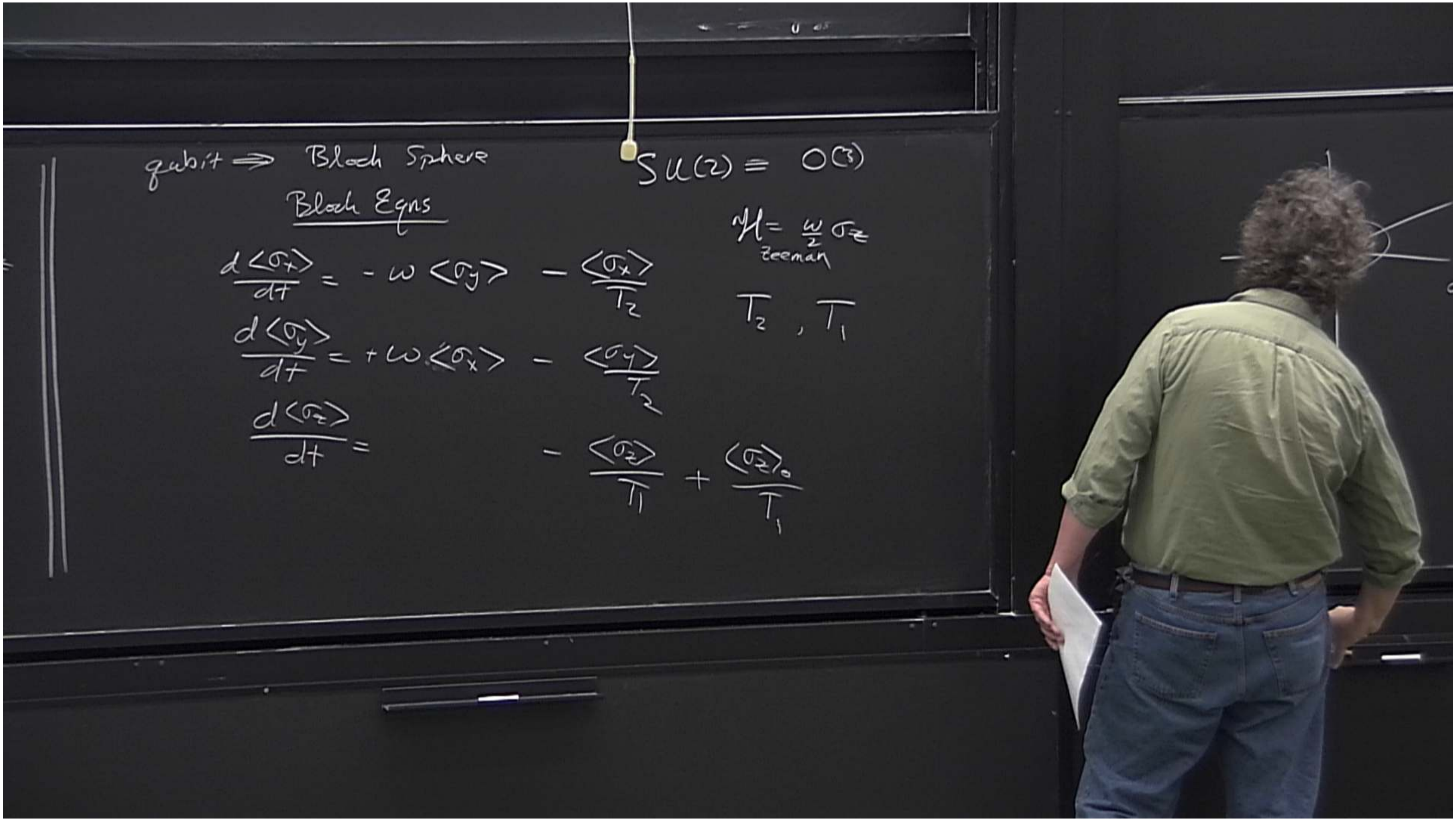


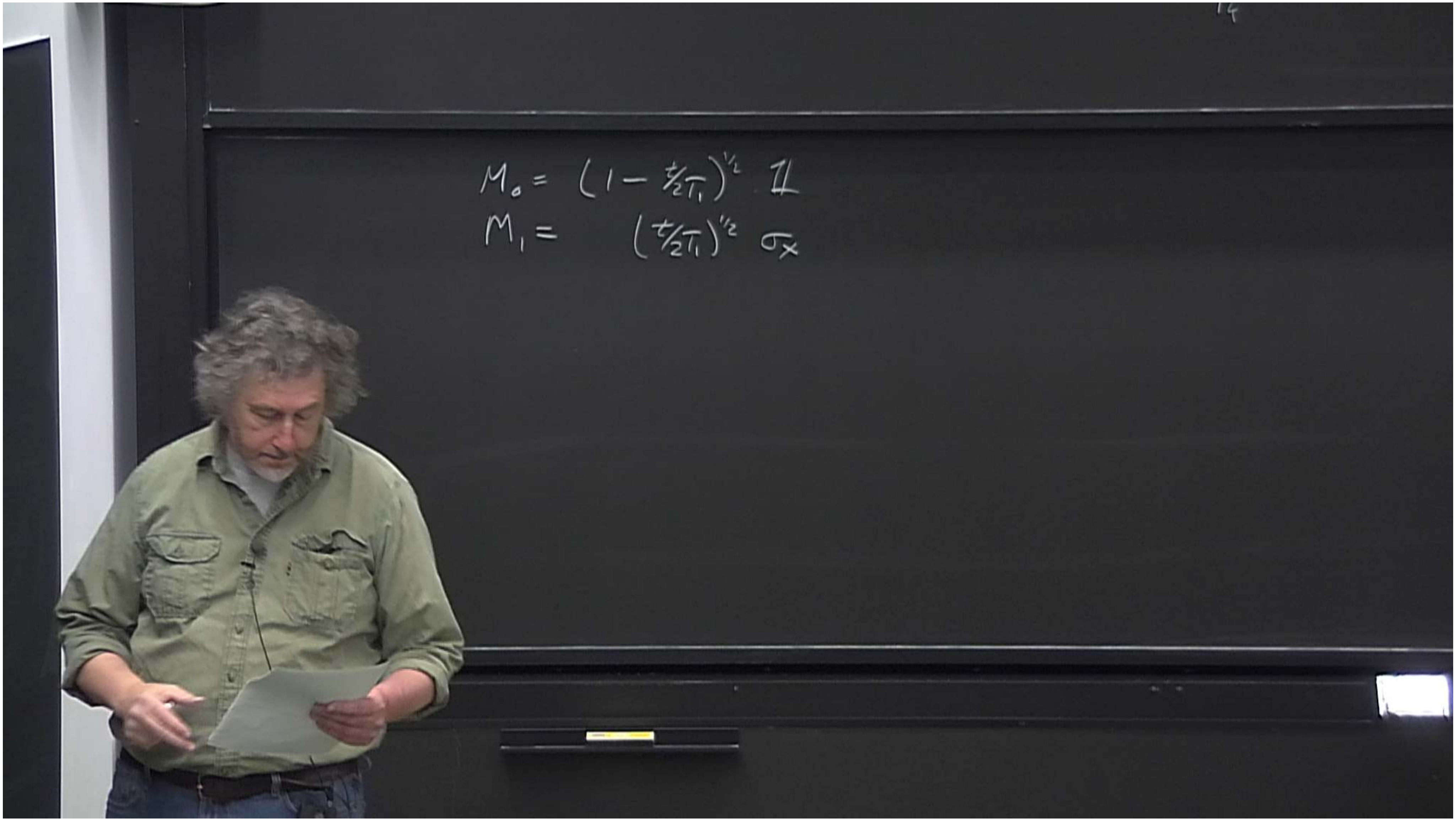

$\rho_{out}(t) = \int P(z)\, \mathcal{U}(z,t)\, \rho(0)\, \mathcal{U}^{-1}(z,t)\, dz$
$\tilde{\rho}_{out}(t) = \$\ \tilde{\rho}(0)$; $\rho = a_0 \mathbb{1} + a_1 \sigma_x + a_2 \sigma_y + a_3 \sigma_z$
$\tilde{\rho} = \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{pmatrix}$

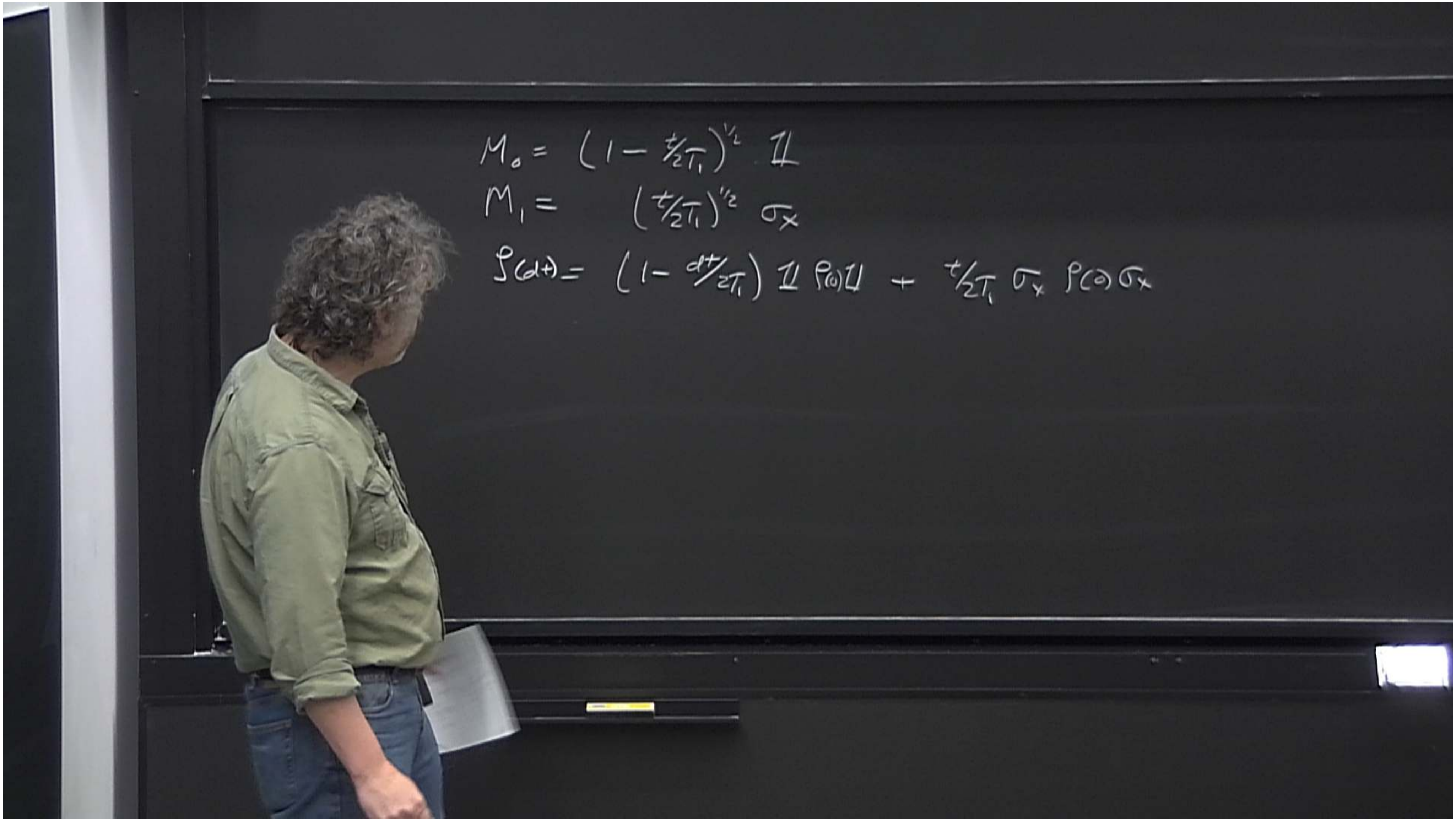

$\rho_{out}(t) = \int P(z)\, \mathcal{U}(z,t)\, \rho(0)\, \mathcal{U}^{-1}(z,t)\, dz$
$\tilde{\rho}_{out}(t) = \$\, \tilde{\rho}(0)$; $\rho = a_0 \mathbb{1} + a_1 \sigma_x + a_2 \sigma_y + a_3 \sigma_z$
$\tilde{\rho} = \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{pmatrix}$
$\rho(t) = \sum M_k\, \rho(0)\, M_k^{+}$; $M_k = \sqrt{p_k}\, \mathcal{U}_k$

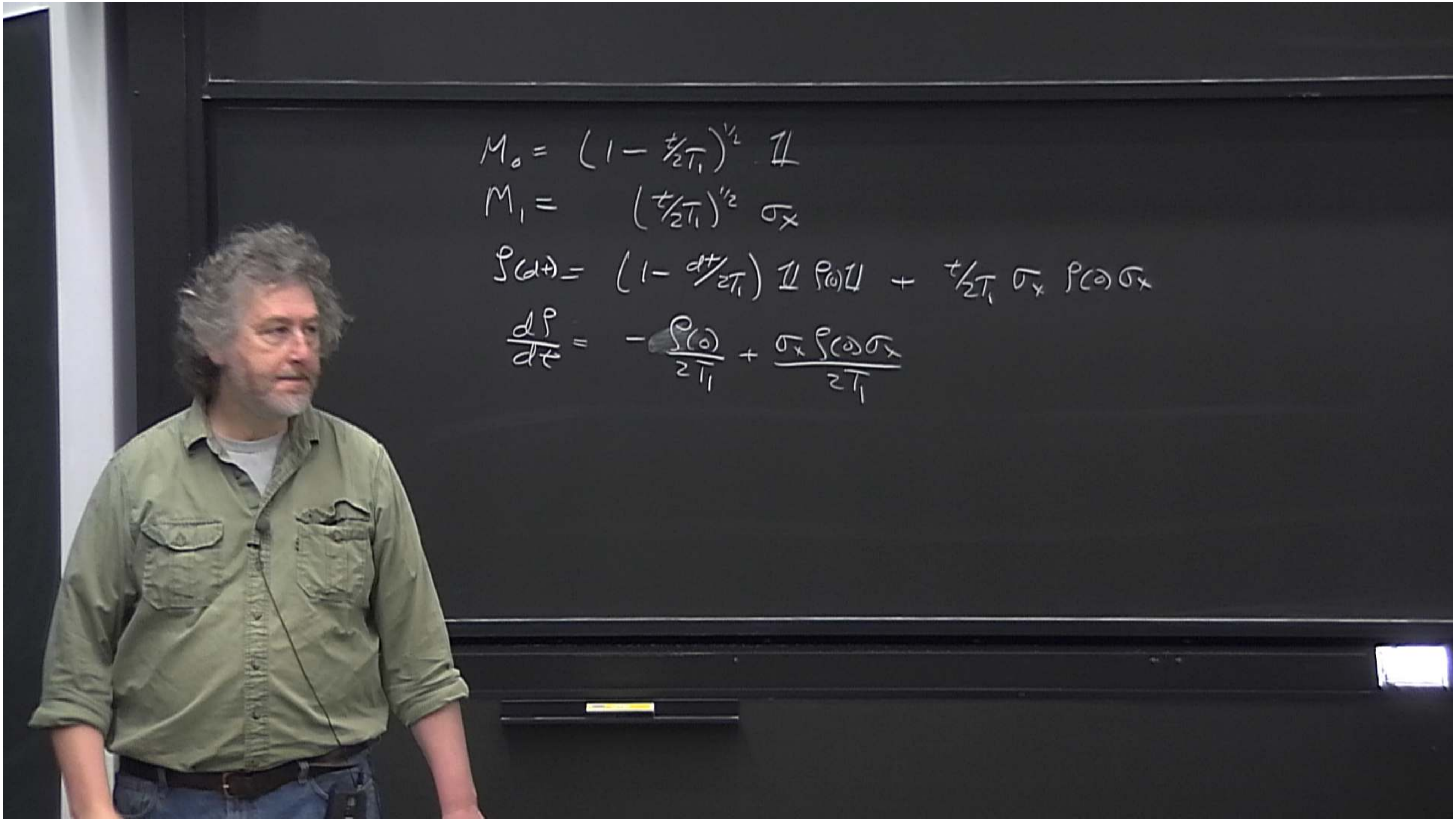

qubit ⇒ Bloch Sphere
Bloch Eqns
SU(2) = O(3)
d⟨σx⟩/dt = - ω ⟨σy⟩ - ⟨σx⟩/T2
d⟨σy⟩/dt = + ω ⟨σx⟩ - ⟨σy⟩/T2
d⟨σz⟩/dt = - ⟨σz⟩/T1

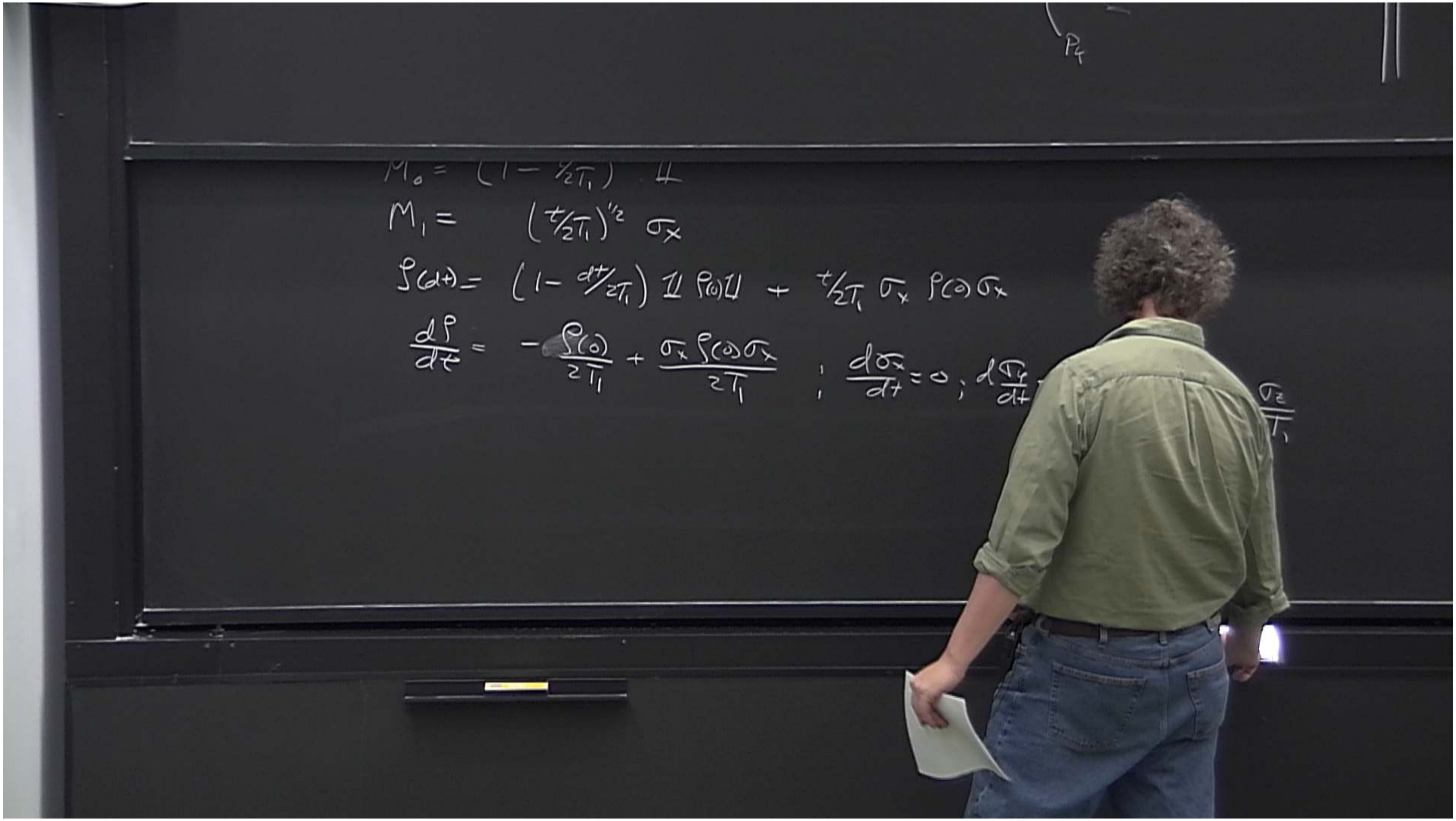

qubit ⇒ Bloch Sphere
Bloch Eqns
$\frac{d\langle\sigma_x\rangle}{dt} = -\omega\langle\sigma_y\rangle - \frac{\langle\sigma_x\rangle}{T_2}$
$\frac{d\langle\sigma_y\rangle}{dt} = +\omega\langle\sigma_x\rangle - \frac{\langle\sigma_y\rangle}{T_2}$
$\frac{d\langle\sigma_z\rangle}{dt} = - \frac{\langle\sigma_z\rangle}{T_1}$
$SU(2) = O(3)$
$\mathcal{H}_{Zeeman} = \frac{\omega}{2}\sigma_z$
$T_2 \; , \; T_1$
$\sigma_x + a_2\sigma_y + a_3\sigma_z$

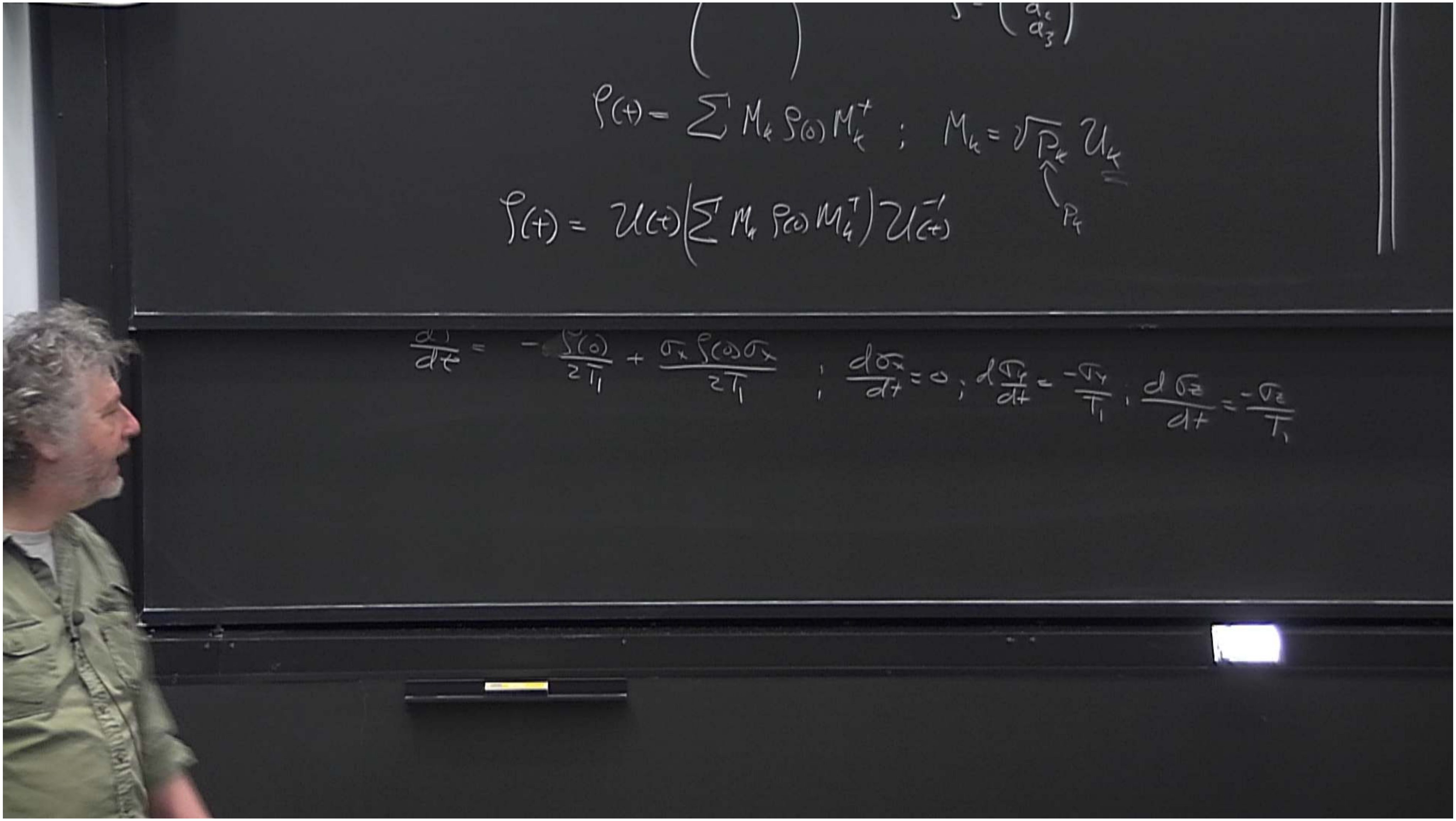

qubit ⇒ Bloch Sphere
Bloch Eqns
$SU(2) \cong O(3)$
$\mathcal{H} = \frac{\omega}{2}\sigma_z$
Zeeman
T_2 , T_1
$\frac{d\langle\sigma_x\rangle}{dt} = -\omega\langle\sigma_y\rangle - \frac{\langle\sigma_x\rangle}{T_2}$
$\frac{d\langle\sigma_y\rangle}{dt} = +\omega\langle\sigma_x\rangle - \frac{\langle\sigma_y\rangle}{T_2}$
$\frac{d\langle\sigma_z\rangle}{dt} = - \frac{\langle\sigma_z\rangle}{T_1} + \frac{\langle\sigma_z\rangle_0}{T_1}$

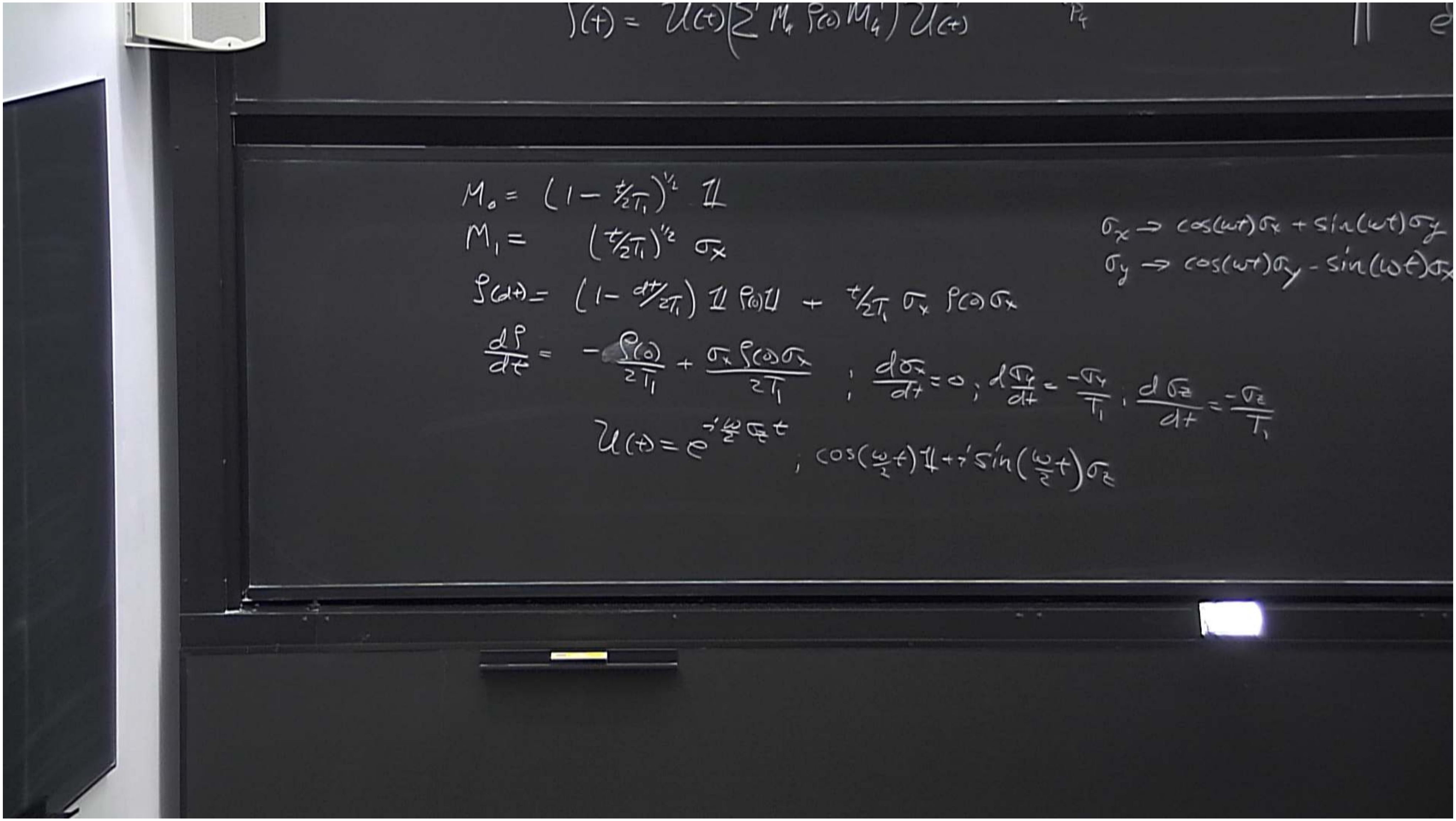

$M_0 = (1 - t/2T_1)^{1/2} \mathbb{1}$
$M_1 = (t/2T_1)^{1/2} \sigma_x$


$M_0 = (1 - t/2T_1)^{1/2} \, \mathbb{1}$
$M_1 = (t/2T_1)^{1/2} \, \sigma_x$
$\rho(dt) = (1 - dt/2T_1) \, \mathbb{1} \, \rho(0) \, \mathbb{1} + t/2T_1 \, \sigma_x \, \rho(0) \, \sigma_x$

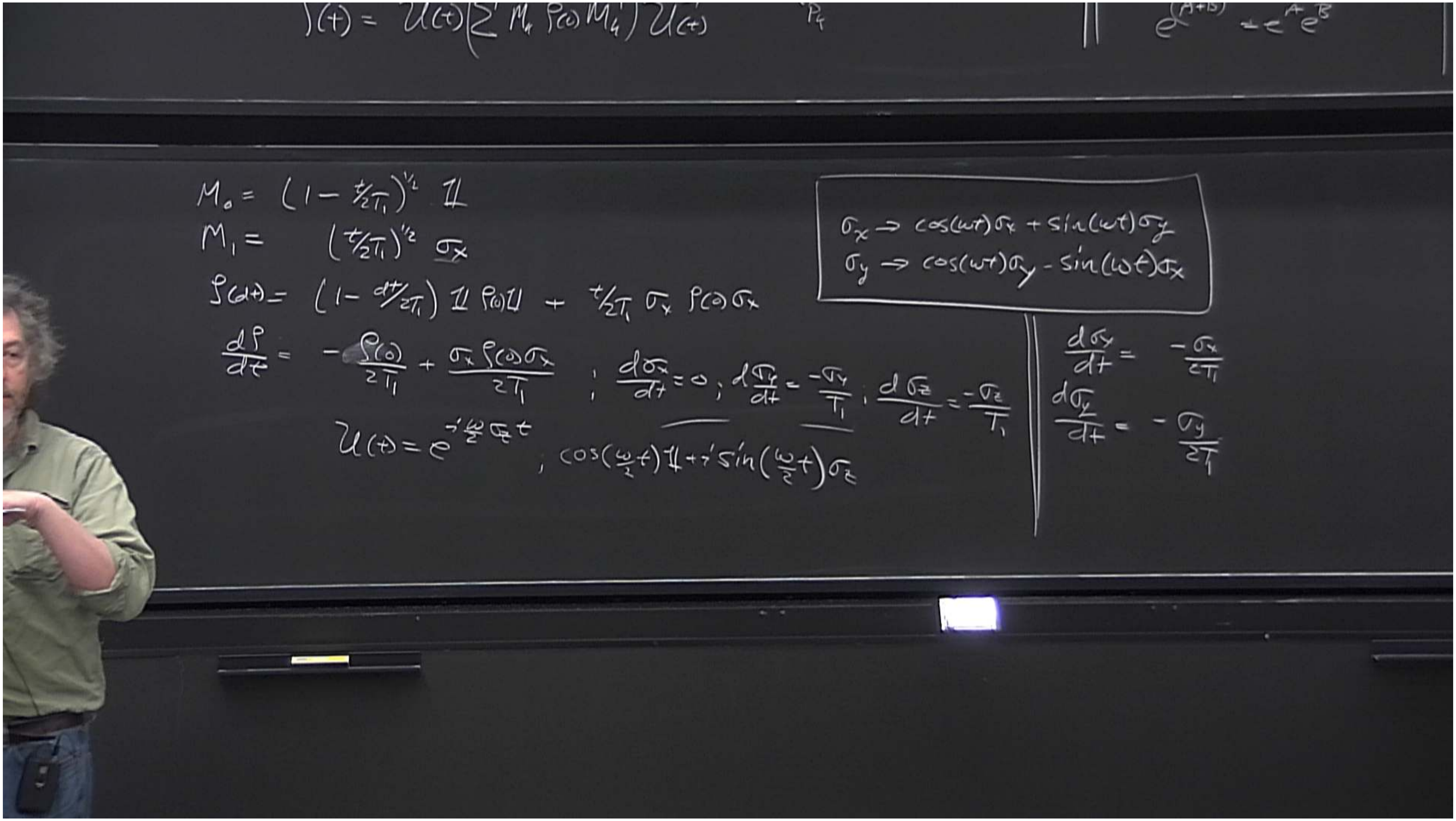

$M_0 = (1 - t/2T_1)^{1/2}\ \mathbb{1}$
$M_1 = (t/2T_1)^{1/2}\ \sigma_x$
$\rho(dt) = (1 - dt/2T_1)\ \mathbb{1}\ \rho(0)\ \mathbb{1} + t/2T_1\ \sigma_x\ \rho(0)\ \sigma_x$
$\frac{d\rho}{dt} = -\frac{\rho(0)}{2T_1} + \frac{\sigma_x\ \rho(0)\ \sigma_x}{2T_1}$

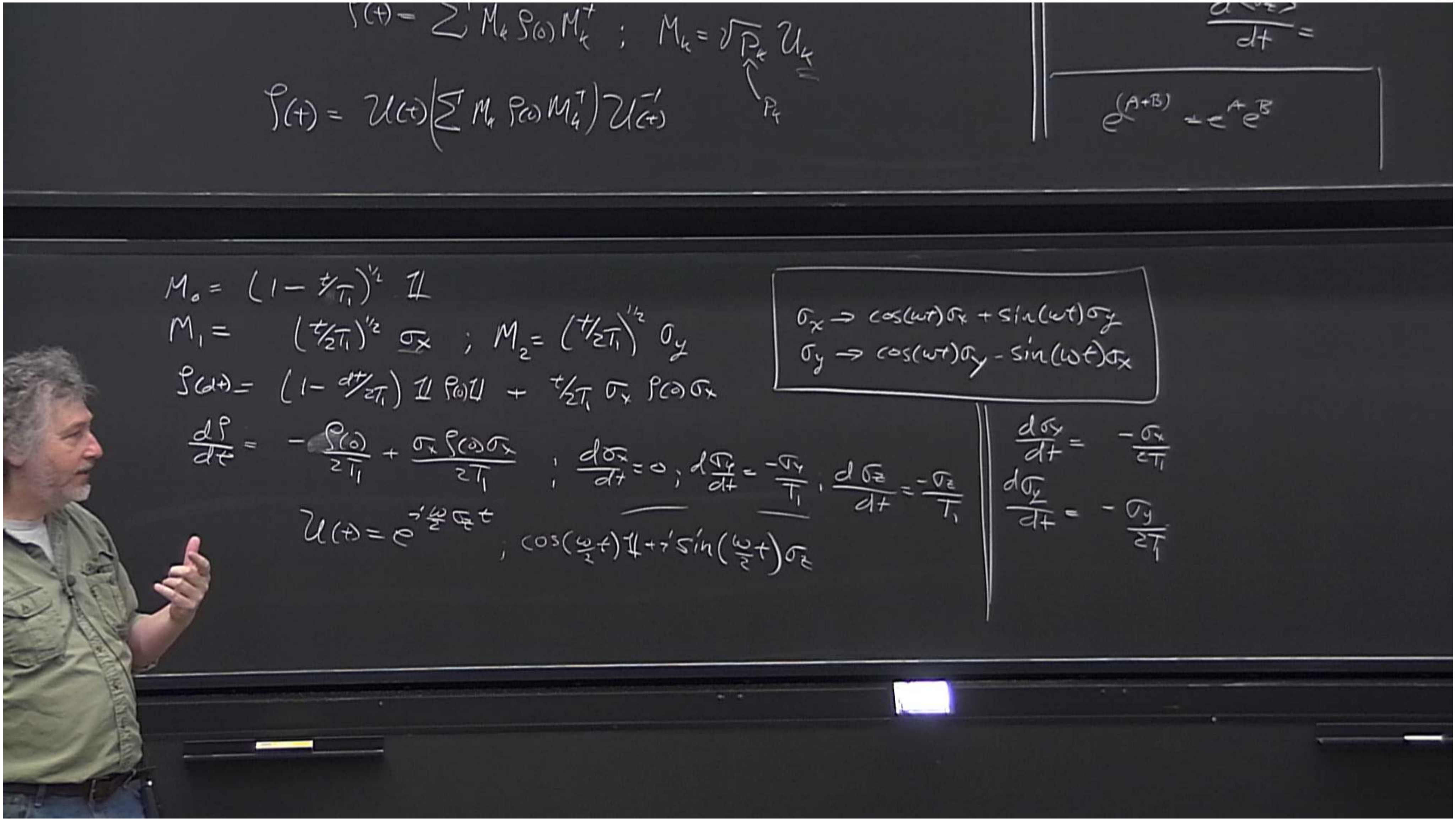

$M_1 = (t/2T_1)^{1/2}\, \sigma_x$
$\rho(dt) = (1 - dt/2T_1)\, 1\!\!1\, \rho(0)\, 1\!\!1 + t/2T_1\, \sigma_x\, \rho(0)\, \sigma_x$
$\frac{d\rho}{dt} = -\frac{\rho(0)}{2T_1} + \frac{\sigma_x \rho(0) \sigma_x}{2T_1}$; $\frac{d\sigma_x}{dt} = 0$;

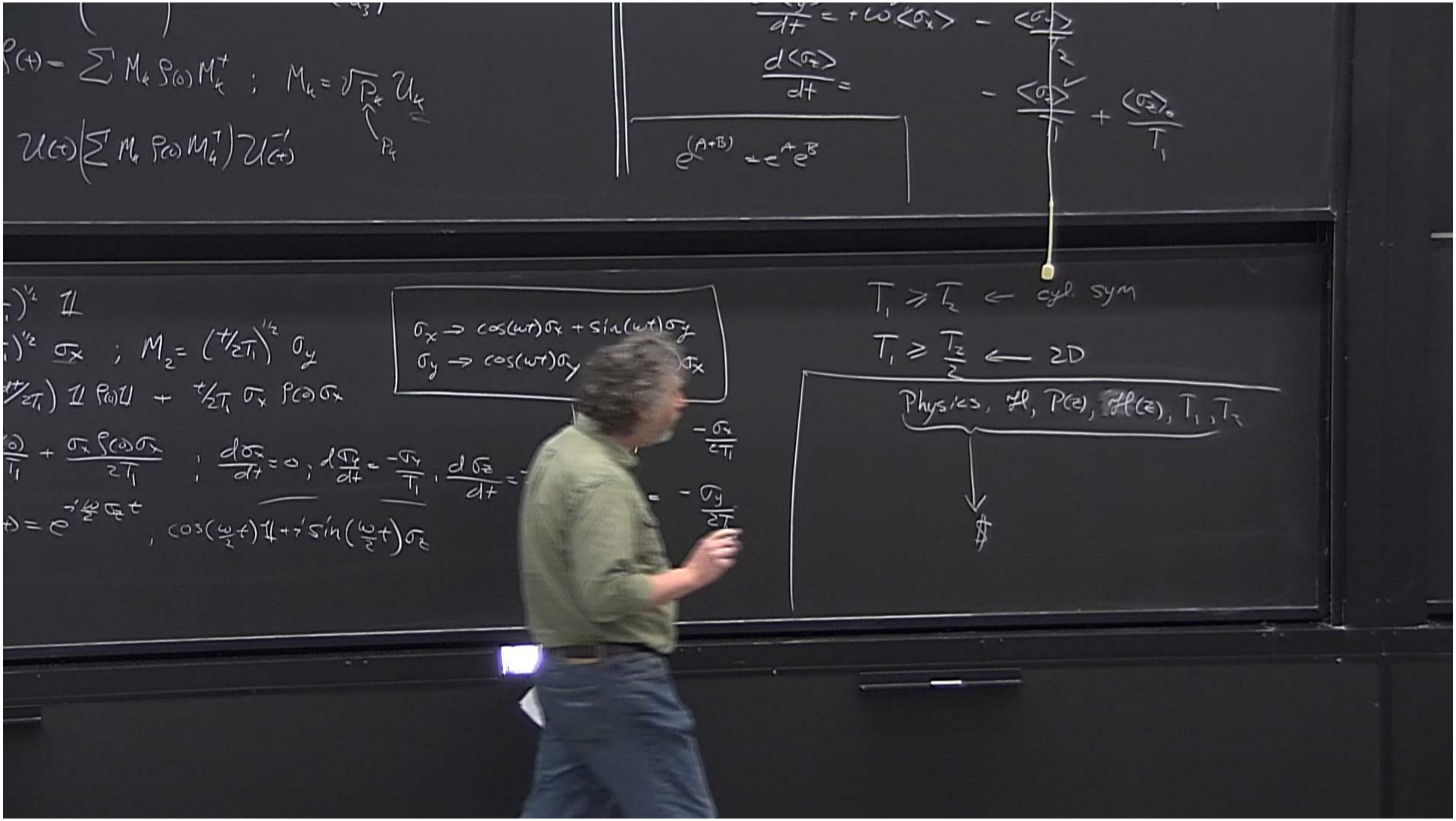

$\rho(t) = \sum M_k \rho(0) M_k^\dagger$; $M_k = \sqrt{p_k}\, U_k$
$\rho(t) = U(t)\left(\sum M_k \rho(0) M_k^\dagger\right) U^{-1}(t)$
$\frac{d\rho}{dt} = -\frac{\rho(0)}{2T_1} + \frac{\sigma_x \rho(0) \sigma_x}{2T_1}$; $\frac{d\sigma_x}{dt} = 0$; $\frac{d\sigma_y}{dt} = \frac{-\sigma_y}{T_1}$; $\frac{d\sigma_z}{dt} = \frac{-\sigma_z}{T_1}$



$\rho(t) = \mathcal{U}(t)\left(\sum M_\mu \rho(0) M_\mu^\dagger\right) \mathcal{U}^\dagger(t)$
$M_0 = (1 - t/2T_1)^{1/2}\, \mathbb{1}$
$M_1 = (t/2T_1)^{1/2}\, \sigma_x$
$\rho(dt) = (1 - dt/2T_1)\, \mathbb{1}\, \rho(0)\, \mathbb{1} + t/2T_1\, \sigma_x\, \rho(0)\, \sigma_x$
$\frac{d\rho}{dt} = -\frac{\rho(0)}{2T_1} + \frac{\sigma_x \rho(0) \sigma_x}{2T_1}$; $\frac{d\sigma_x}{dt} = 0$; $\frac{d\sigma_y}{dt} = \frac{-\sigma_y}{T_1}$; $\frac{d\sigma_z}{dt} = \frac{-\sigma_z}{T_1}$
$\mathcal{U}(t) = e^{-i\frac{\omega}{2}\sigma_z t}$; $\cos(\frac{\omega}{2}t)\,\mathbb{1} + i\sin(\frac{\omega}{2}t)\,\sigma_z$
$\sigma_x \to \cos(\omega t)\sigma_x + \sin(\omega t)\sigma_y$
$\sigma_y \to \cos(\omega t)\sigma_y - \sin(\omega t)\sigma_x$


ρ(t) = U(t)(Σ M_k ρ(0) M_k†) U(t)†
e^(A+B) ≠ e^A e^B
M_0 = (1 − t/2T_1)^½ 𝟙
M_1 = (t/2T_1)^½ σ_x
ρ(dt) = (1 − dt/2T_1) 𝟙 ρ(0) 𝟙 + t/2T_1 σ_x ρ(0) σ_x
dρ/dt = − ρ(0)/2T_1 + σ_x ρ(0) σ_x/2T_1 ; dσ_x/dt = 0 ; dσ_y/dt = −σ_y/T_1 ; dσ_z/dt = −σ_z/T_1
U(t) = e^(−i ω/2 σ_z t) ; cos(ω/2 t) 𝟙 + i sin(ω/2 t) σ_z
σ_x → cos(ωt) σ_x + sin(ωt) σ_y
σ_y → cos(ωt) σ_y − sin(ωt) σ_x
dσ_x/dt = −σ_x/2T_1
dσ_y/dt = −σ_y/2T_1


ρ(t) = Σ' M_k ρ(0) M_k^† ; M_k = √p_k U_k
ρ(t) = U(t) (Σ' M_k ρ(0) M_k^†) U^{-1}(t)
p_k
d/dt =
e^(A+B) ≠ e^A e^B
M_0 = (1 − t/T_1)^{1/2} 𝟙
M_1 = (t/2T_1)^{1/2} σ_x ; M_2 = (t/2T_1)^{1/2} σ_y
ρ(dt) = (1 − dt/2T_1) 𝟙 ρ(0) 𝟙 + t/2T_1 σ_x ρ(0) σ_x
dρ/dt = − ρ(0)/2T_1 + σ_x ρ(0) σ_x/2T_1 ; dσ_x/dt = 0 ; dσ_y/dt = −σ_y/T_1 ; dσ_z/dt = −σ_z/T_1
U(t) = e^{−i ω/2 σ_z t} ; cos(ω/2 t) 𝟙 + i sin(ω/2 t) σ_z
σ_x → cos(ωt) σ_x + sin(ωt) σ_y
σ_y → cos(ωt) σ_y − sin(ωt) σ_x
dσ_x/dt = −σ_x/2T_1
dσ_y/dt = −σ_y/2T_1


T1 ≫ T2 ← cyl. sym
T1 ≥ T2/2 ← 2D
Physics, H, P(z), H(z), T1, T2

$$\rho_{out}(t) = \int P(z)\, \mathcal{U}(z,t)\, \rho(0)\, \mathcal{U}^{-1}(z,t)\, dz$$

$$\tilde{\rho}_{out}(t) = \$\ \tilde{\rho}(0) \quad ; \quad \rho = a_0 \mathbb{1} + a_1\sigma_x + a_2\sigma_y + a_3\sigma_z$$

$$\tilde{\rho} = \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{pmatrix}$$

$$\rho(t) = \sum M_k \rho(0) M_k^\dagger \quad ; \quad M_k = \sqrt{p_k}\, \mathcal{U}_k$$

$$\rho(t) = \mathcal{U}(t)\left(\sum M_k \rho(0) M_k^\dagger\right)\mathcal{U}^{-1}(t)$$

qubit $\Rightarrow$ Bloch Sphere

Bloch Eqns

$$\frac{d\langle\sigma_x\rangle}{dt} = -\omega\langle\sigma_y\rangle - \frac{\langle\sigma_x\rangle}{T_2}$$

$$\frac{d\langle\sigma_y\rangle}{dt} = +\omega\langle\sigma_x\rangle - \frac{\langle\sigma_y\rangle}{T_2}$$

$$\frac{d\langle\sigma_z\rangle}{dt} = \quad - \frac{\langle\sigma_z\rangle}{T_1} + \frac{\langle\sigma_z\rangle_0}{T_1}$$

$$e^{(A+B)} \neq e^A e^B$$

$SU(2) \cong O(3)$

$$\mathcal{H}_{Zeeman} = \frac{\omega}{2}\sigma_z$$

$T_2\ ,\ T_1$

$$M_0 = (1 - t/T_1)^{1/2}\, \mathbb{1}$$

$$M_1 = (t/2T_1)^{1/2}\, \sigma_x \quad ; \quad M_2 = (t/2T_1)^{1/2}\, \sigma_y$$

$$\rho(dt) = (1 - dt/2T_1)\, \mathbb{1}\rho(0)\mathbb{1} + t/2T_1\, \sigma_x \rho(0) \sigma_x$$

$$\frac{d\rho}{dt} = -\frac{\rho(0)}{2T_1} + \frac{\sigma_x \rho(0) \sigma_x}{2T_1} \quad ; \quad \frac{d\sigma_x}{dt} = 0 \ ; \ \frac{d\sigma_y}{dt} = \frac{-\sigma_y}{T_1} \ ; \ \frac{d\sigma_z}{dt} = \frac{-\sigma_z}{T_1}$$

$$\mathcal{U}(t) = e^{-i\frac{\omega}{2}\sigma_z t}, \quad \cos\left(\tfrac{\omega}{2}t\right)\mathbb{1} + i\sin\left(\tfrac{\omega}{2}t\right)\sigma_z$$

$$\sigma_x \Rightarrow \cos(\omega t)\sigma_x + \sin(\omega t)\sigma_y$$

$$\sigma_y \Rightarrow \cos(\omega t)\sigma_y - \sin(\omega t)\sigma_x$$

$$\frac{d\sigma_x}{dt} = \frac{-\sigma_x}{2T_1}$$

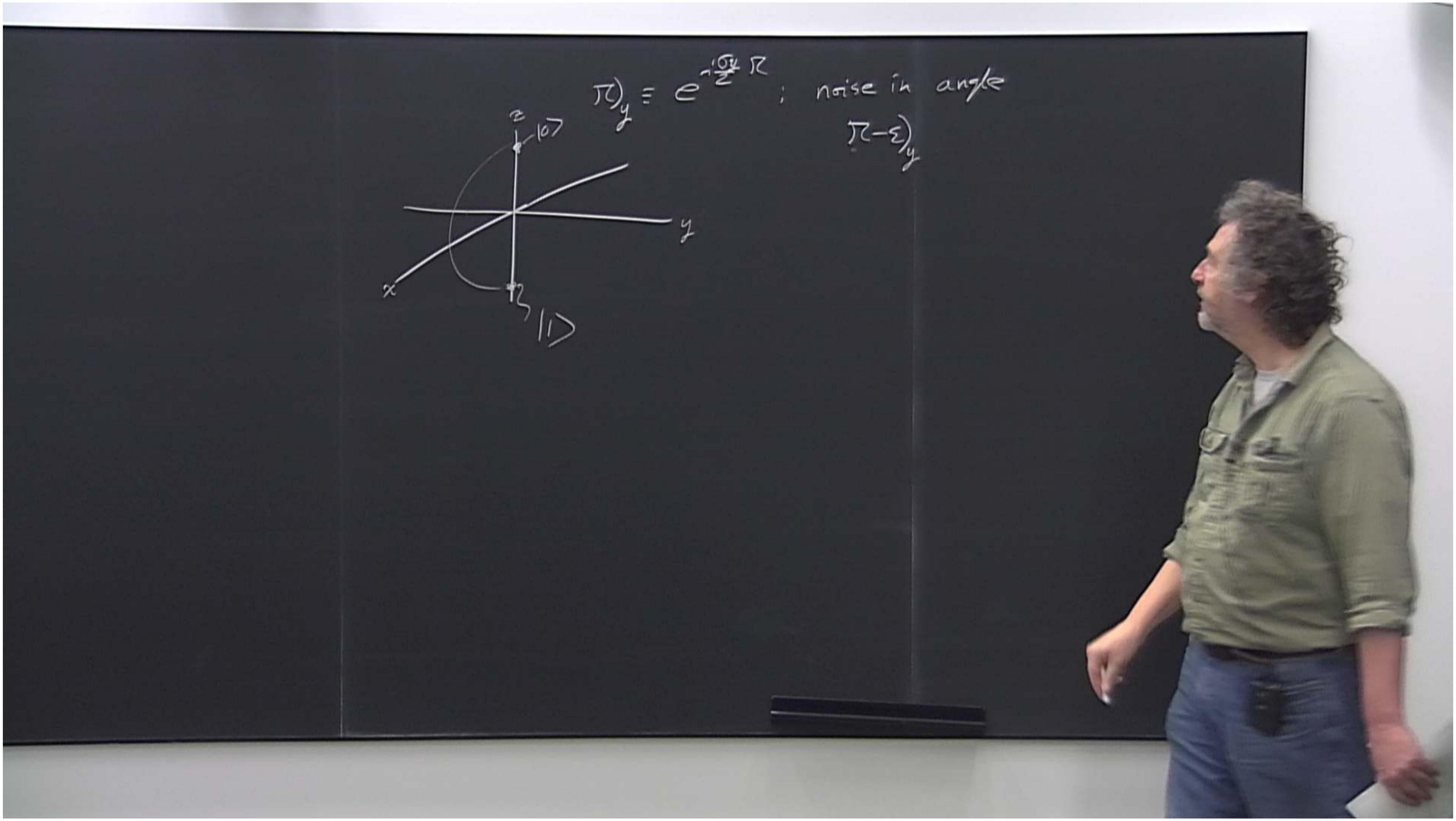
$$\frac{d\sigma_y}{dt} = -\frac{\sigma_y}{2T_1}$$

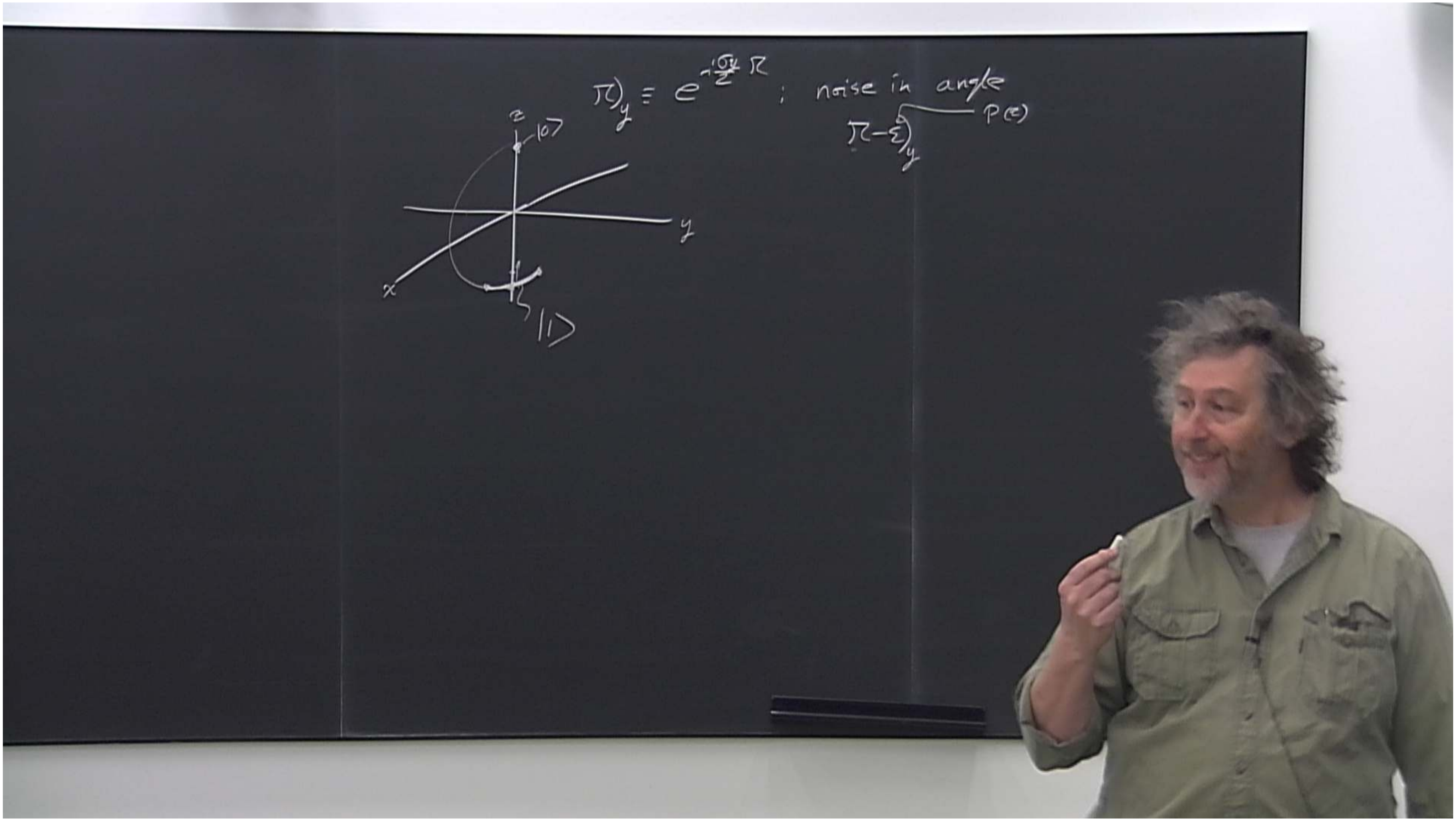
$T_1 \gg T_2 \leftarrow$ cyl. sym

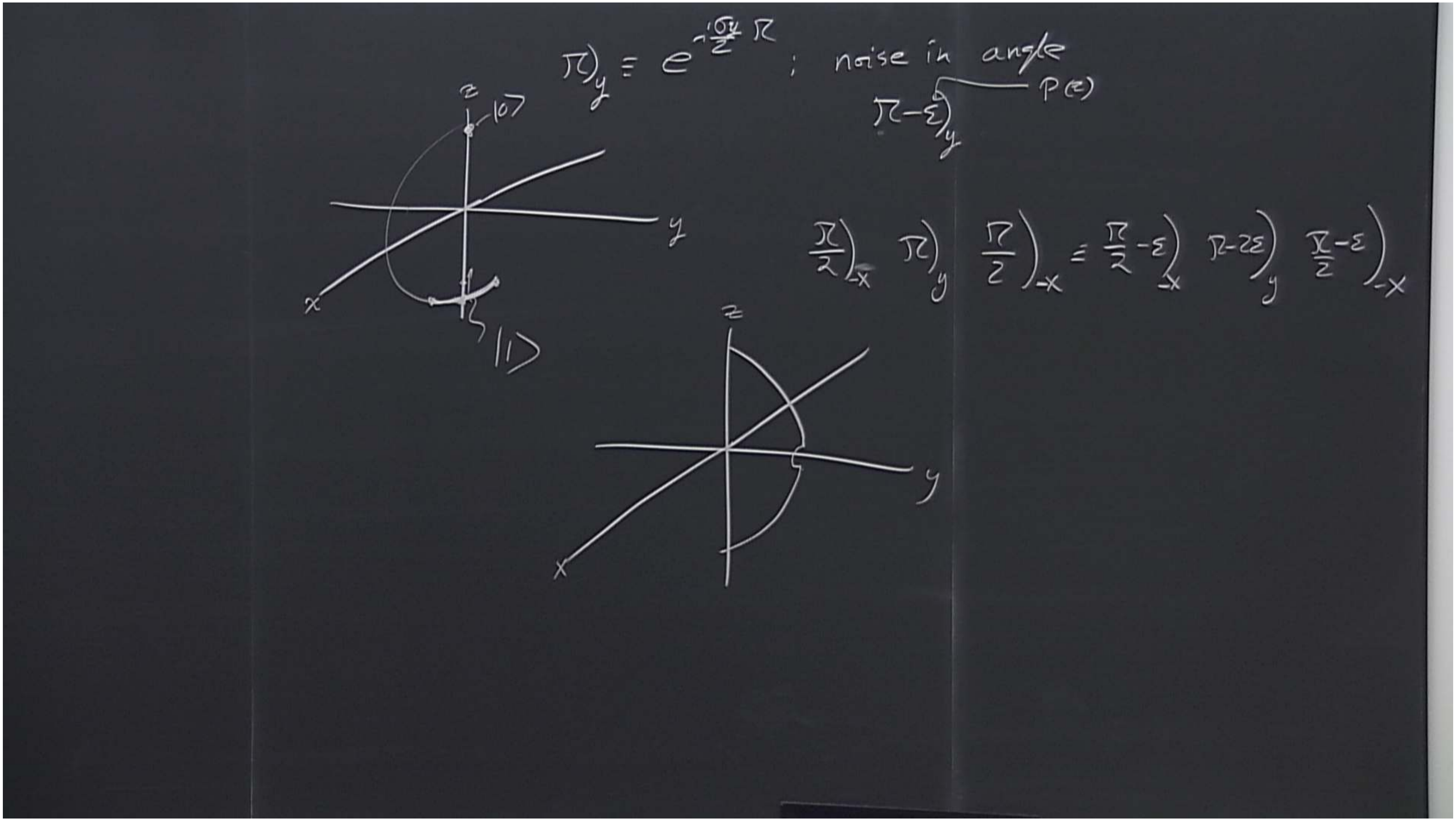
$T_1 \geq \frac{T_2}{2} \longleftarrow$ 2D

Physics, $\mathcal{H}$, $P(z)$, $\mathcal{H}(z)$, T_1, T_2

$\{M_k\}$ $\$$ — Choi


π)y ≡ e^(-iσy/2 π) ; noise in angle
π−ε)y
z
|0>
y
x
|1>


noise in angle
P(ε)
|0>
|1>
x
y
z


π)y ≡ e^(-iσy/2 π) ; noise in angle
π−ε)y — P(ε)
z
|0>
y
x
|1>
π/2)-x π)y π/2)-x = π/2−ε)-x π−2ε)y π/2−ε)-x
z
y
x

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help Wed 9:40 AM dcory

Composite Rot.cdf

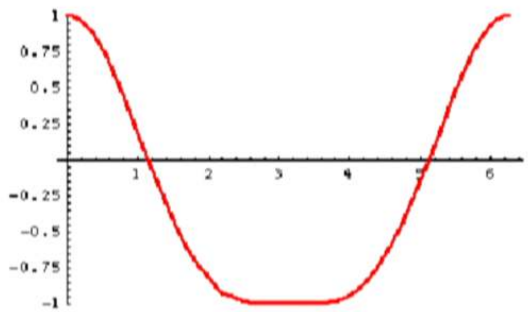
Mathematica Version Advisory

This notebook was created in an earlier version of Mathematica

Most notebooks run without change. This tool scans for possible issues and suggests changes.

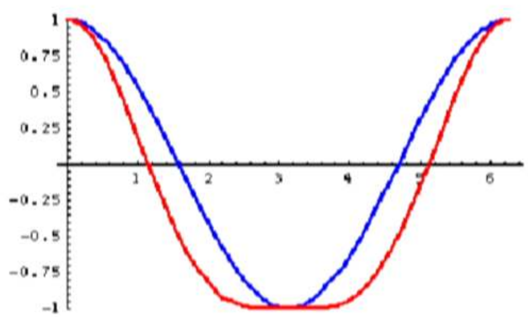
Scan for possible issues | Do not scan this notebook | Never scan notebooks

```
p2 = Plot[MzCrot[a][[3]], {a, 0, 2 Pi}, {PlotRange -> {-1, 1}, PlotStyle → {Thickness[0.01], RGBColor[1, 0, 0]}}]
```



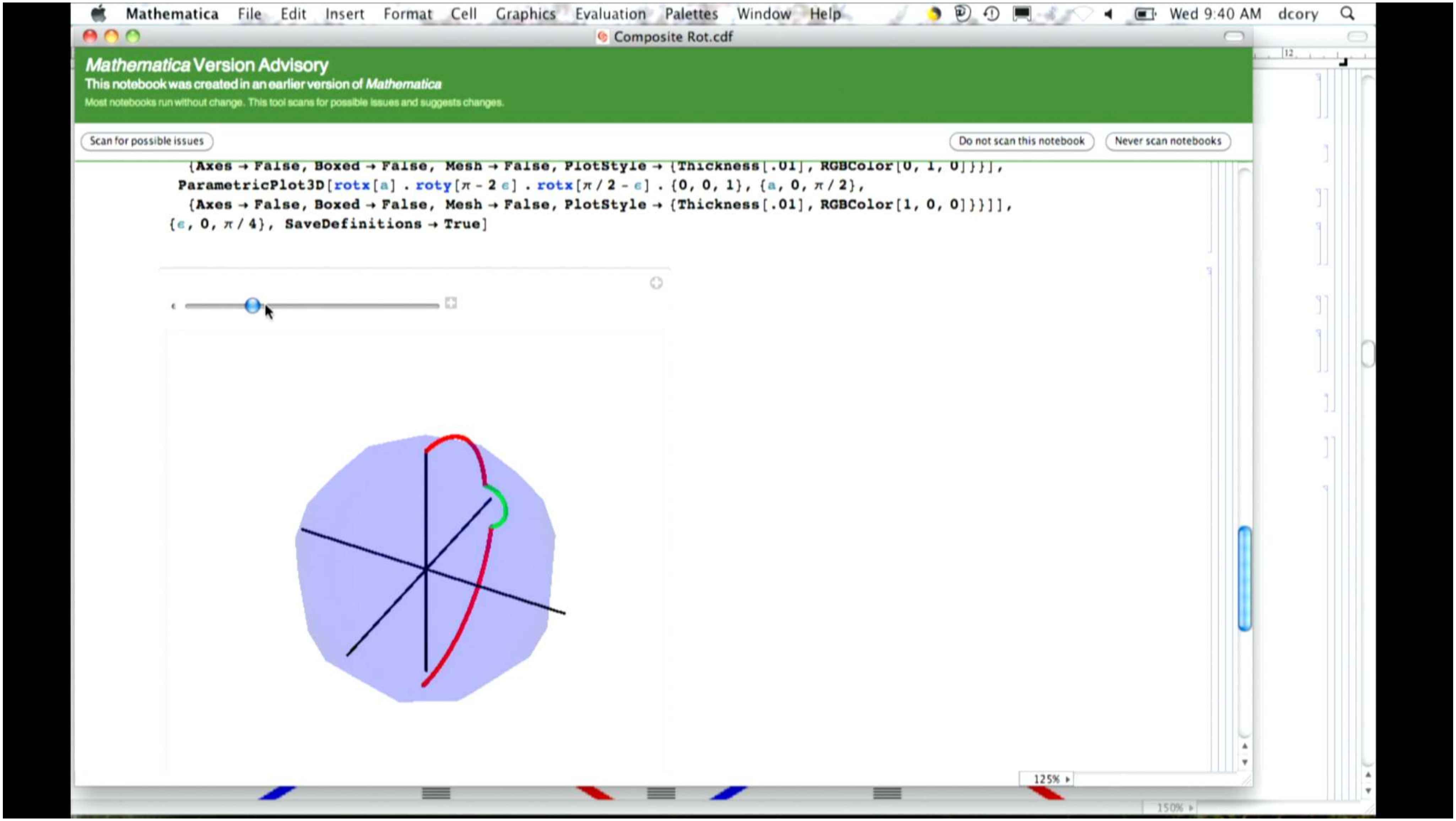
- Graphics -

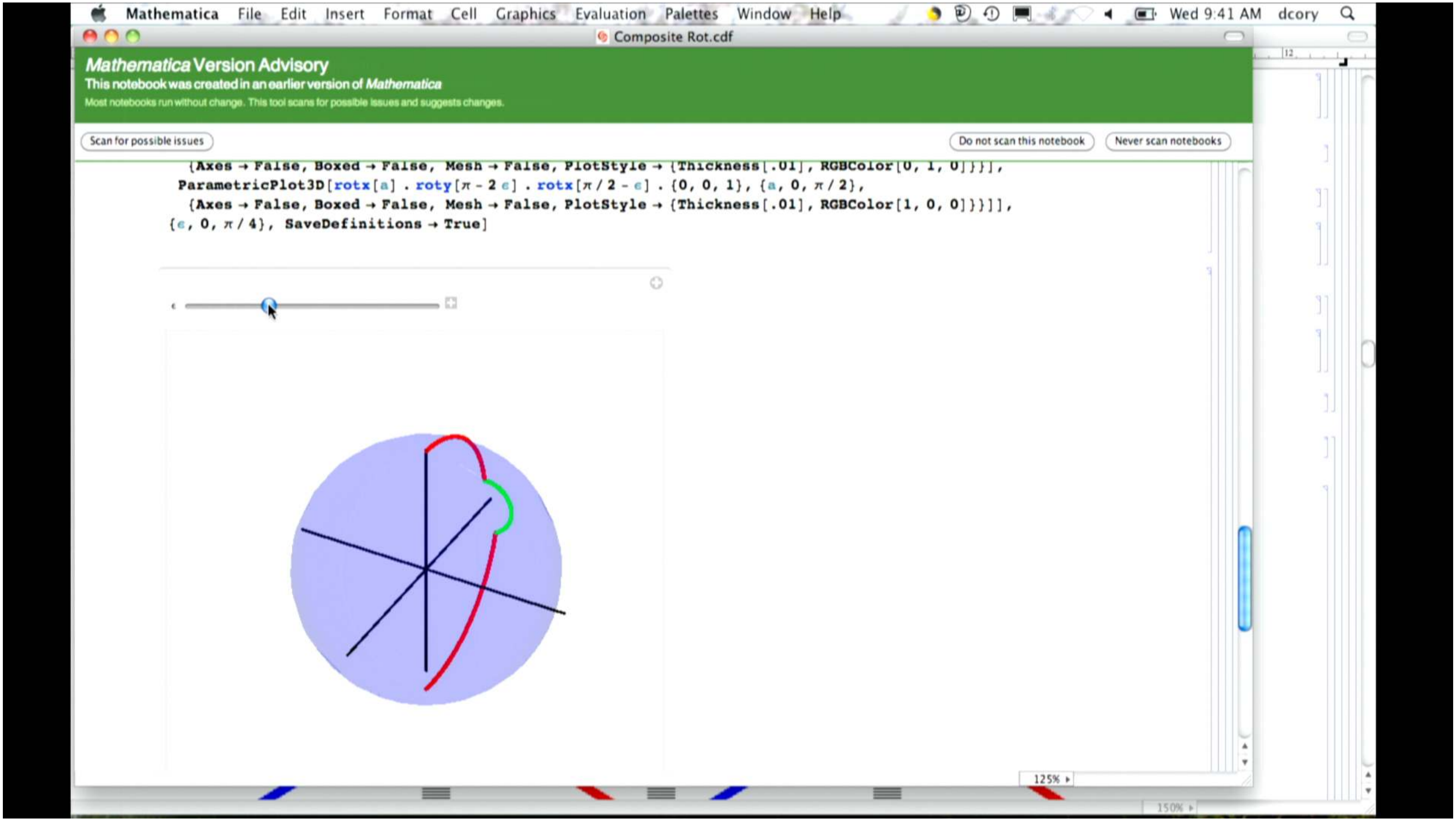
```
Show[p1, p2]
```

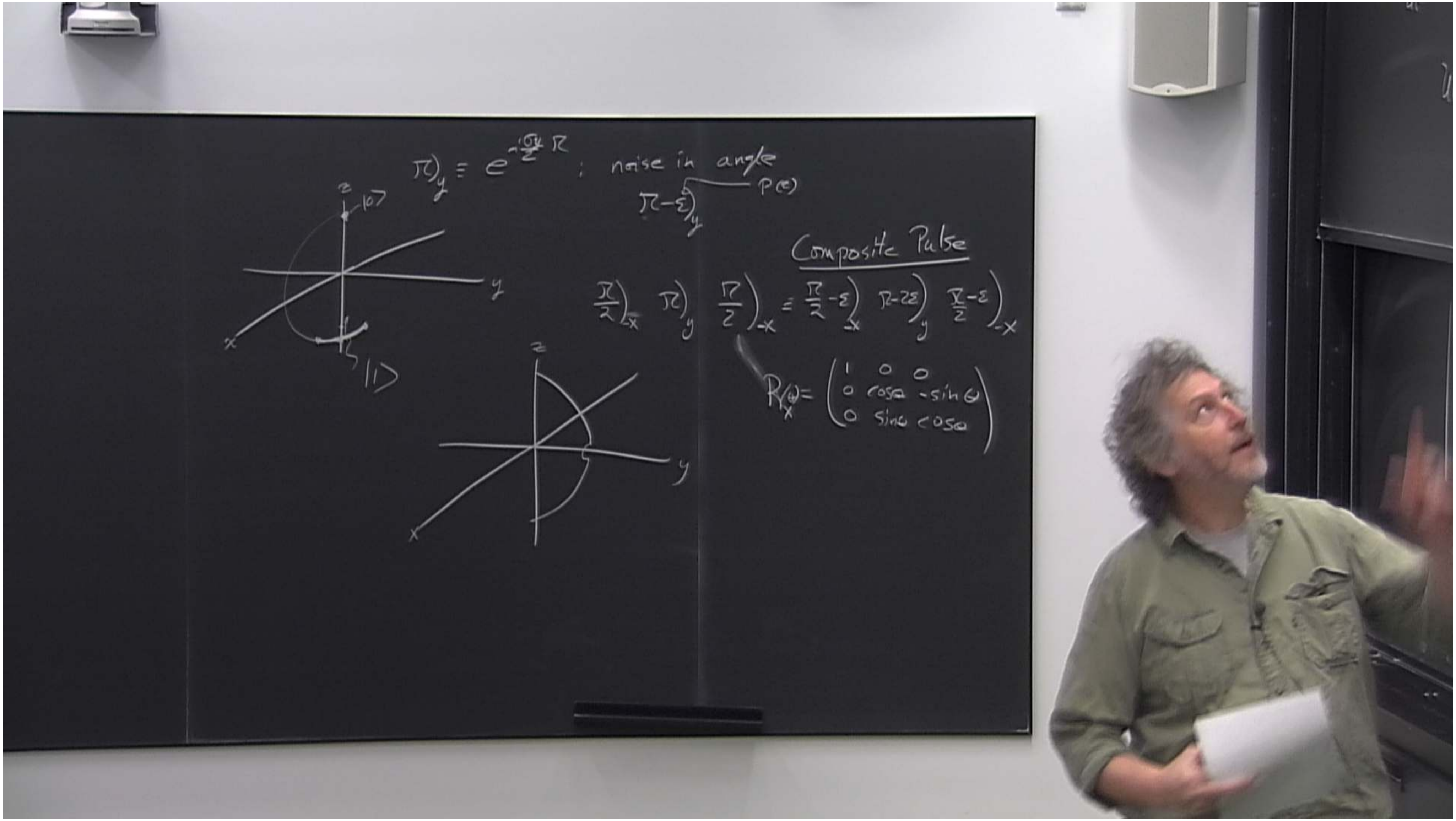


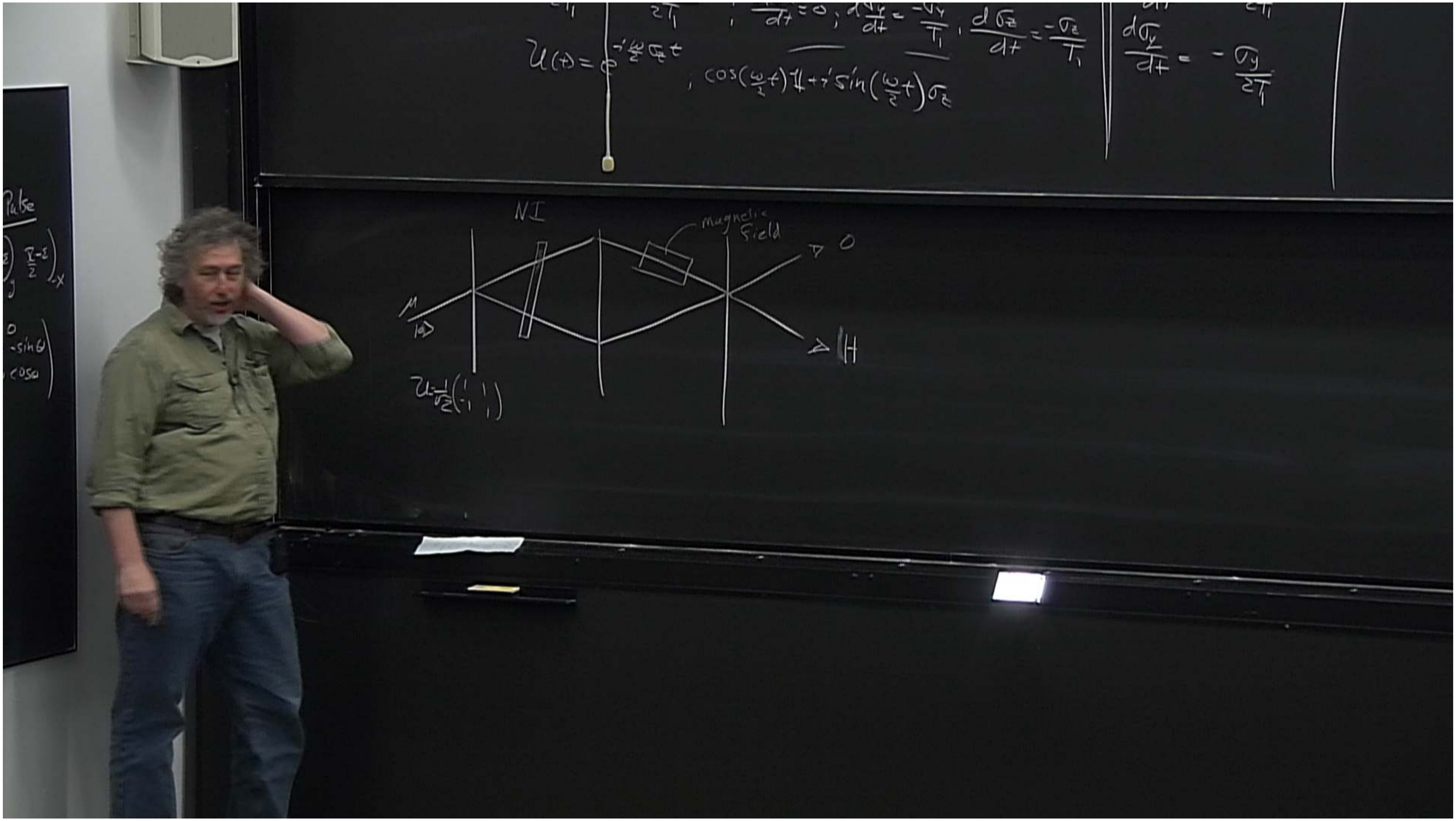
- Graphics -

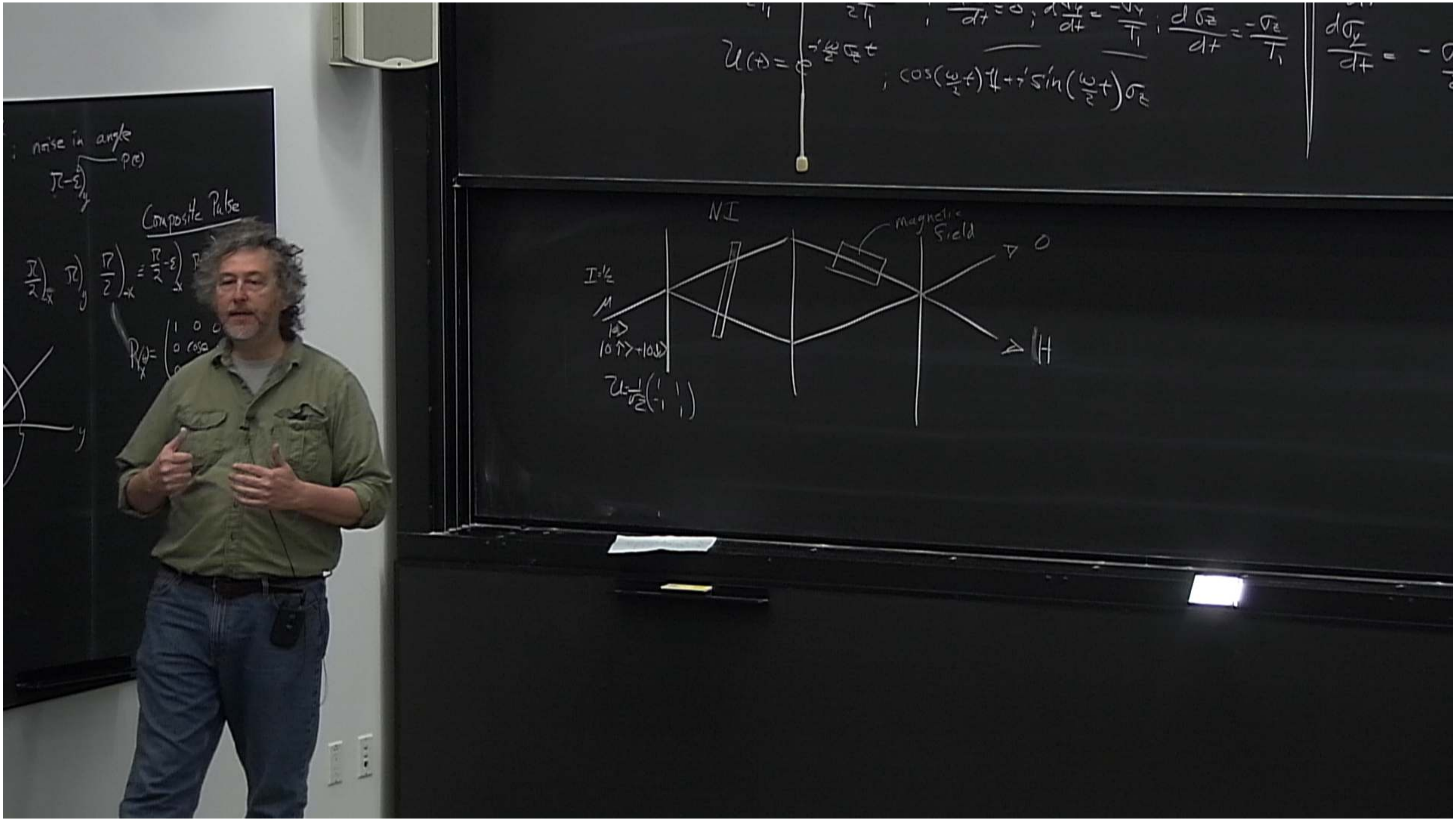
125%

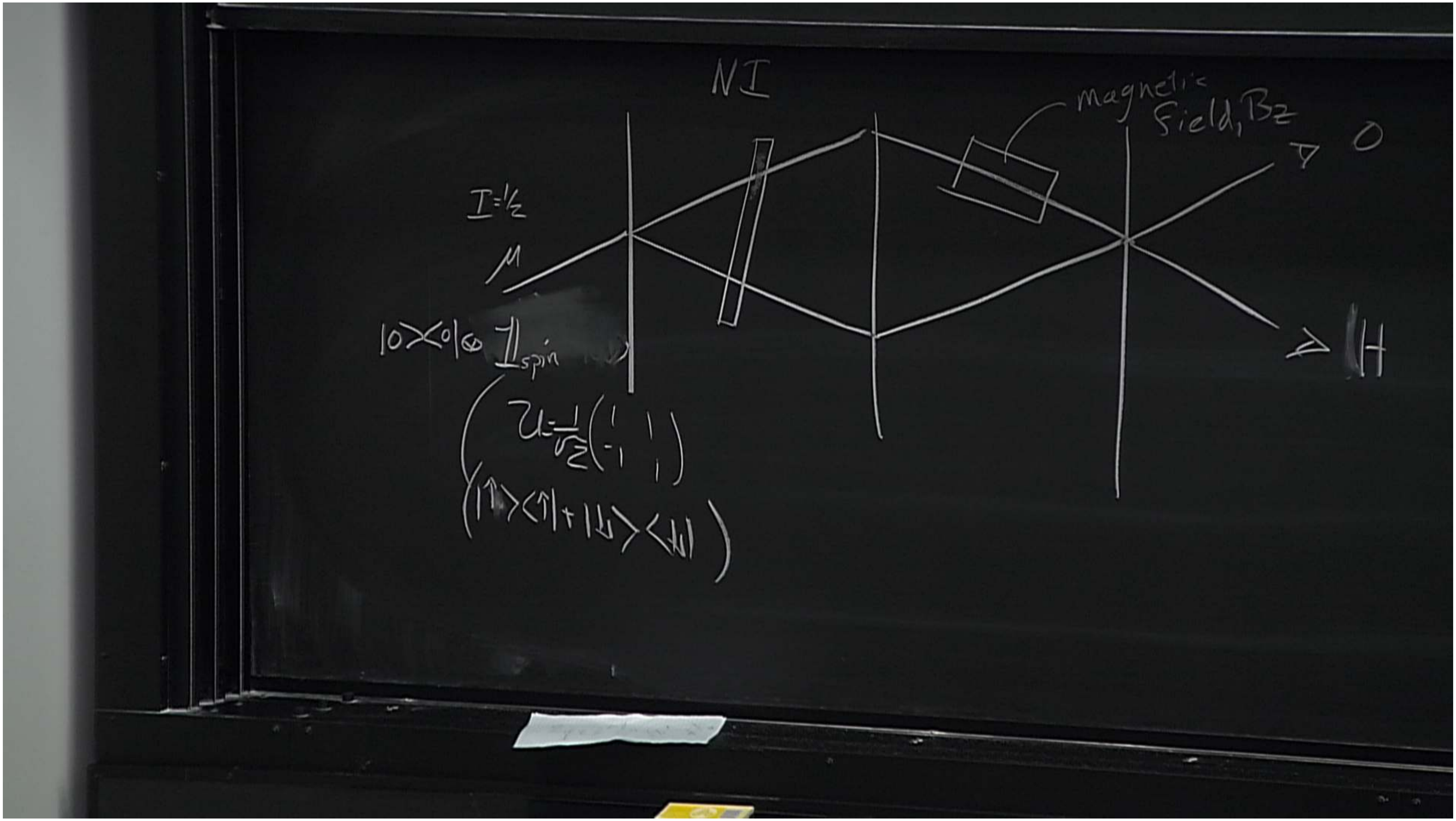

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Wed 9:40 AM dcory
Composite Rot.cdf
Mathematica Version Advisory
This notebook was created in an earlier version of Mathematica
Most notebooks run without change. This tool scans for possible issues and suggests changes.
Scan for possible issues
Do not scan this notebook
Never scan notebooks
{Axes → False, Boxed → False, Mesh → False, PlotStyle → {Thickness[.01], RGBColor[0, 1, 0]}}],
ParametricPlot3D[rotx[a] . roty[π - 2 ϵ] . rotx[π / 2 - ϵ] . {0, 0, 1}, {a, 0, π / 2},
{Axes → False, Boxed → False, Mesh → False, PlotStyle → {Thickness[.01], RGBColor[1, 0, 0]}}]],
{ϵ, 0, π / 4}, SaveDefinitions → True]
125%
150%

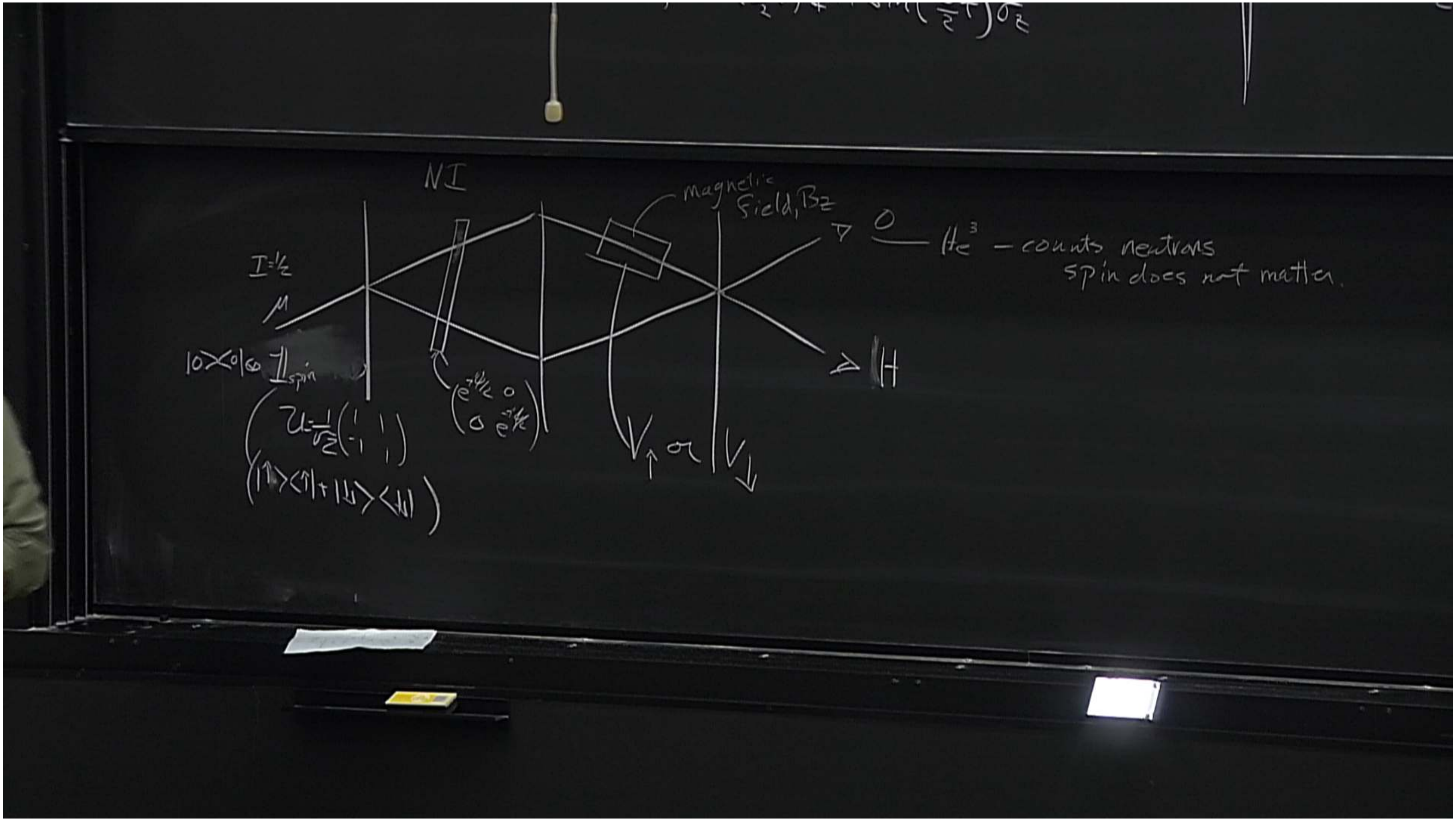

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Wed 9:41 AM dcory
Composite Rot.cdf
Mathematica Version Advisory
This notebook was created in an earlier version of Mathematica
Most notebooks run without change. This tool scans for possible issues and suggests changes.
Scan for possible issues
Do not scan this notebook
Never scan notebooks
{Axes → False, Boxed → False, Mesh → False, PlotStyle → {Thickness[.01], RGBColor[0, 1, 0]}}],
ParametricPlot3D[rotx[a] . roty[π - 2 ε] . rotx[π / 2 - ε] . {0, 0, 1}, {a, 0, π / 2},
{Axes → False, Boxed → False, Mesh → False, PlotStyle → {Thickness[.01], RGBColor[1, 0, 0]}}]],
{ε, 0, π / 4}, SaveDefinitions → True]
125%
150%


noise in angle
P(ε)
Composite Pulse
z
|0>
|1>
y
x


NI
magnetic field
|0⟩
|1⟩




NI
magnetic field, Bz
I=½
μ
0
H


NI
magnetic field, Bz
He³ – counts neutrons
spin does not matter
I=½
H
V↑ or V↓

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help Wed 9:54 AM dcory

Composite Rot.cdf

QE Lec 3.cdf

```
res5up[a_, b_] := TrigReduce[
  ExpToTrig[Simplify[Ubladeg[π / 4] . Um . Uphase[a] . Usample[b] . Ubladeg[π / 4] . in .
     Ubladeginv[π / 4] . Uphaseinv[a] . Usampleinv[b] . Uminv . Ubladeginv[π / 4]]]]

res5up[a, b]
```

$$\left\{\left\{\frac{1}{2}(1+\text{Cos}[a+b]),\ \frac{1}{2}\,i\,\text{Sin}[a+b]\right\},\ \left\{-\frac{1}{2}\,i\,\text{Sin}[a+b],\ \frac{1}{2}(1-\text{Cos}[a+b])\right\}\right\}$$

```
res5down[a_, b_] := TrigReduce[ExpToTrig[
   Simplify[Ubladeg[π / 4] . Um . Uphase[a] . Usample[-b] . Ubladeg[π / 4] . in .
     Ubladeginv[π / 4] . Uphaseinv[a] . Usampleinv[-b] . Uminv . Ubladeginv[π / 4]]]]
```

Note that the magnetic phase is directly proportional to the z-component of the neutron spin.

```
M5Oup[a_, b_] := Tr[Ezp . res5up[a, b]]
M5Odown[a_, b_] := Tr[Ezp . res5down[a, b]]
M5Hup[a_, b_] := Tr[Ezm . res5up[a, b]]
M5Hdown[a_, b_] := Tr[Ezm . res5down[a, b]]
```

For an unpolarized neutron beam we start with an equal mixture of spin up and spin down. Note that there is no coherence in the spin state: it is up or down with equal probability.

```
M5O[a_, b_] := (M5Oup[a, b] + M5Odown[a, b]) / 2
M5H[a_, b_] := (M5Hup[a, b] + M5Hdown[a, b]) / 2
Animate[
 Show[Plot[M5O[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
    PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}],
  Plot[M5H[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
    PlotStyle → {RGBColor[1, 0, 0], Thickness[0.01]}, PlotRange → {0, 1}}]],
 {b, 0, 2 π}, AnimationRunning → False]
```

b

200%

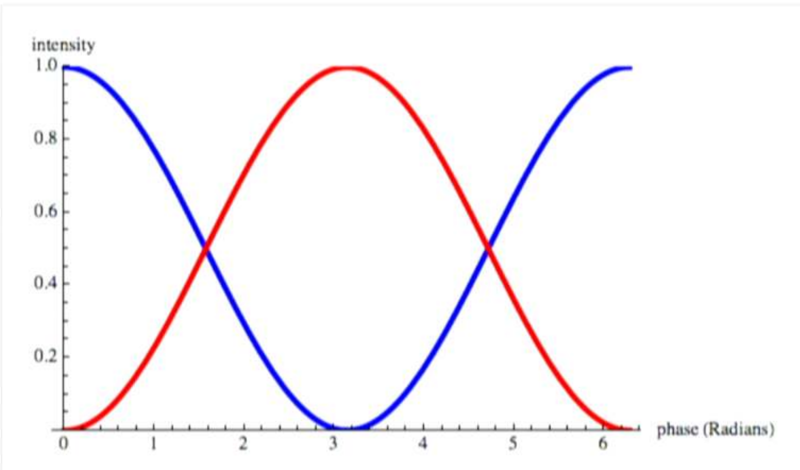
For an unpolarized neutron beam we start with an equal mixture of spin up and spin down. Note that there is no coherence in the spin state: it is up or down with equal probability.

```
M5O[a_, b_] := (M5Oup[a, b] + M5Odown[a, b]) / 2

M5H[a_, b_] := (M5Hup[a, b] + M5Hdown[a, b]) / 2

Animate[
 Show[Plot[M5O[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
    PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}],
  Plot[M5H[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
    PlotStyle → {RGBColor[1, 0, 0], Thickness[0.01]}, PlotRange → {0, 1}}]],
 {b, 0, 2 π}, AnimationRunning → False]
```

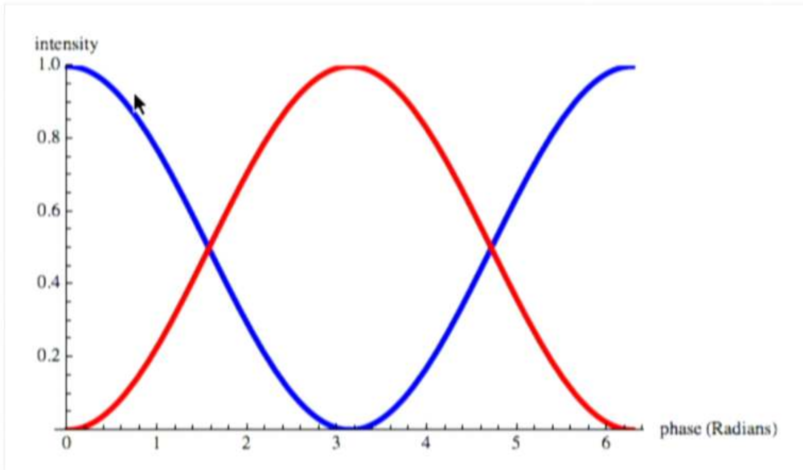
b



If we plot what happens to the two spin states then the total picture is easier to see. Of course we can do this

```
Animate[
 Show[Plot[M5O[a, b], {a, 0, 2 π}, {AxesLabel → {"phase  (Radians)", "intensity" },
    PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}],
  Plot[M5H[a, b], {a, 0, 2 π}, {AxesLabel → {"phase  (Radians)", "intensity" },
    PlotStyle → {RGBColor[1, 0, 0], Thickness[0.01]}, PlotRange → {0, 1}}]],
 {b, 0, 2 π}, AnimationRunning → False]
```

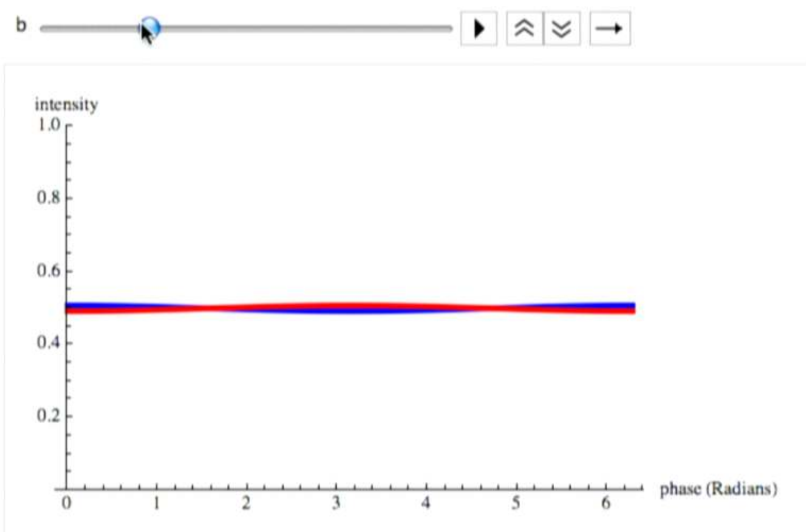
b



If we plot what happens to the two spin states then the total picture is easier to see. Of course we can do this experiment by either preparing the neutrons in a particular state or by using a spin polarized detector. Does it matter which we use?

```
Manipulate[Show[
  Plot[M5O[a, b], {a, 0, 2 π}, {AxesLabel → {"phase  (Radians)", "O-beam intensity" },
```

```
Animate[
 Show[Plot[M5O[a, b], {a, 0, 2 π}, {AxesLabel → {"phase  (Radians)", "intensity"},
    PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}],
  Plot[M5H[a, b], {a, 0, 2 π}, {AxesLabel → {"phase  (Radians)", "intensity"},
    PlotStyle → {RGBColor[1, 0, 0], Thickness[0.01]}, PlotRange → {0, 1}}]],
 {b, 0, 2 π}, AnimationRunning → False]
```



If we plot what happens to the two spin states then the total picture is easier to see. Of course we can do this experiment by either preparing the neutrons in a particular state or by using a spin polarized detector. Does it matter which we use?

```
Manipulate[Show[
  Plot[M5O[a, b], {a, 0, 2 π}, {AxesLabel → {"phase  (Radians)", "O-beam intensity"},
```

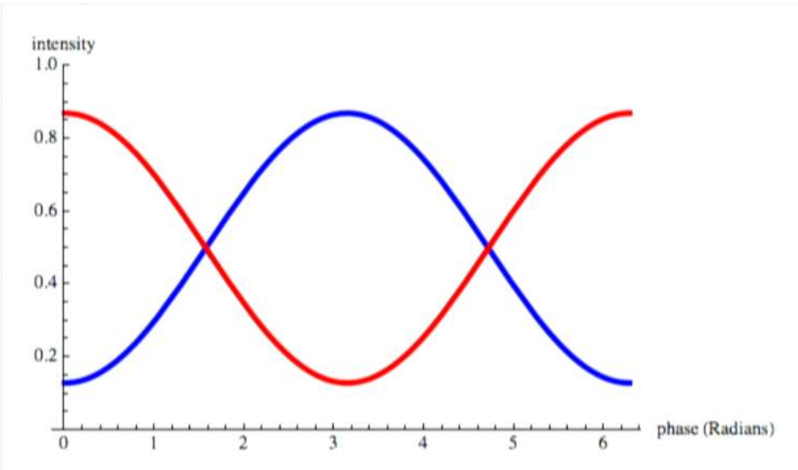
Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help Wed 9:56 AM dcory

Composite Rot.cdf

QE Lec 3.cdf

```
Animate[
 Show[Plot[M5O[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
    PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}],
  Plot[M5H[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
    PlotStyle → {RGBColor[1, 0, 0], Thickness[0.01]}, PlotRange → {0, 1}}]],
 {b, 0, 2 π}, AnimationRunning → False]
```

b



If we plot what happens to the two spin states then the total picture is easier to see. Of course we can do this experiment by either preparing the neutrons in a particular state or by using a spin polarized detector. Does it matter which we use?

```
Manipulate[Show[
  Plot[M5O[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "O-beam intensity"},
```

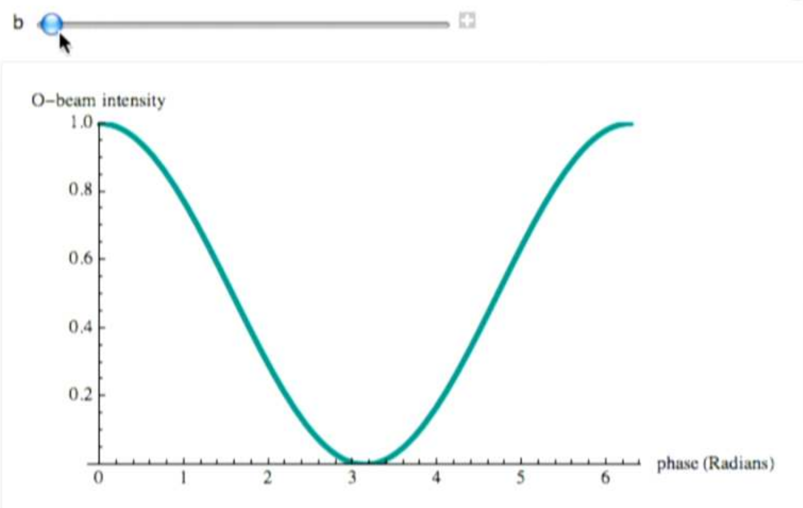
200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help Wed 9:56 AM dcory

Composite Rot.cdf

QE Lec 3.cdf

```
  Plot[M5Odown[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
    PlotStyle → {RGBColor[0, .5, .5], Thickness[0.01]}, PlotRange → {0, 1}}]],
 {b, 0, 2 π}, SaveDefinitions → True]
```




```
Manipulate[Show[
  Plot[M5H[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "H-beam intensity"},
    PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}],
  Plot[M5Hup[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
    PlotStyle → {RGBColor[0, 1, 0], Thickness[0.01]}, PlotRange → {0, 1}}],
  Plot[M5Hdown[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
    PlotStyle → {RGBColor[0, 0.5, 0.5], Thickness[0.01]}, PlotRange → {0, 1}}]],
 {b, 0, 2 π}, SaveDefinitions → True]
```

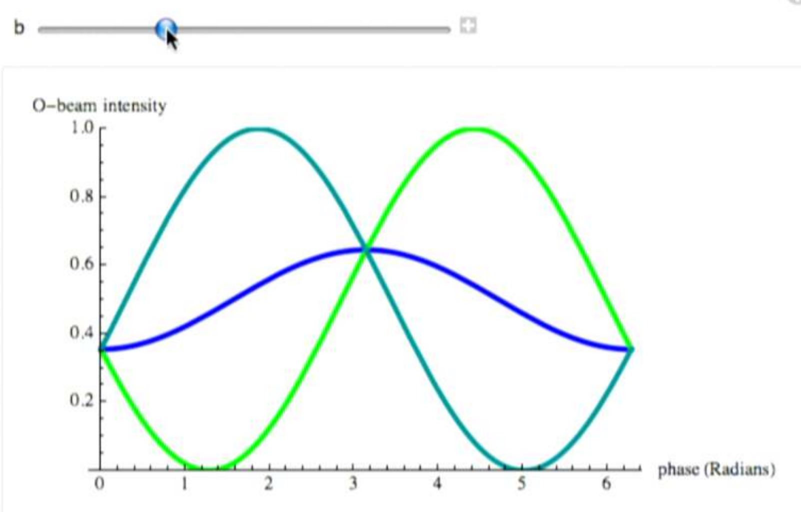
200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help Wed 9:57 AM dcory

Composite Rot.cdf

QE Lec 3.cdf

```
Plot[M5Odown[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
   PlotStyle → {RGBColor[0, .5, .5], Thickness[0.01]}, PlotRange → {0, 1}}]],
 {b, 0, 2 π}, SaveDefinitions → True]
```




```
Manipulate[Show[
  Plot[M5H[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "H-beam intensity"},
    PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}],
  Plot[M5Hup[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
    PlotStyle → {RGBColor[0, 1, 0], Thickness[0.01]}, PlotRange → {0, 1}}],
  Plot[M5Hdown[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
    PlotStyle → {RGBColor[0, 0.5, 0.5], Thickness[0.01]}, PlotRange → {0, 1}}]],
 {b, 0, 2 π}, SaveDefinitions → True]
```

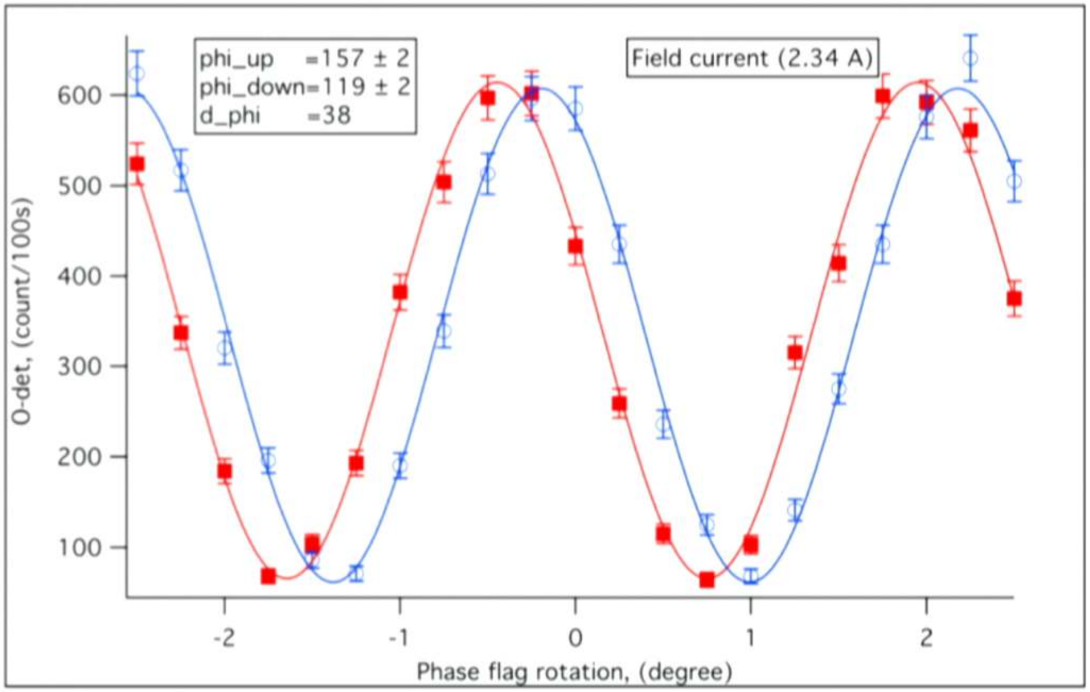
200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help Wed 10:00 AM dcory

Composite Rot.cdf

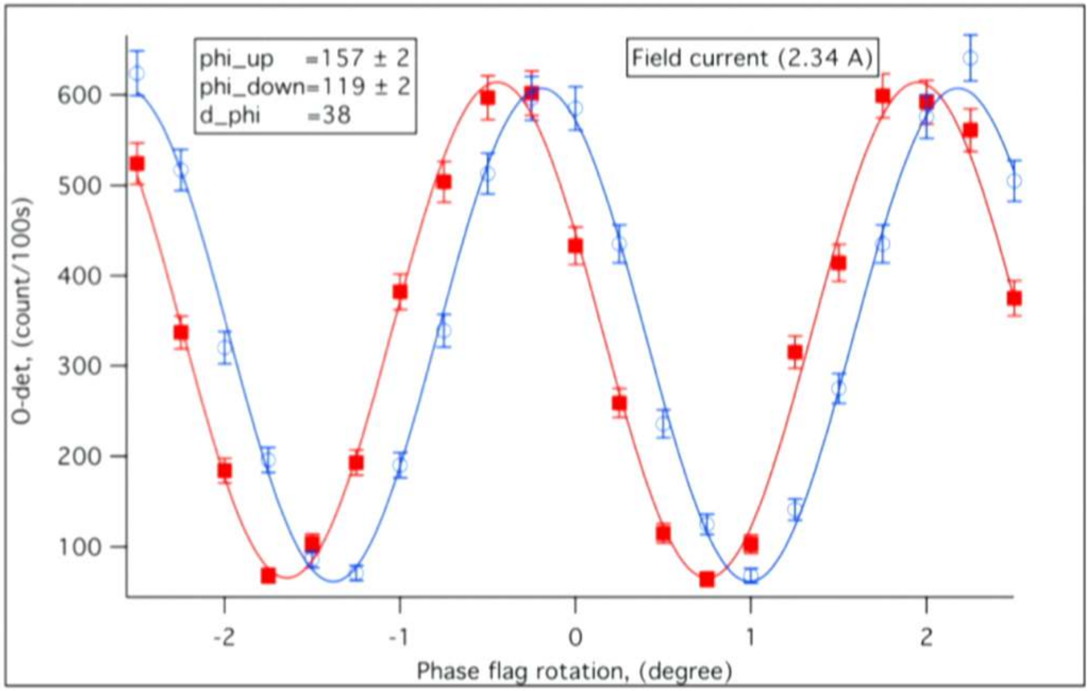
QE Lec 3.cdf

The phase flag can be magnetic and since the neutrons have spin we expect the contrast to be a function of this magnetic field. Here we look at a simple example where the spin degree of freedom remains separable throughout the experiment and thus we do not need to expand the Hilbert space to describe the experiment. Latter we will look at experiments where the spin and path degrees of freedom become entangled.



Here we must add a new description where we run two experiments one for each neutron spin state. Note the neutron is a spin 1/2 and the magnetic field in the sample is assumed to be uniform.

this magnetic field. Here we look at a simple example where the spin degree of freedom remains separable throughout the experiment and thus we do not need to expand the Hilbert space to describe the experiment. Latter we will look at experiments where the spin and path degrees of freedom become entangled.



Here we must add a new description where we run two experiments one for each neutron spin state. Note the neutron is a spin 1/2 and the magnetic field in the sample is assumed to be uniform.

```
res5up[a_, b_] := TrigReduce[
```