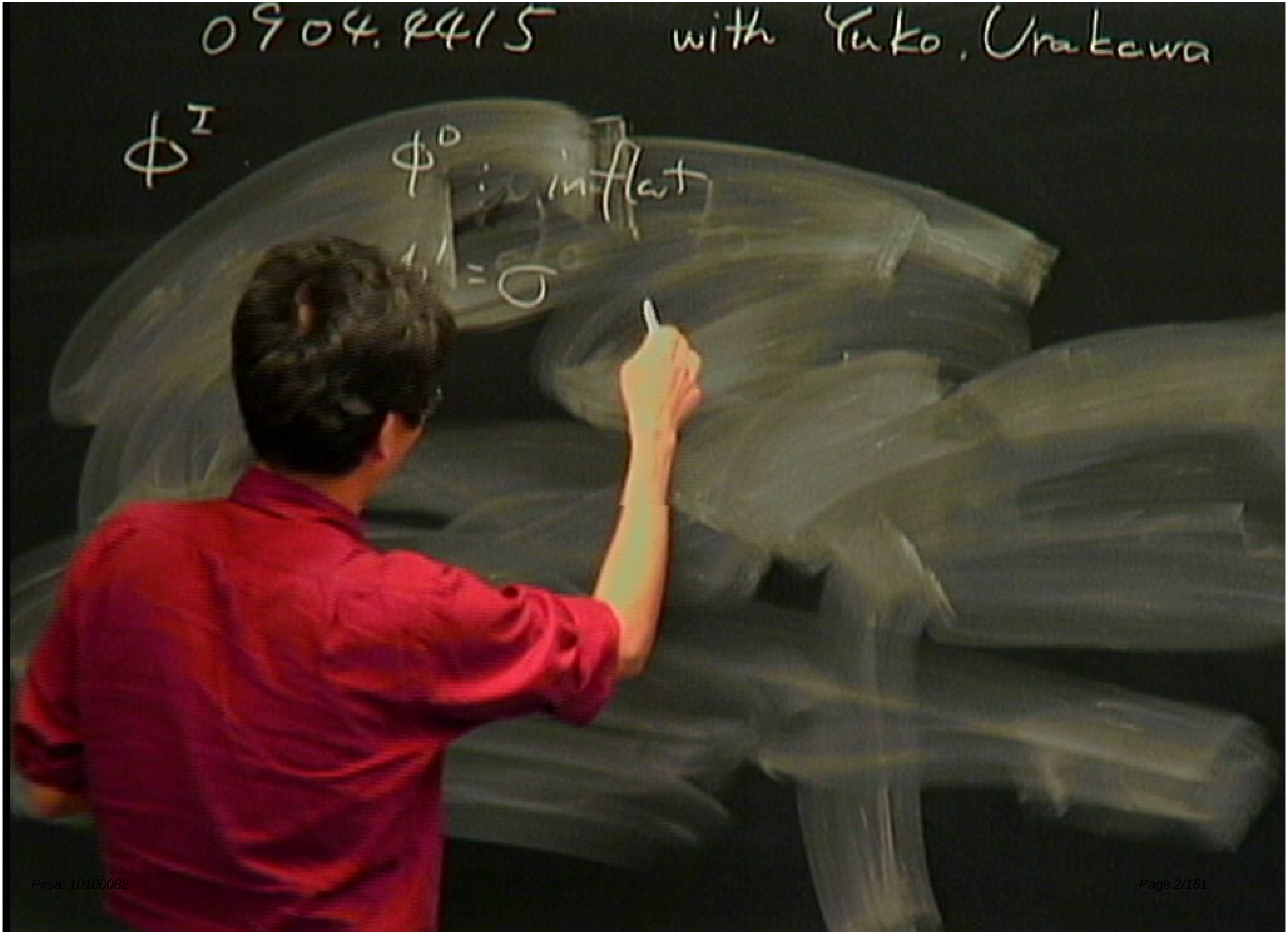
Title: Effects of decoherence on IR divergence

Date: Oct 30, 2010 11:30 AM

URL: http://pirsa.org/10100082

Abstract: We propose one way to regularize the fluctuations generated during inflation. We show that, as long as we consider the case that the non-linear interaction acts for a finite duration, observable fluctuations are free from IR divergences not only in the single field models but also in the multi field model. In contrast to the single field model, to discuss observables, we need to take into account the effects of quantum decoherence which pick up a unique history of the universe from various possibilities contained in initial quantum state set naturally in the early stage of the universe.

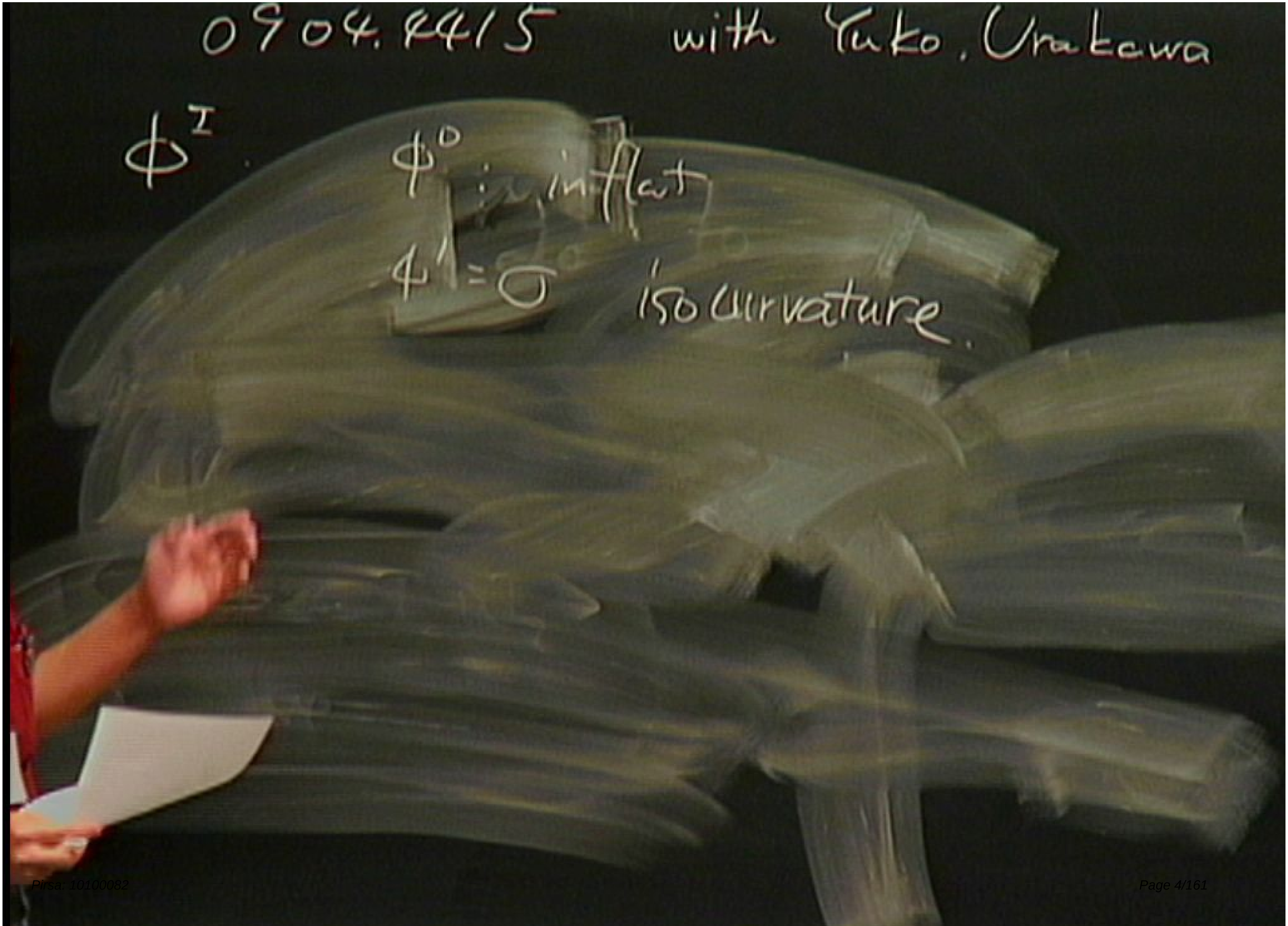

0904.4415
with Yuko. Urakawa
ϕ^I
ϕ^0 : inflat
$\phi^1 = \sigma$

0904.4415 with Yuko Urakawa

ϕ^I

ϕ^0 : inflat

$\phi^1 = \sigma$ isocurvature.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$$\langle \sigma^2 \rangle \approx \int_{k_{min}}^{k_{cut}}$$

$$k_{cut} = \epsilon a H$$

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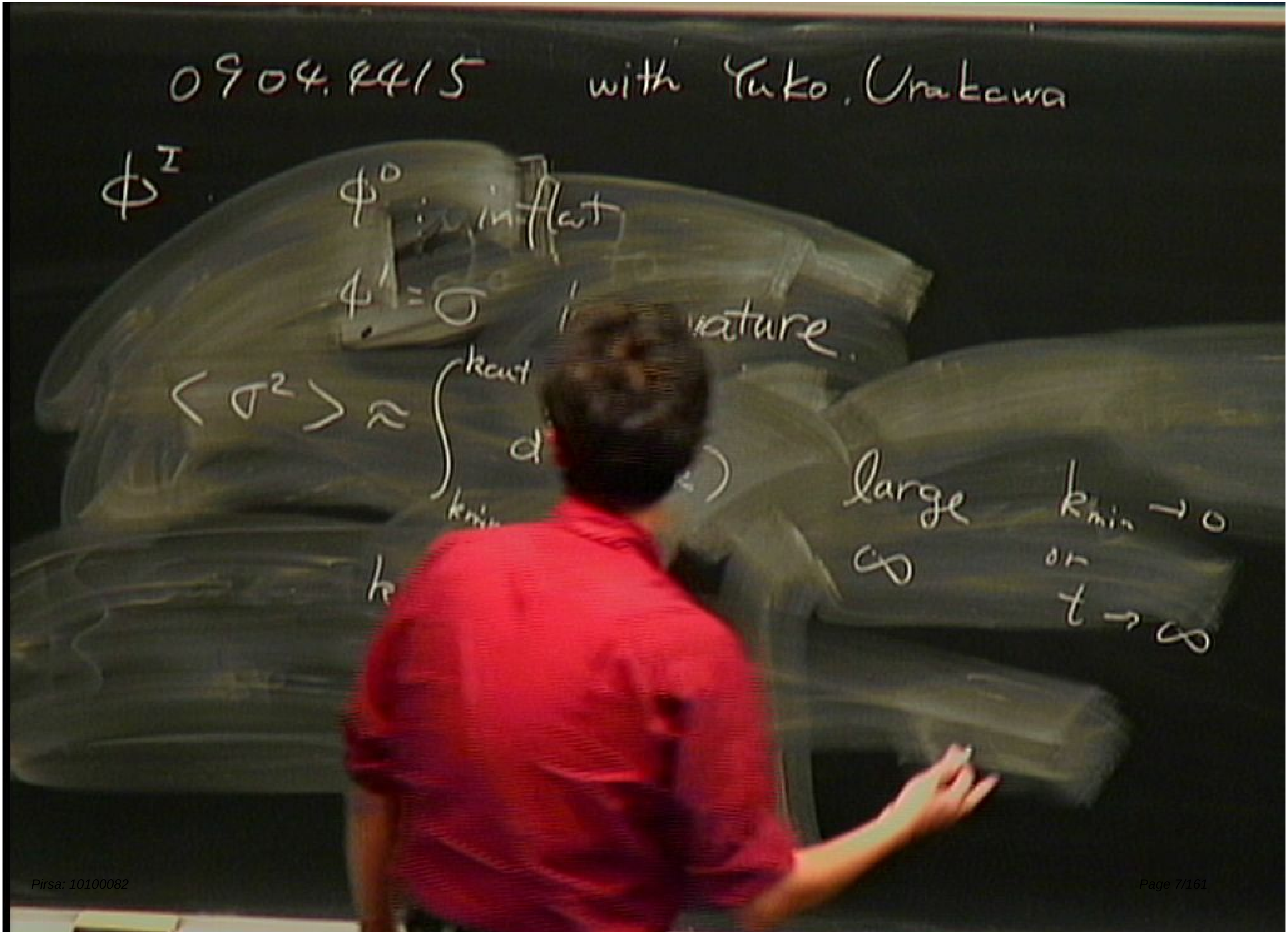
0904.4415 with Yuko Urakawa
φ^I
φ^0 : inflaton
φ^1 = σ
curvature
⟨σ²⟩ ≈ ∫ kcut kmin d
large
∞
kmin → 0
or
t → ∞

0904.4415 with Yuko Urakawa

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ϕ^0 : inflat

$\phi^1 = \sigma$ isocurvature

$\langle \sigma^2 \rangle \approx \int_{k_{min}}^{k_{cut}} d^3k \, P_\sigma(k)$ large $k_{min} \to 0$

∞ or

$t \to \infty$

$k_{cut} = \epsilon a H$

0904.4415 with Yuko Urakawa

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large $\quad k_{min} \to 0$

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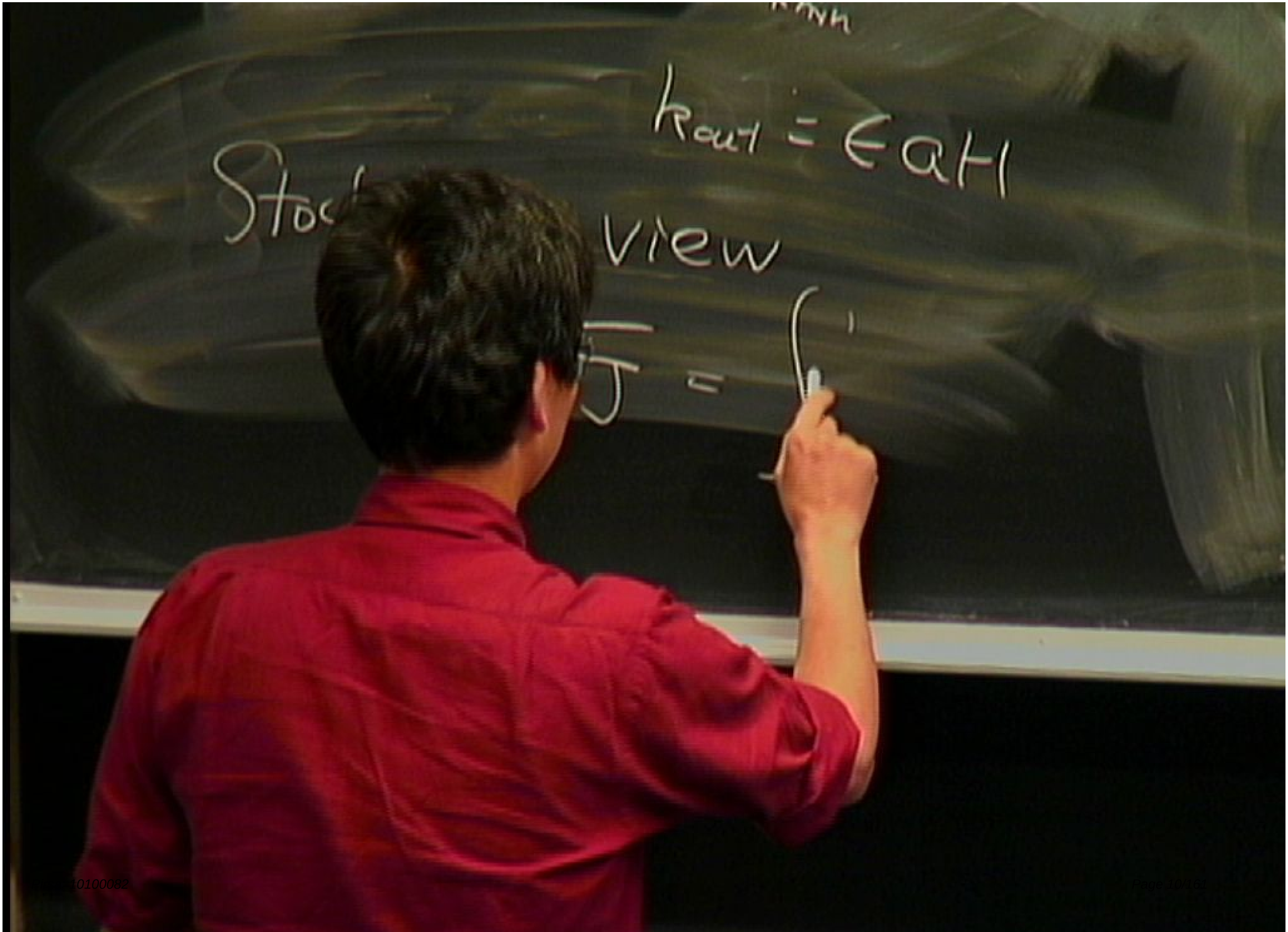
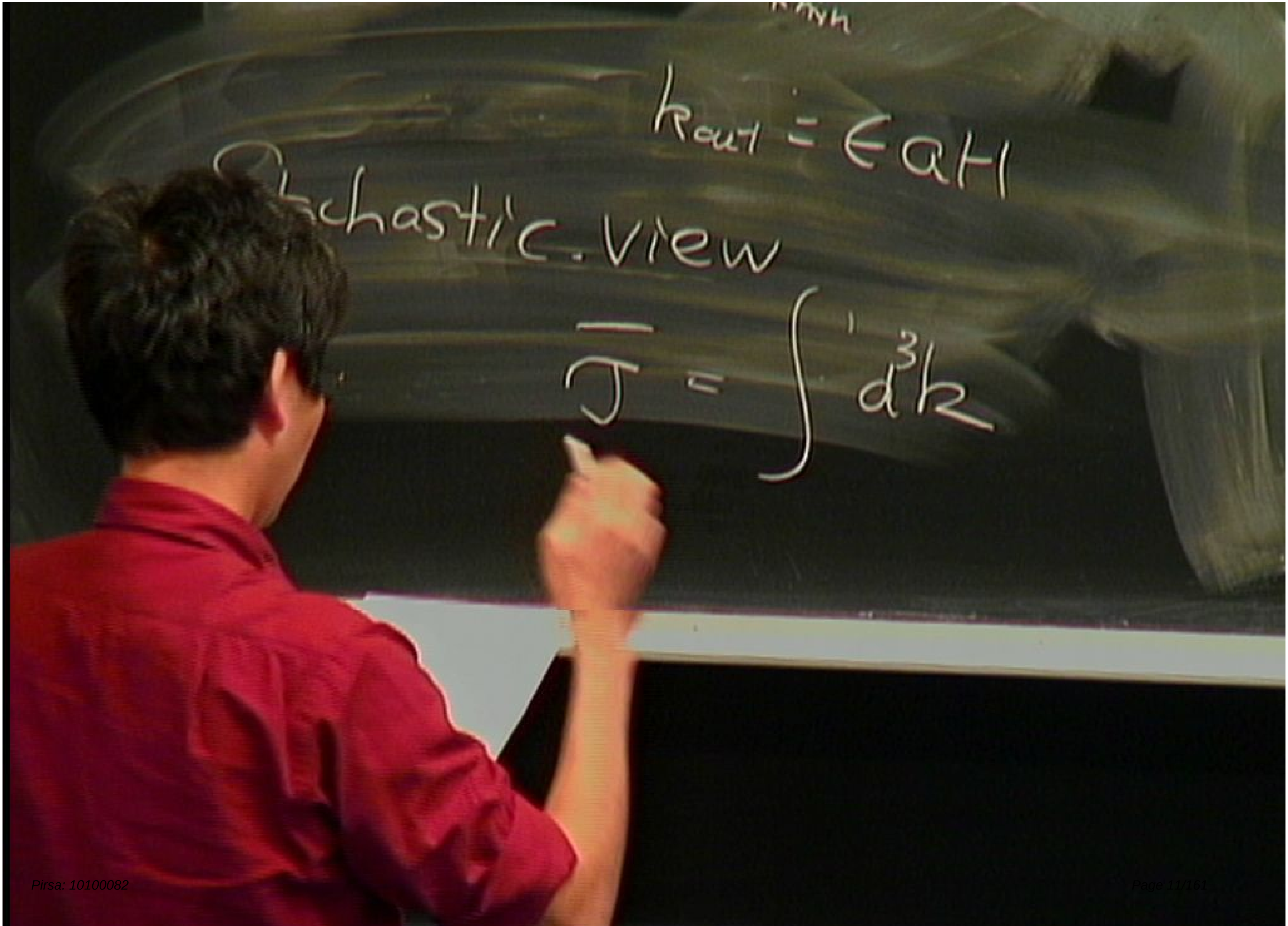

kout = εaH
view


$k_{out} = \epsilon a H$
$\bar{J} = \int d^3k$

$$\langle \sigma^2 \rangle \approx \int_{k_{min}} d^3k \, P_\sigma(k)$$

large $k_{min} \to 0$

∞ or $t \to \infty$

$k_{cut} = \epsilon a H$

Stochastic view

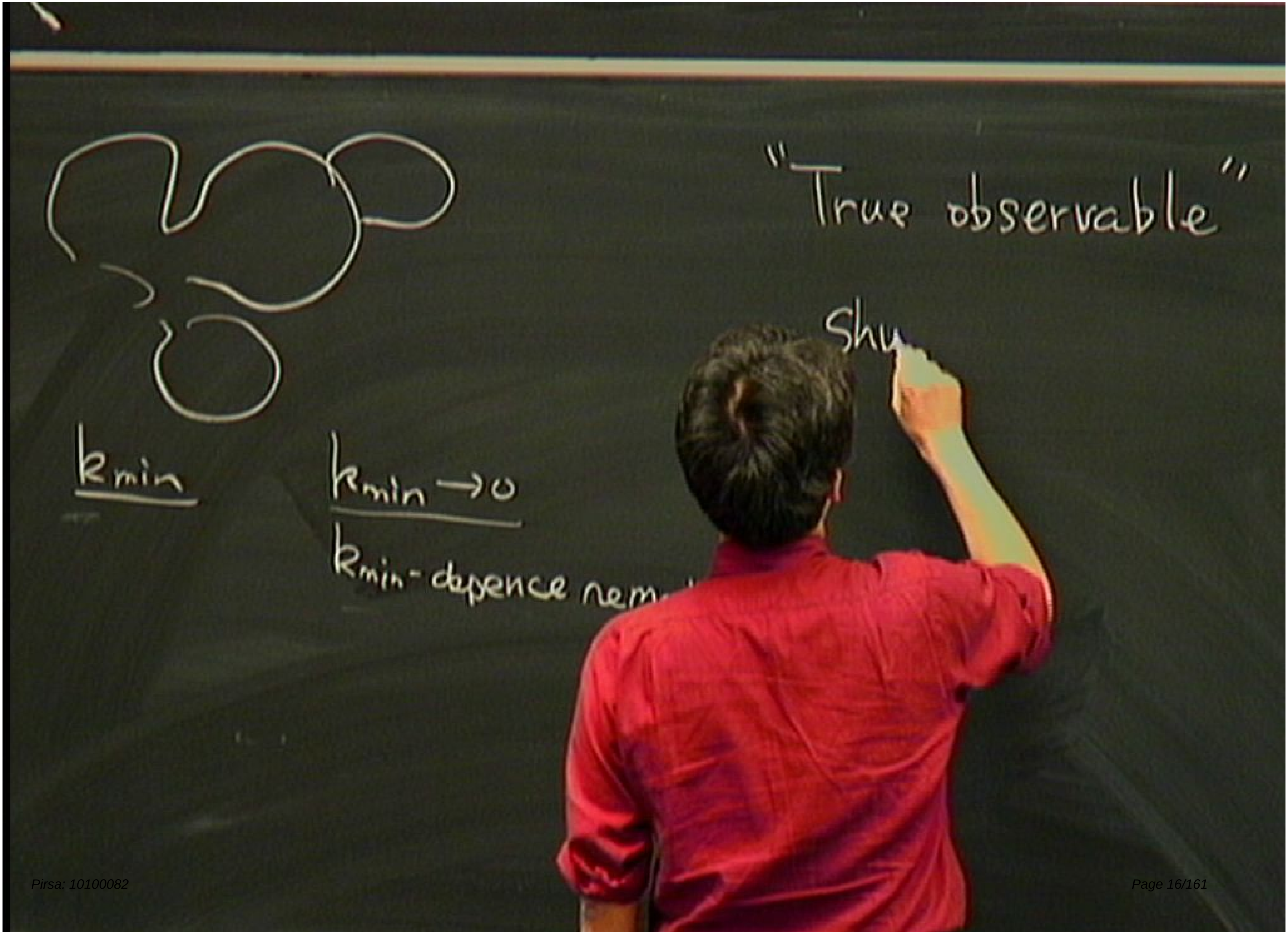
$$\bar{\sigma} = \int d^3k \, \Theta(k_{cut} - k) \, \sigma_k \, e^{i\mathbf{k}\cdot\mathbf{x}}$$

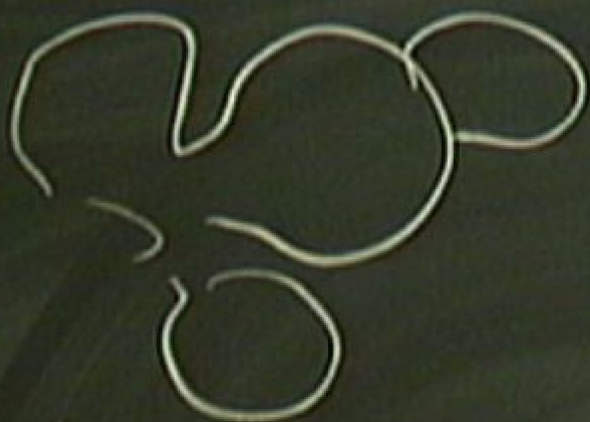
k_{min}

$\underline{k_{min}}$

$\underline{k_{min} \to 0}$

k_{min}- depen.


"True observable"
Shu
k_{min}
$k_{min} \to 0$
k_{min}-depence



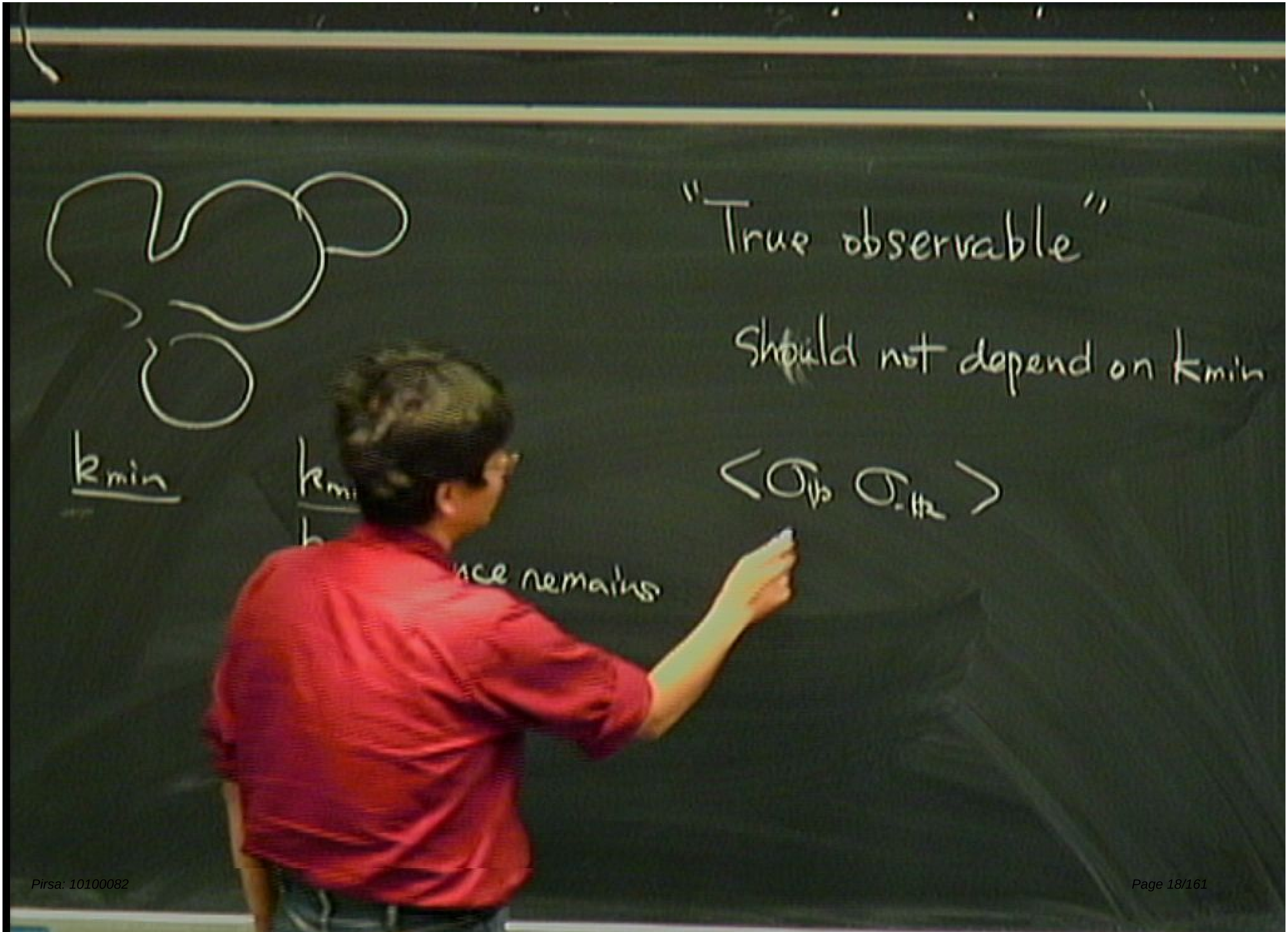
"True observable"

Should not depend on k_{min}

$\underline{k_{min}}$

$\underline{k_{min} \to 0}$

k_{min}- depence remains


"True observable"
Should not depend on kmin
kmin
remains

k_{min}

$k_{min} \to 0$

k_{min}-dependence remains

"True observable"

Should not depend on k_{min}

$\langle \sigma_{k} \sigma_{-k} \rangle$

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Should not depend on k_{min}

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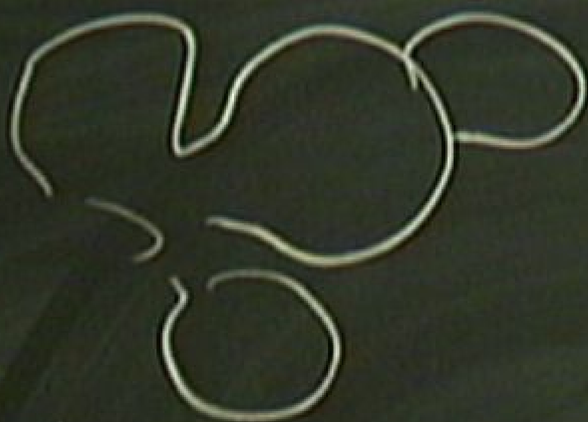
k_{min}

$k_{min} \to 0$

k_{min}-depence remains



"True observable"

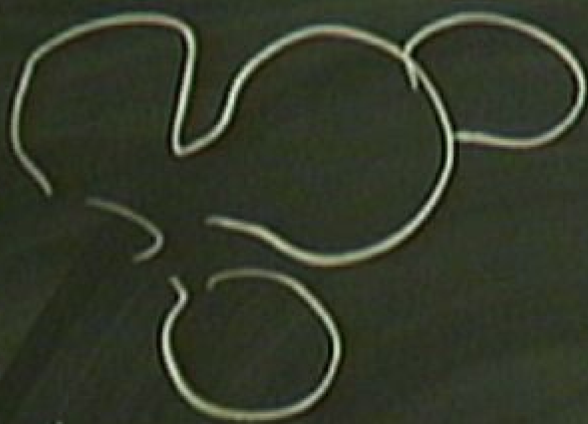
Should not depend on k_{min}

$\langle \underline{\sigma_k} \, \sigma_{-k} \rangle$

$\underline{k_{min}}$

$\underline{k_{min} \to 0}$

k_{min}-depence remains



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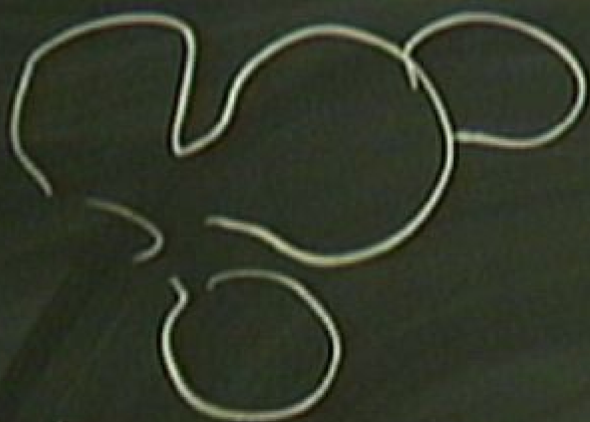

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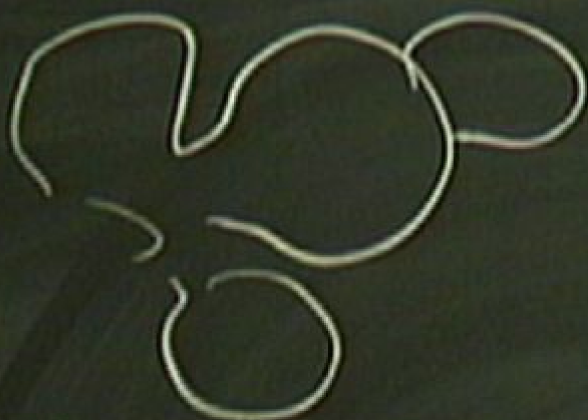


"True observable"

Should not depend on k_{min}

$\underline{k_{min}}$

$\underline{k_{min} \to 0}$

k_{min}-depence remains

$\langle \sigma_{k} \, \sigma_{-k} \rangle$

$\langle \sigma(x) \; \sigma(y) \rangle$

$x, y \subset \bigcirc$

$\underline{k_{min}}$

$\underline{k_{min} \to 0}$

k_{min}-depence remains

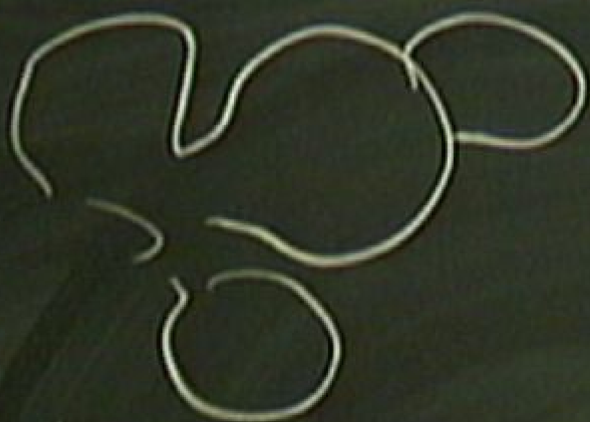
"True observable"

Should not depend on k_{min}

$\langle \underline{\sigma_{k}}\, \sigma_{-k} \rangle$

$\langle \sigma(x)\ \sigma(y) \rangle$

$x, y \subset \odot$



$\underline{k_{min}}$

$\underline{k_{min} \to 0}$

k_{min}-depence remains

"True observable"

Should not depend on k_{min}

$\langle \sigma_k \, \sigma_{-k} \rangle$

$\langle \sigma(x) \;\; \sigma(y) \rangle$

$x, y \subset \Theta$

can be divergent

"True observable"

Should not depend on k_{min}

k_{min}

$k_{min} \to 0$

k_{min}- depence remains

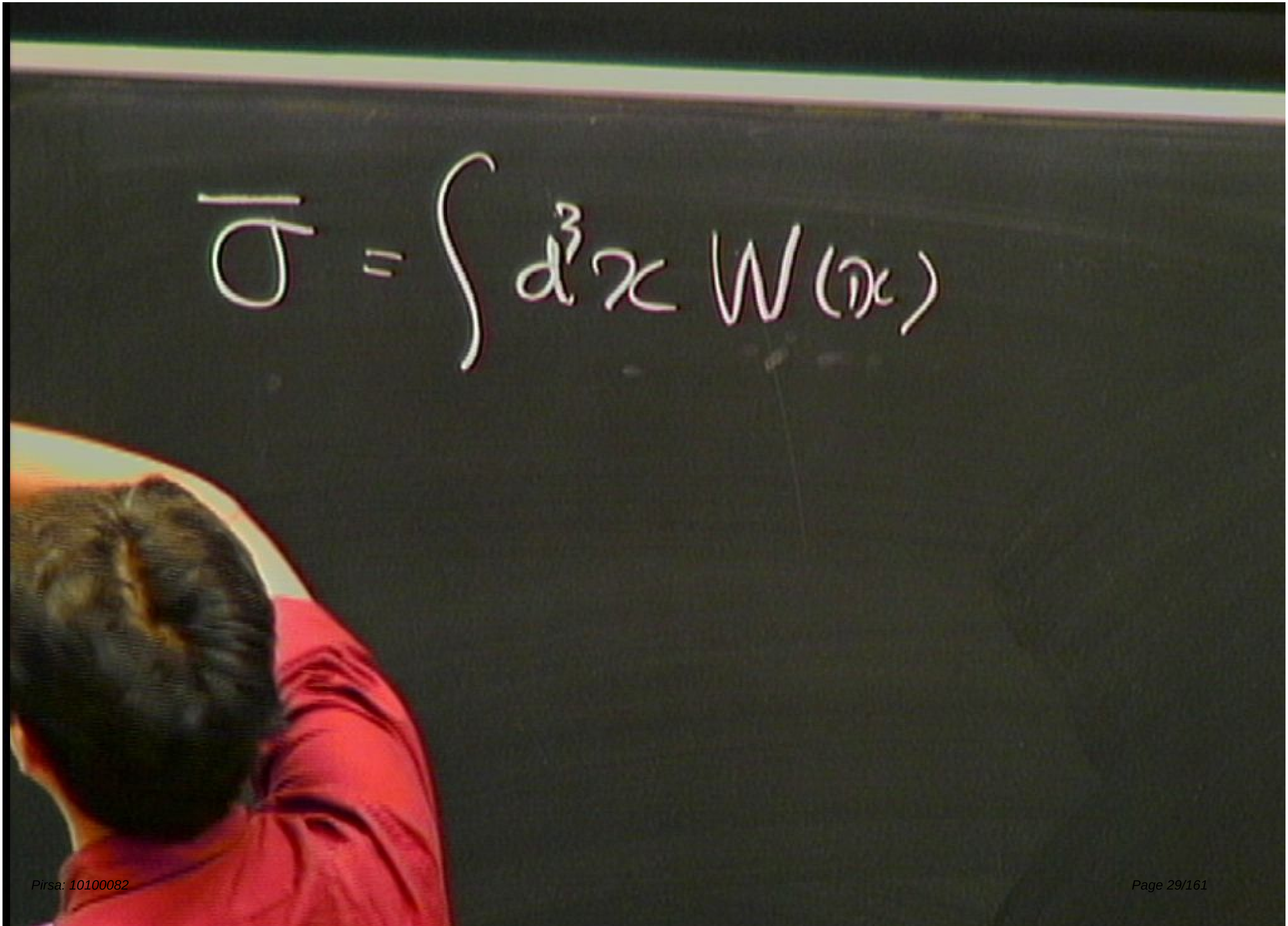
$\zeta = \zeta(\delta\phi^I)$

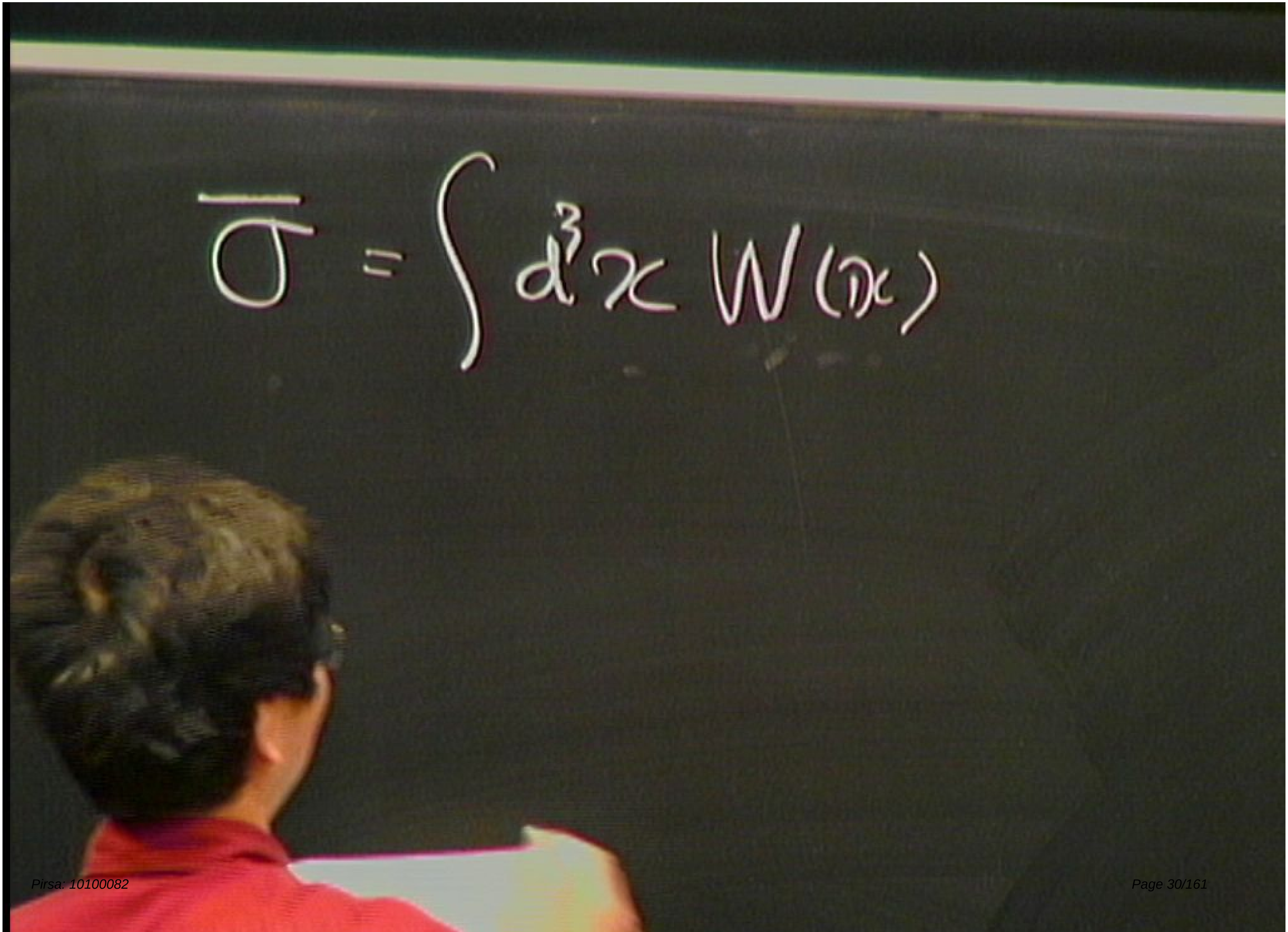
$\langle \sigma_k \, \sigma_{-k} \rangle$

$\langle \sigma(x) \;\; \sigma(y) \rangle$

$x, y \subset \bigcirc$

can be divergent


$\overline{\sigma} = \int d^3x \, W(x)$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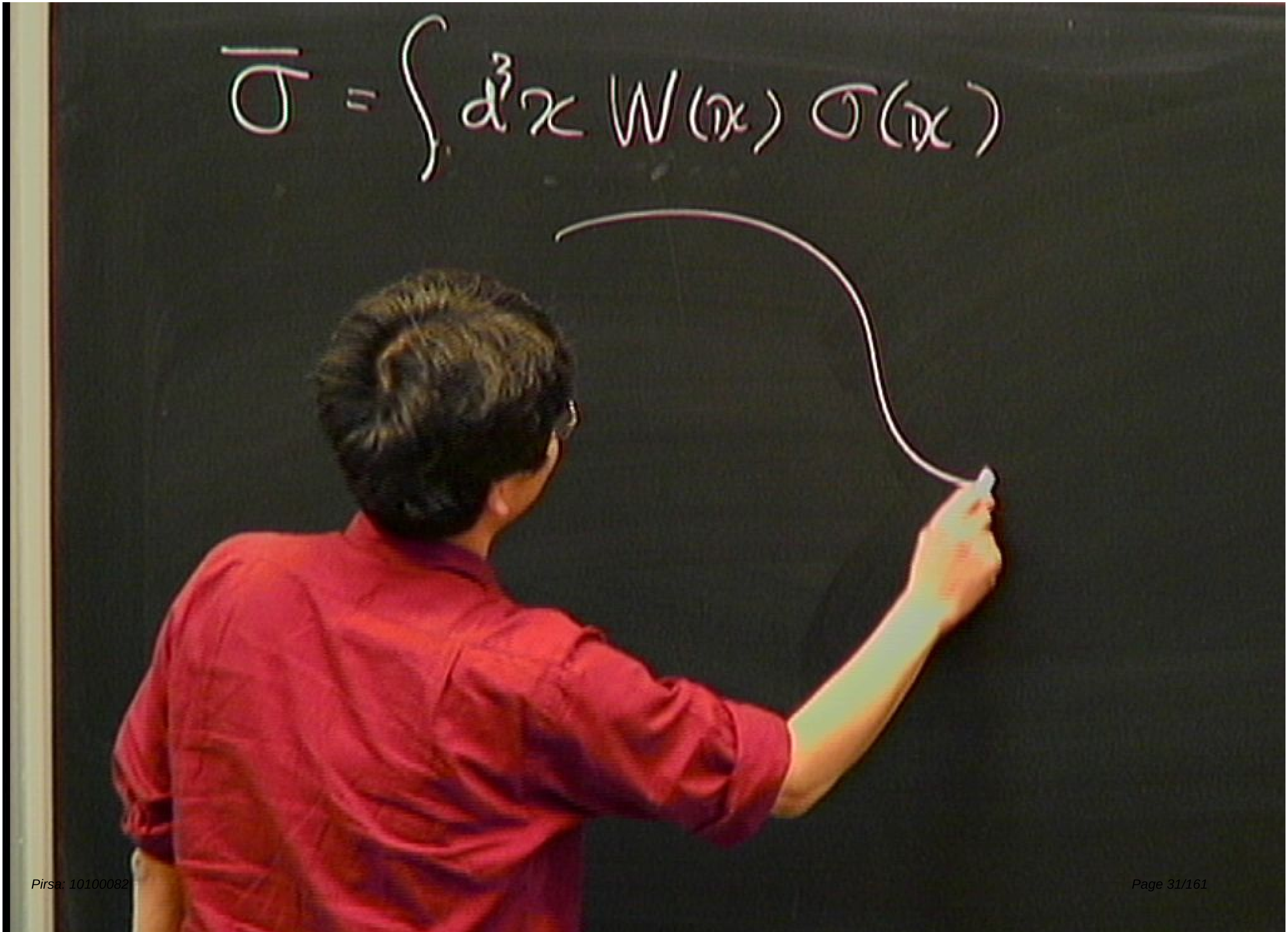
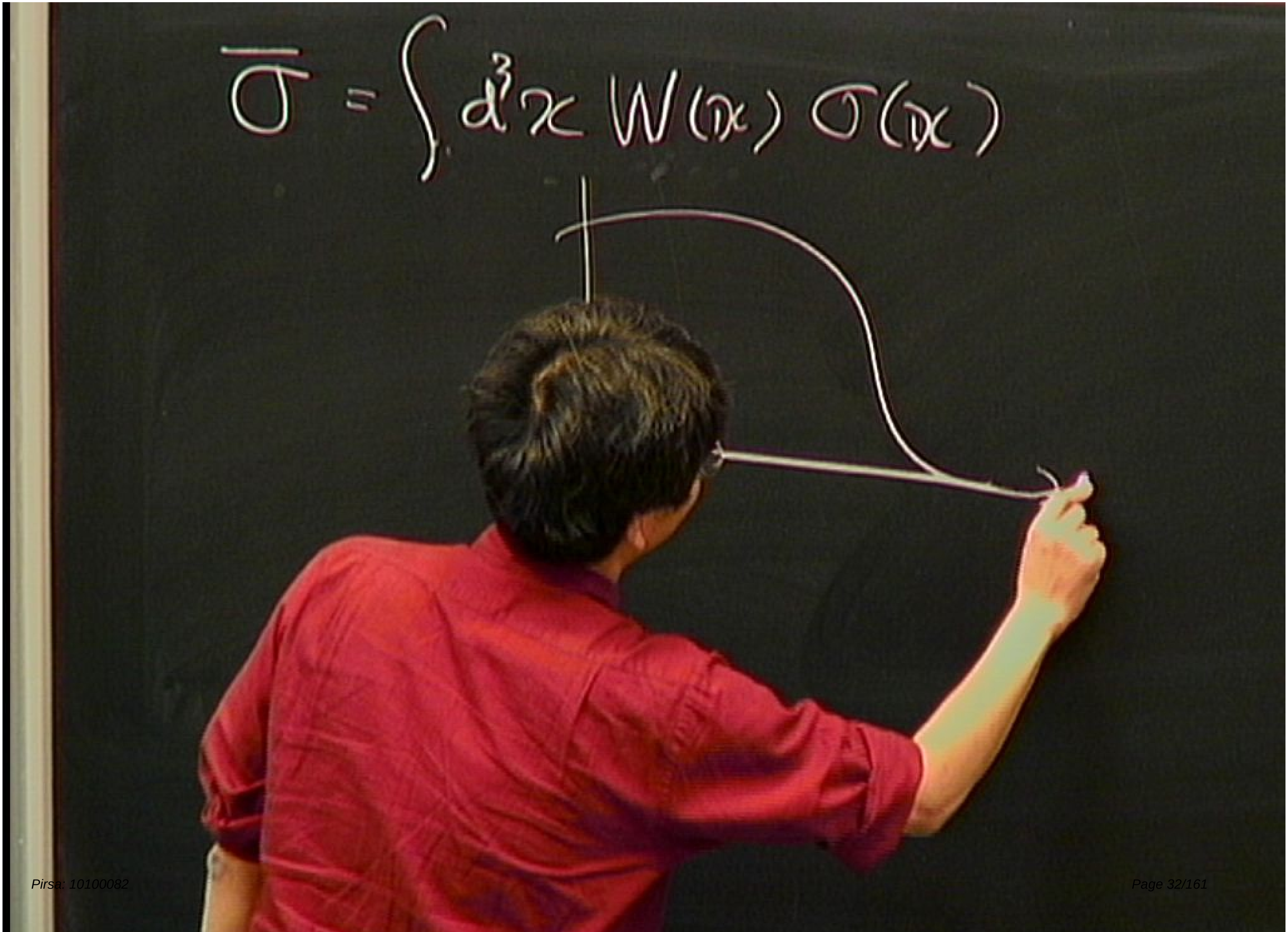
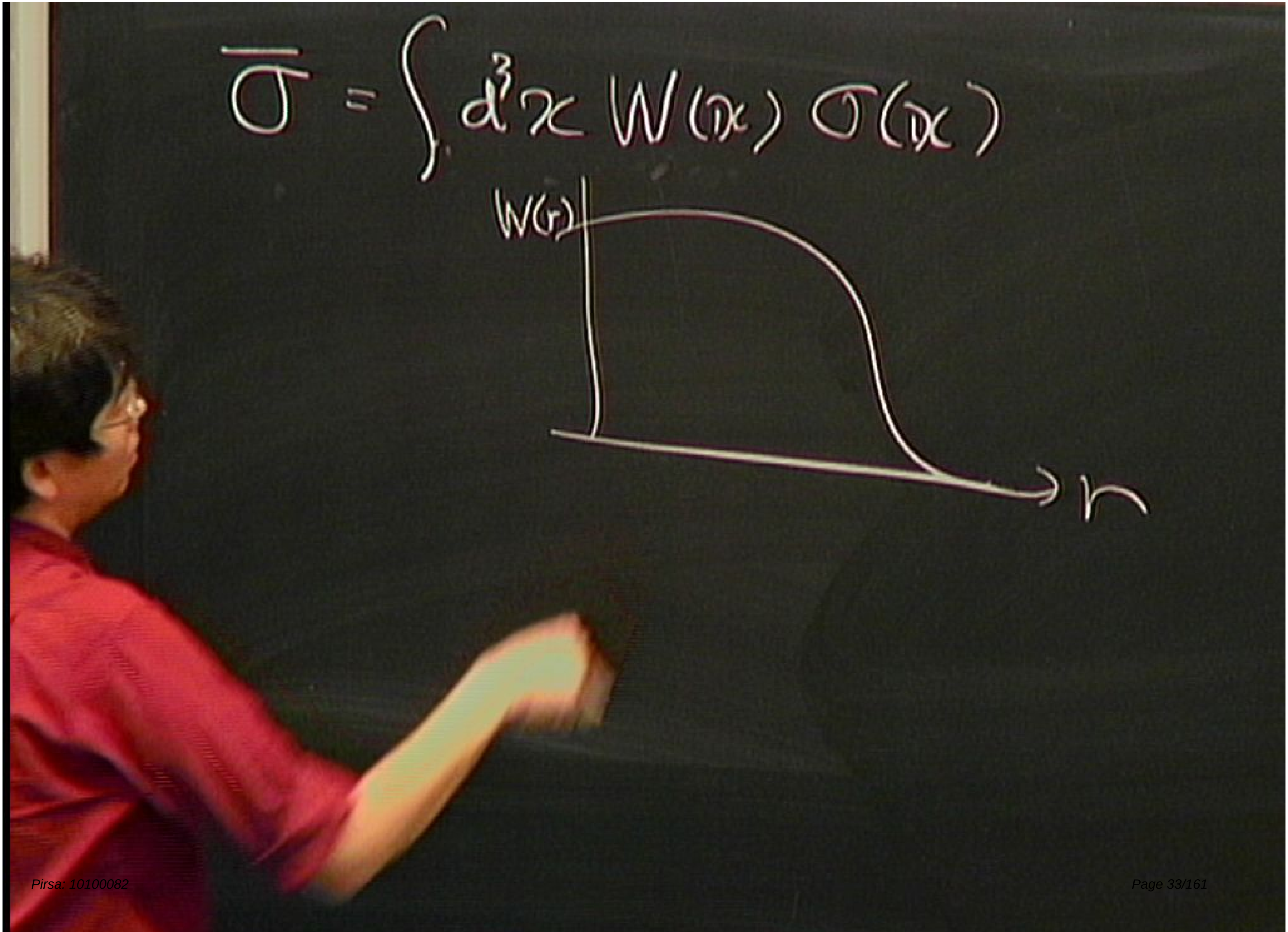
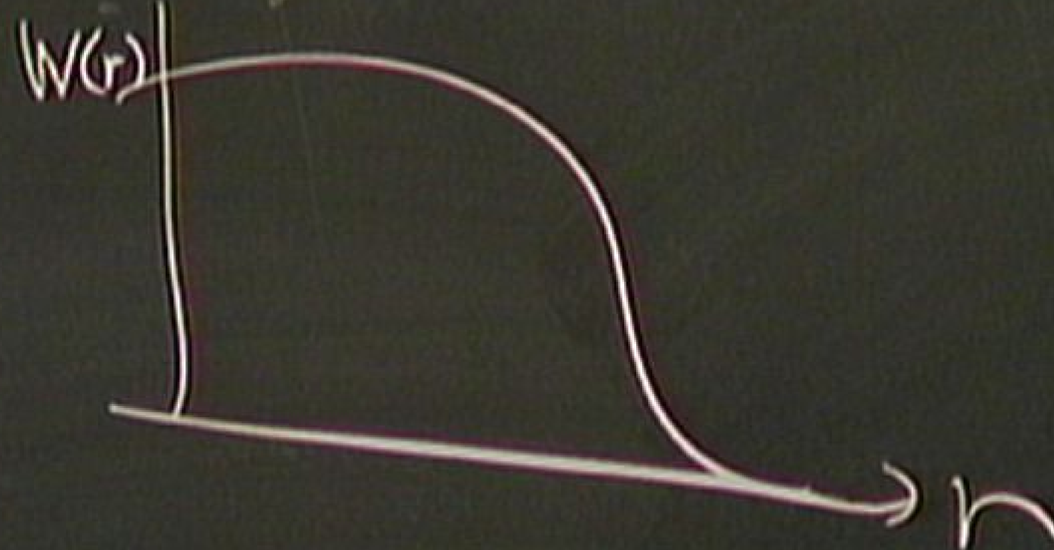

$\bar{\sigma} = \int d^3x \, W(\mathbf{x}) \, \sigma(\mathbf{x})$



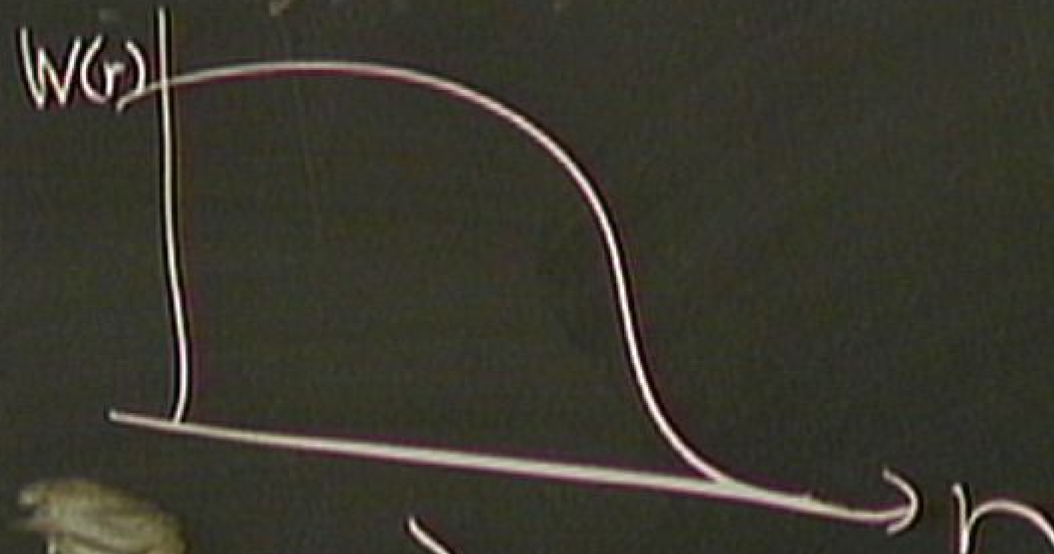
$\bar{\sigma} = \int d^2x \, W(x) \, \sigma(x)$


$\bar{\sigma} = \int d^2x \, W(x) \, \sigma(x)$
W(r)
r

$$\bar{\sigma} = \int d^3x \, W(x)\, \sigma(x)$$

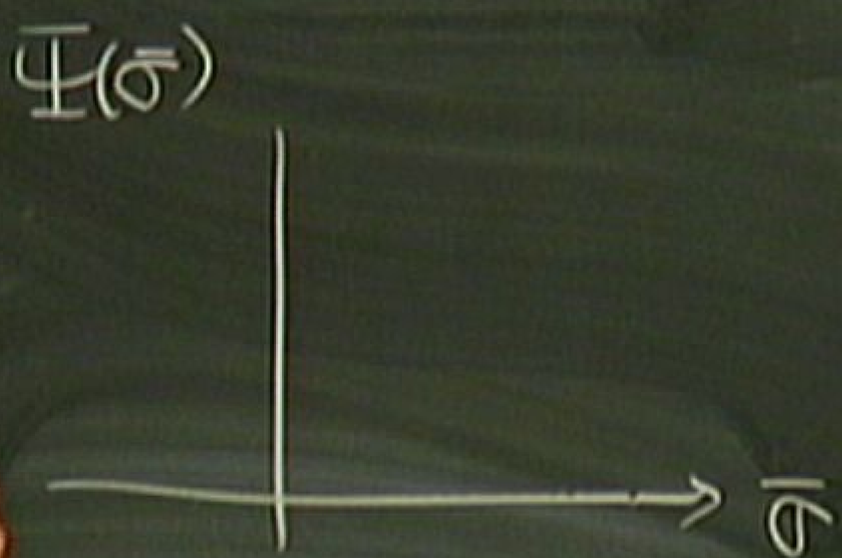


$$\bar{\sigma} = \int d^3x \, W(x) \, \sigma(x)$$



$$\Big\{ \underset{1\,\mathrm{dof}}{\bar{\sigma}}, \ \sigma - \bar{\sigma} \Big\}$$

Do we really observe large fluctuation of $\bar{\sigma}$



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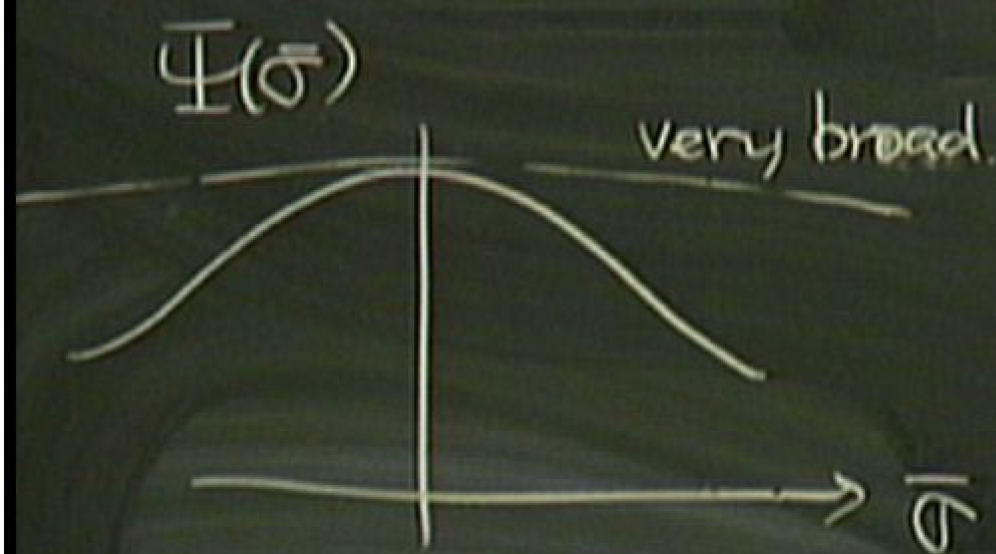
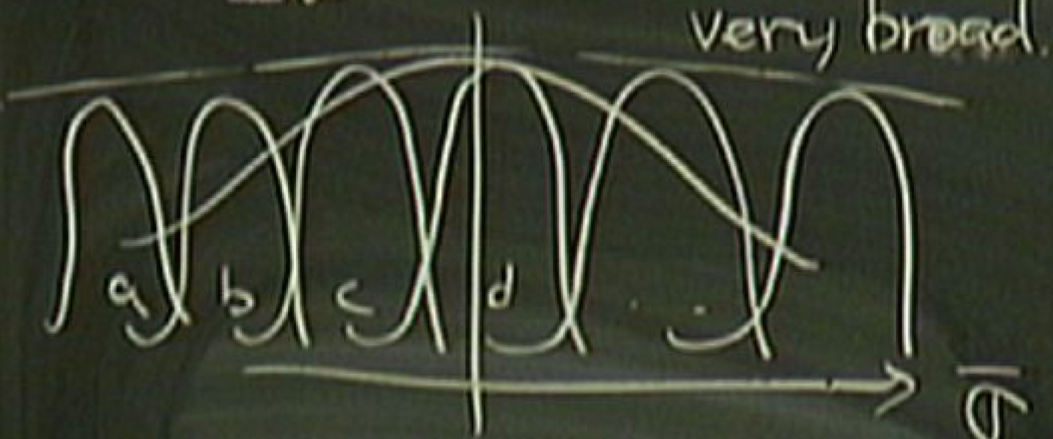
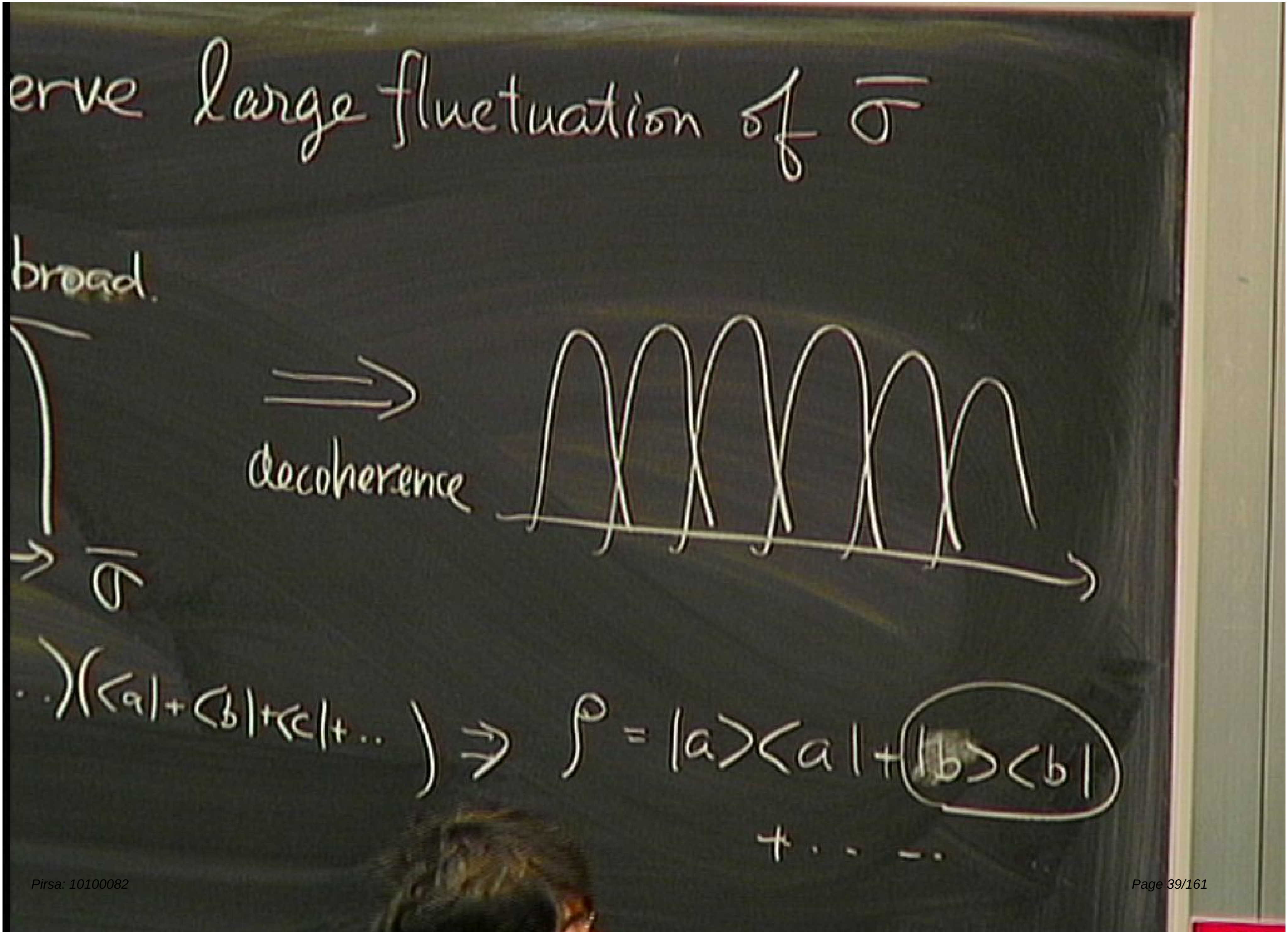


Do we really observe large fluctuation of $\bar{\sigma}$

$\Psi(\bar{\sigma})$

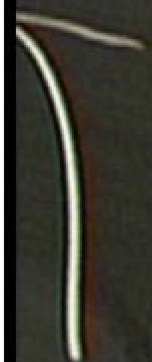


$$\rho = \left(|a\rangle + |b\rangle + |c\rangle + \dots\right)\left(\langle a| + \langle b| + \langle c| + \dots\right)$$


erve large fluctuation of σ̄
broad.
decoherence
σ̄
..)(<a|+<b|+<c|+..) ⇒ ρ = |a><a| + |b><b|
+ . . . .

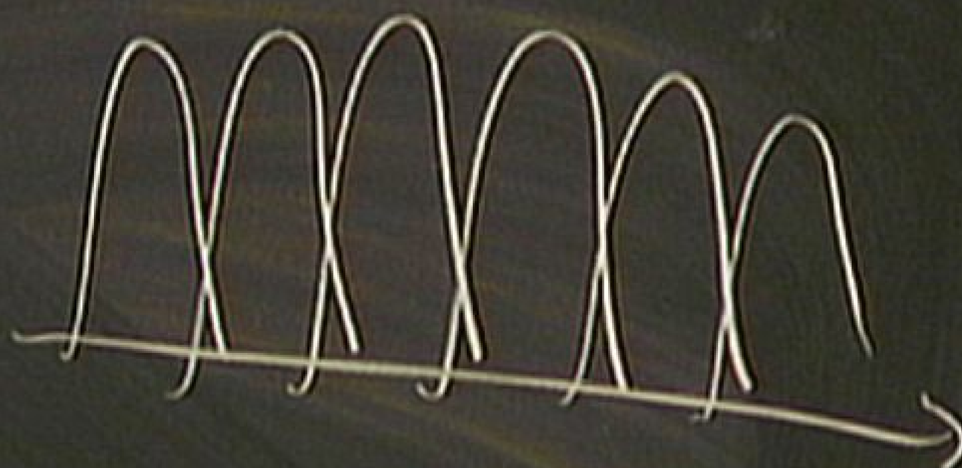
erve large fluctuation of $\bar{\sigma}$

broad.



$\Rightarrow \bar{\sigma}$

$\Longrightarrow$ decoherence



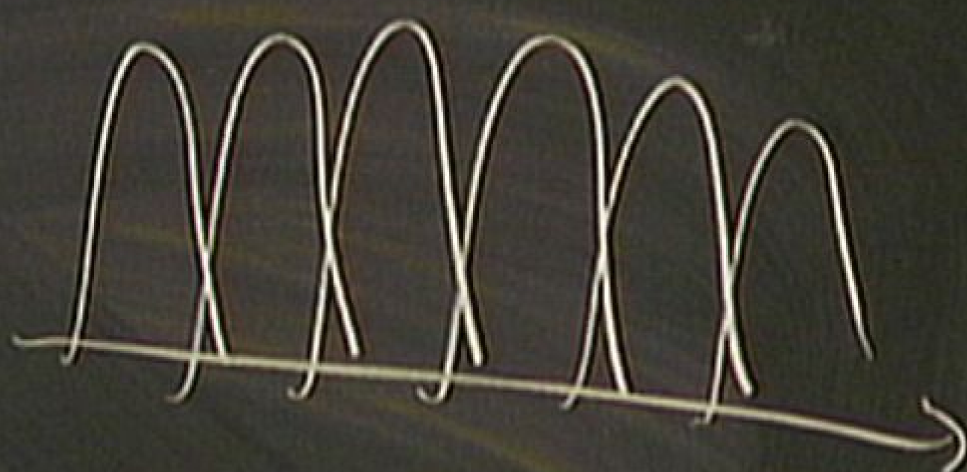
$$\ldots)(\langle a| + \langle b| + \langle c| + \ldots) \Rightarrow \rho = |a\rangle\langle a| + |b\rangle\langle b| + \ldots$$

erve large fluctuation of $\bar{\sigma}$

broad

$\Longrightarrow$

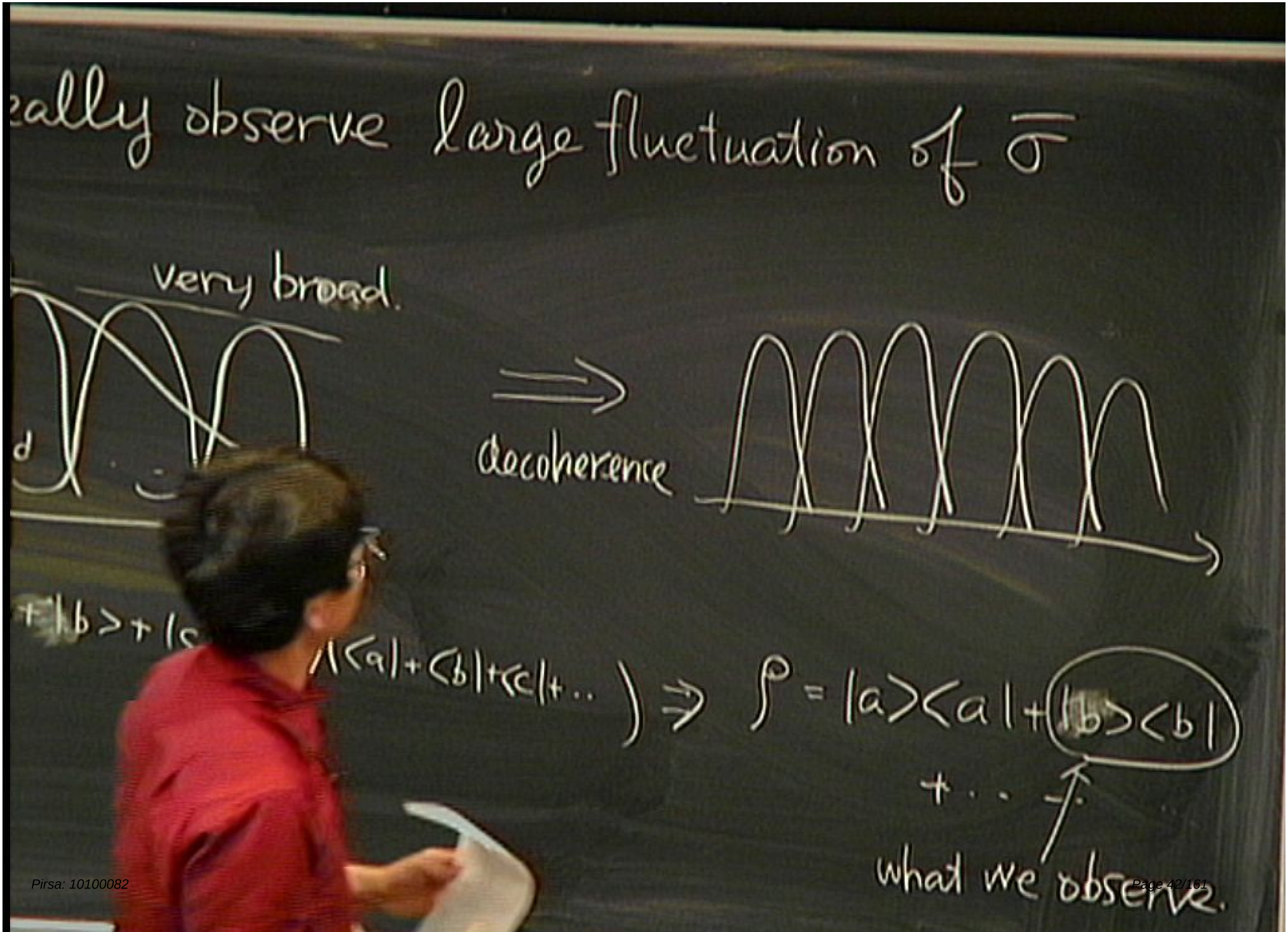
decoherence

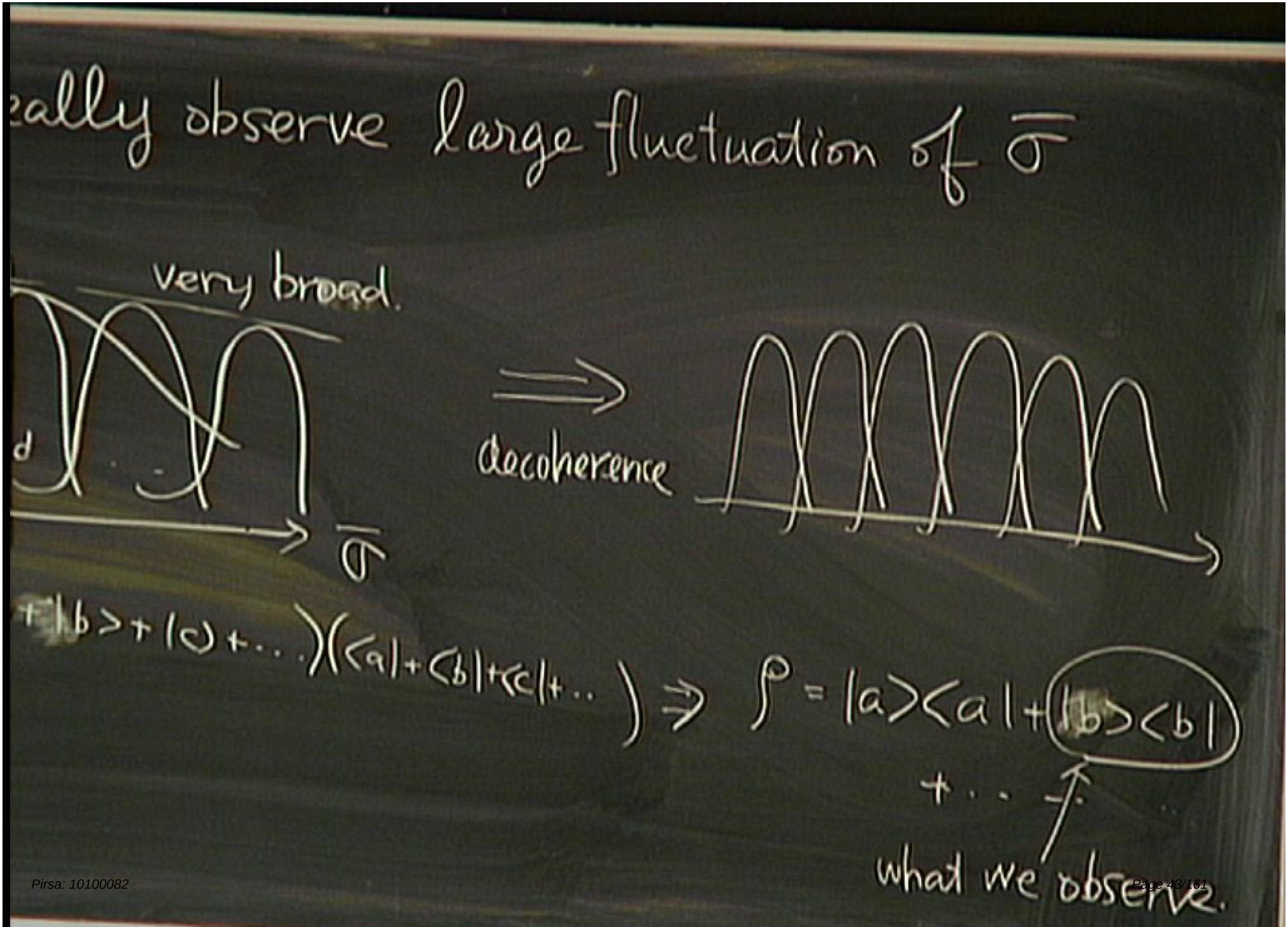


$\to \bar{\sigma}$

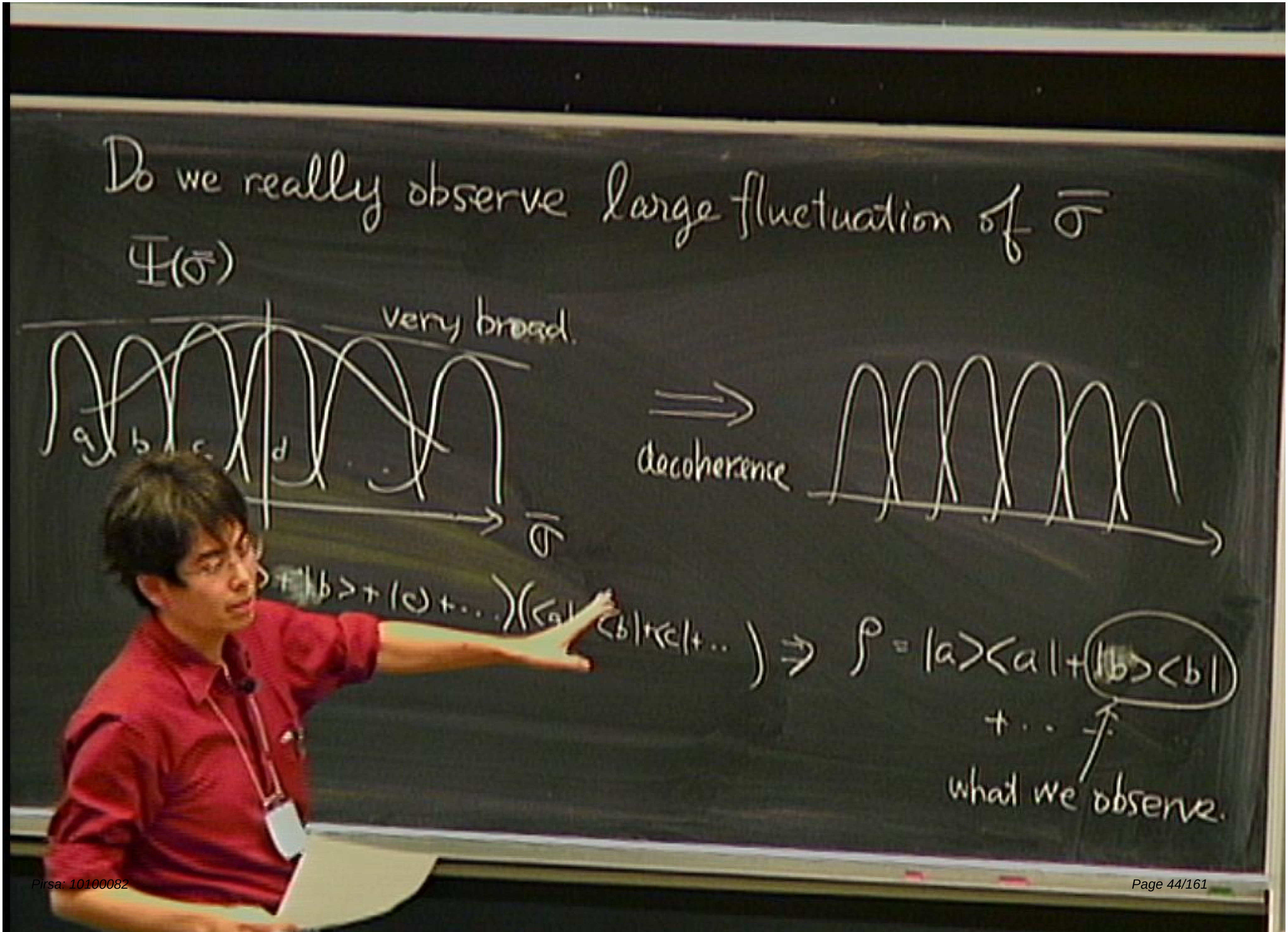
$\ldots)(\langle a| + \langle b| + \langle c| + \ldots) \Rightarrow \rho = |a\rangle\langle a| + |b\rangle\langle b|$

$+ \ldots$


ally observe large fluctuation of σ̄
very broad
decoherence
ρ = |a><a| + |b><b|
+ . . .
what we observe.

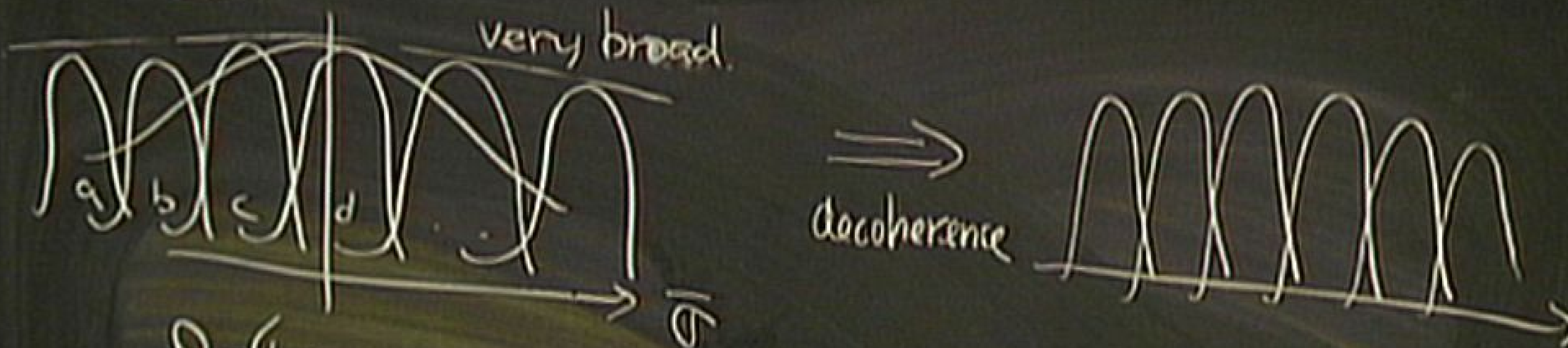


...ally observe large fluctuation of $\bar{\sigma}$
very broad
d
decoherence
$\bar{\sigma}$
$+|b\rangle + |c\rangle + \dots)(\langle a| + \langle b| + \langle c| + \dots) \Rightarrow \rho = |a\rangle\langle a| + |b\rangle\langle b| + \dots$
what we observe.


Do we really observe large fluctuation of $\bar{\sigma}$
$\Psi(\bar{\sigma})$
very broad
a
b
c
d
decoherence
$\bar{\sigma}$
$|b\rangle + |c\rangle + \dots)(\langle a| + \langle b| + \langle c| + \dots) \Rightarrow \rho = |a\rangle\langle a| + |b\rangle\langle b| + \dots$
what we observe.

Do we really observe large fluctuation of $\bar{\sigma}$

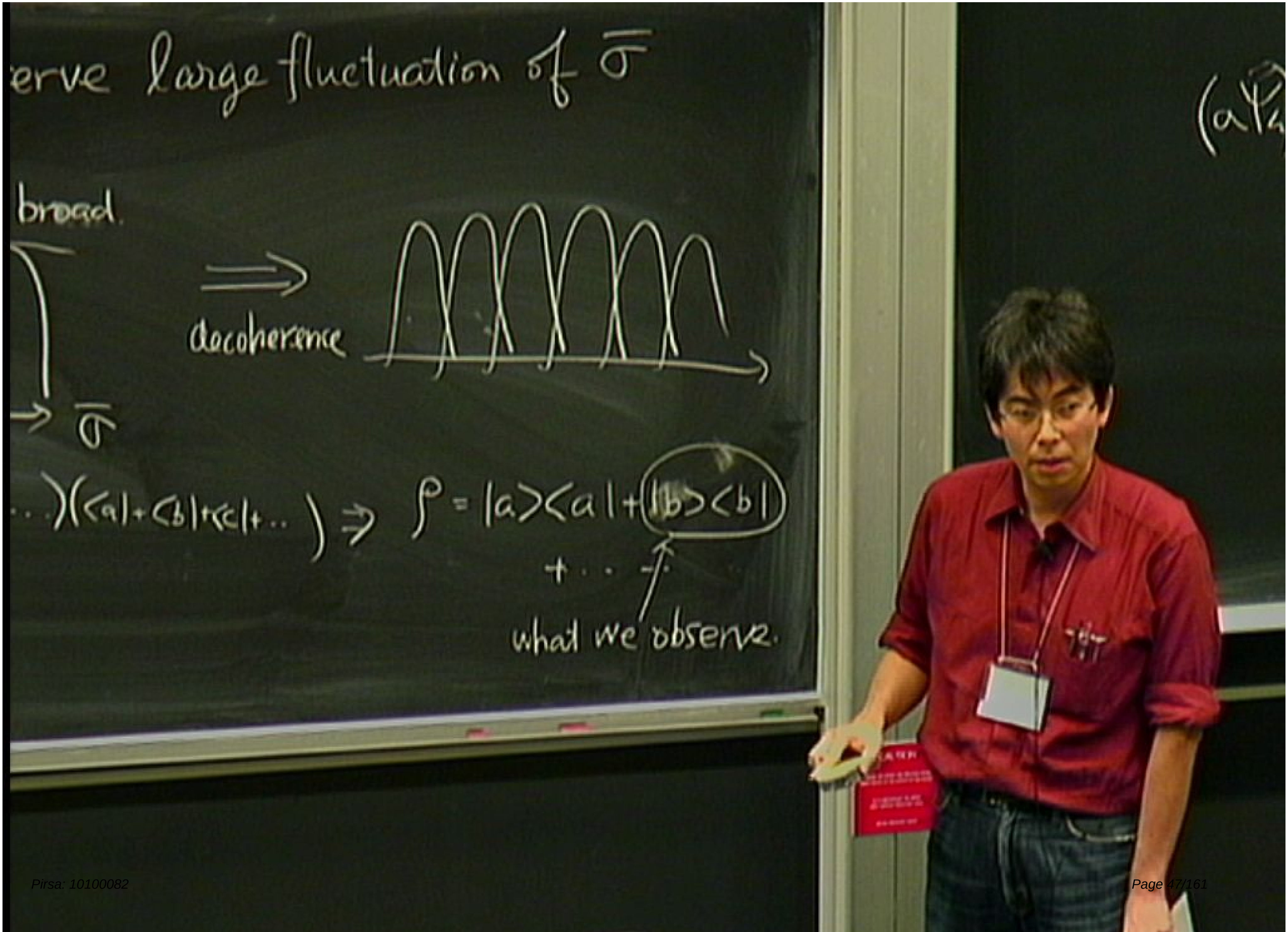
$\Psi(\bar{\sigma})$



$$\rho = \left(|a\rangle + |b\rangle + |c\rangle + \ldots\right)\left(\langle a| + \langle b| + \langle c| + \ldots\right) \Rightarrow \rho = |a\rangle\langle a| + |b\rangle\langle b| + \ldots$$

what we observe.

$$\left(a\psi_k\right)'' + \left(k^2 - \frac{a''}{a}\right)\left(a\psi_k\right) = 0$$


erve large fluctuation of $\bar{\sigma}$
broad
decoherence
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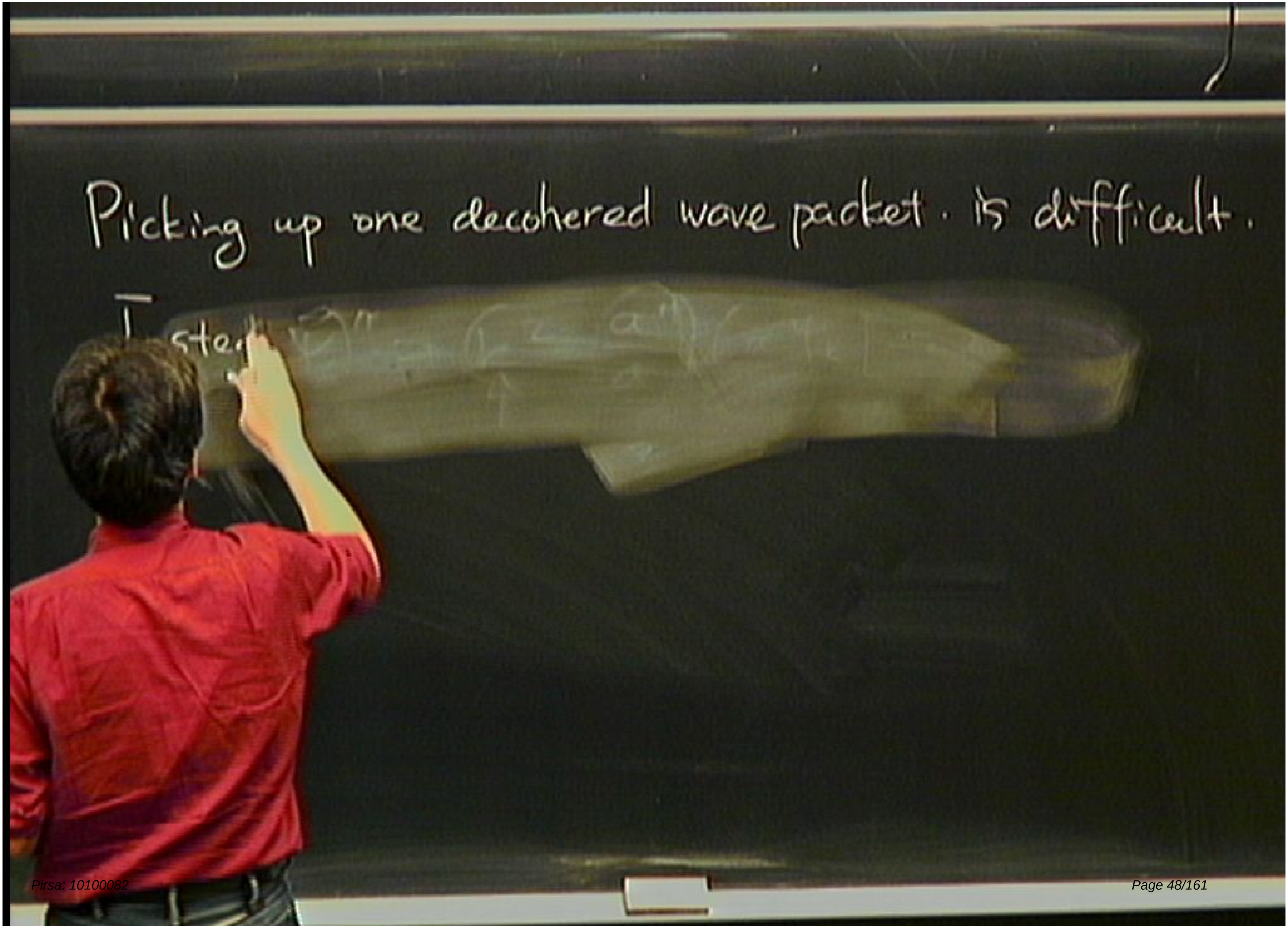
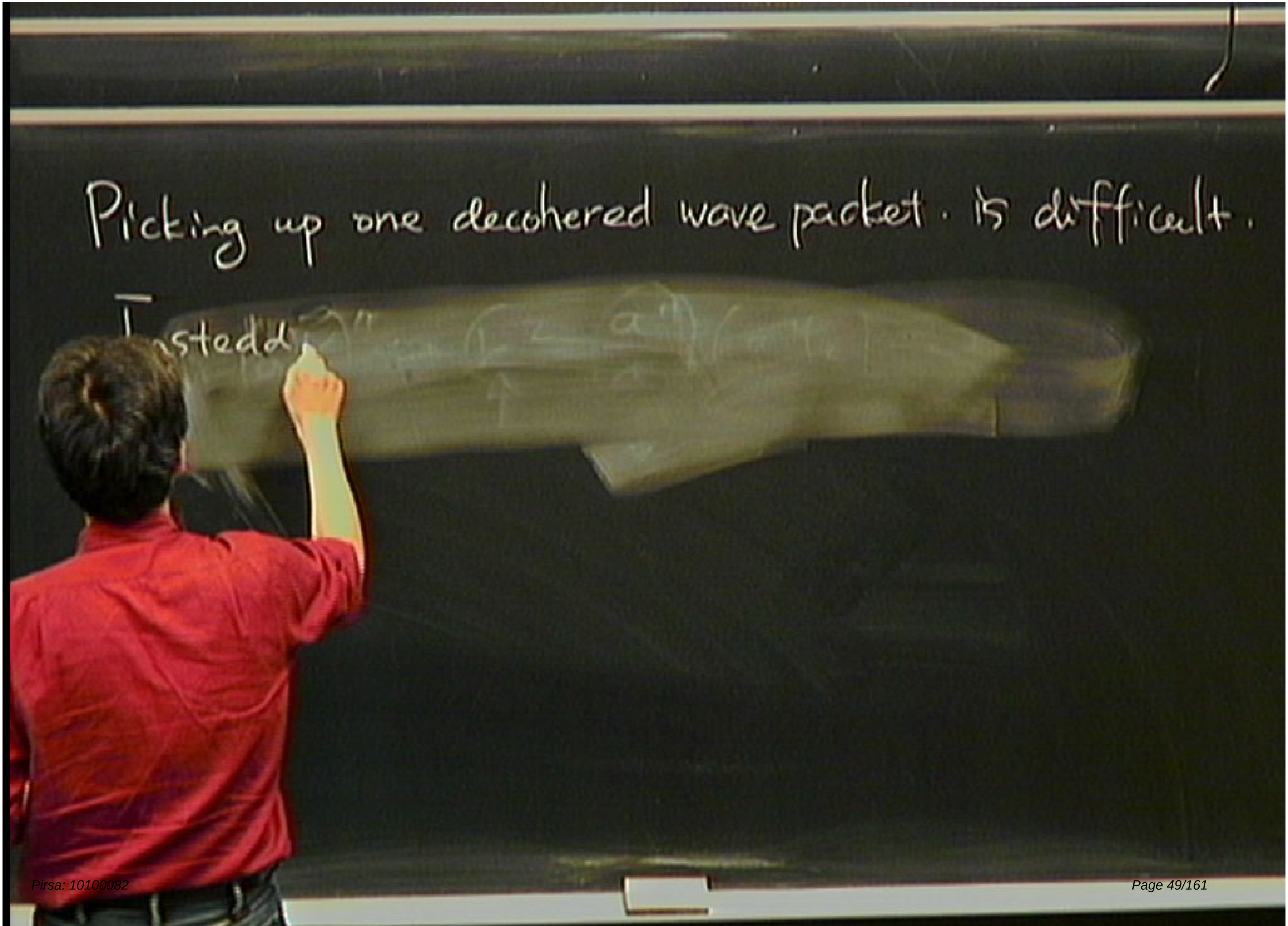
$\ldots)(\langle a| + \langle b| + \langle c| + \ldots) \Rightarrow \rho = |a\rangle\langle a| + |b\rangle\langle b|$
$+ \cdots +$
what we observe.


Picking up one decohered wave packet. is difficult.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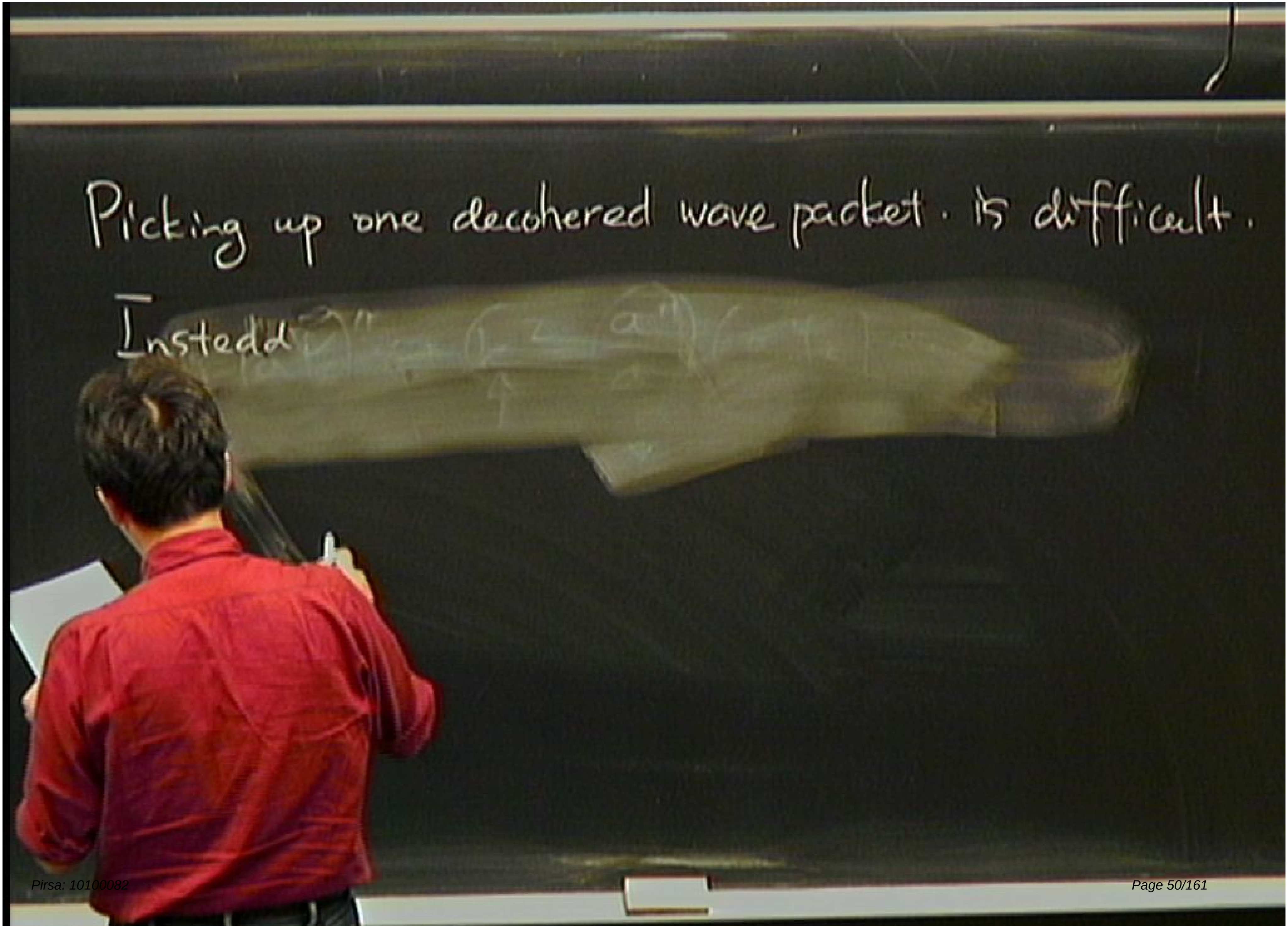
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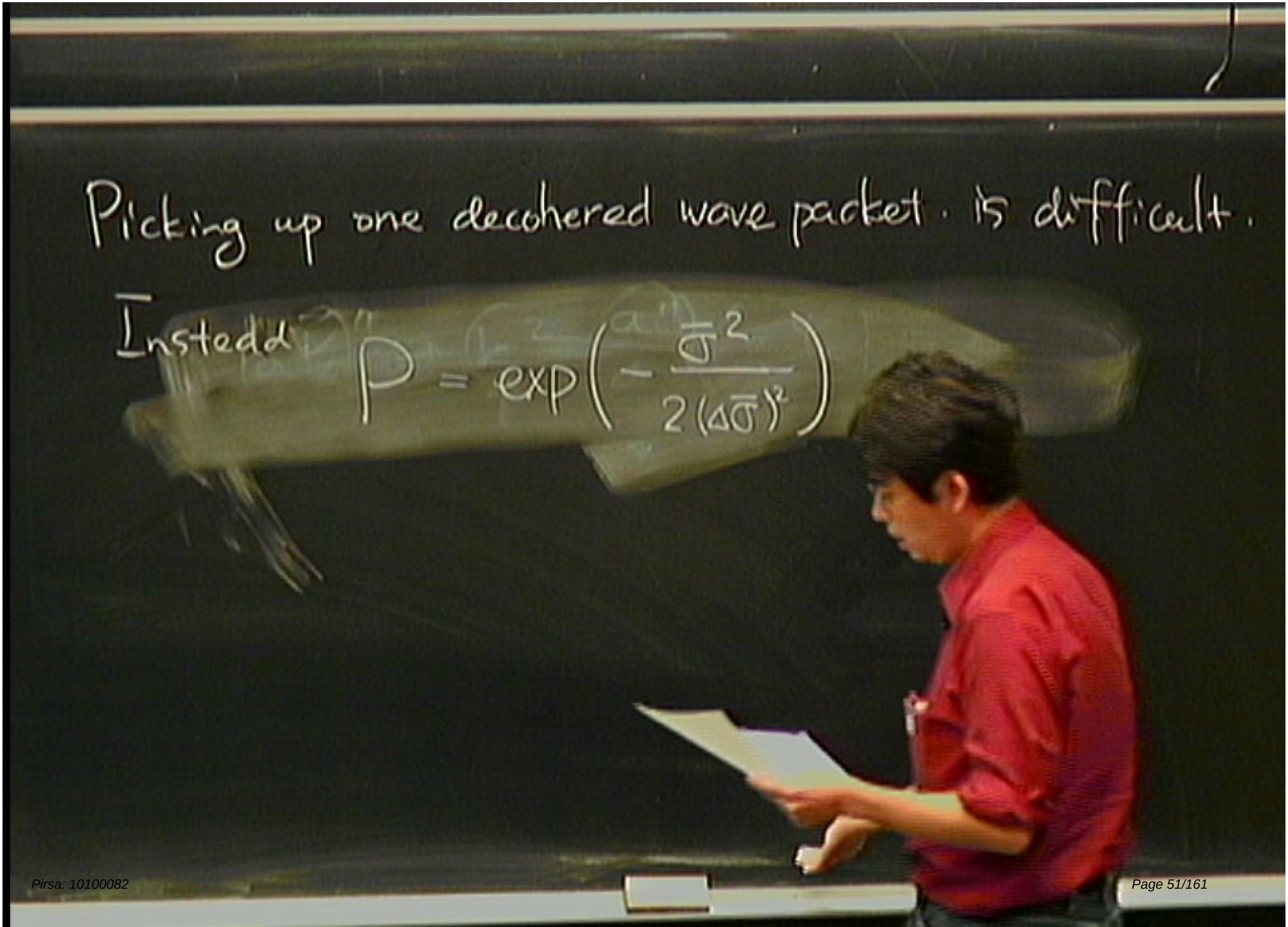
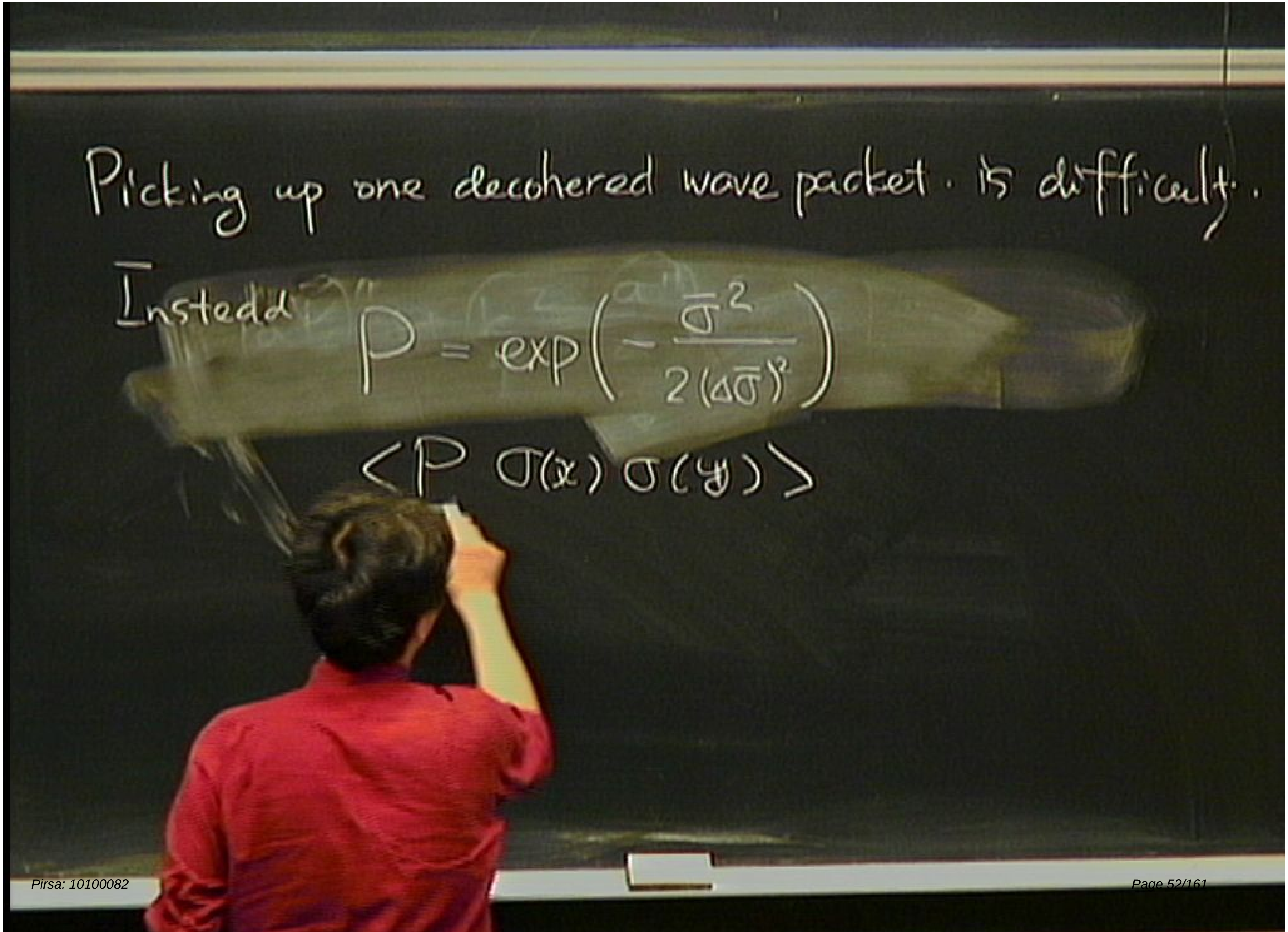
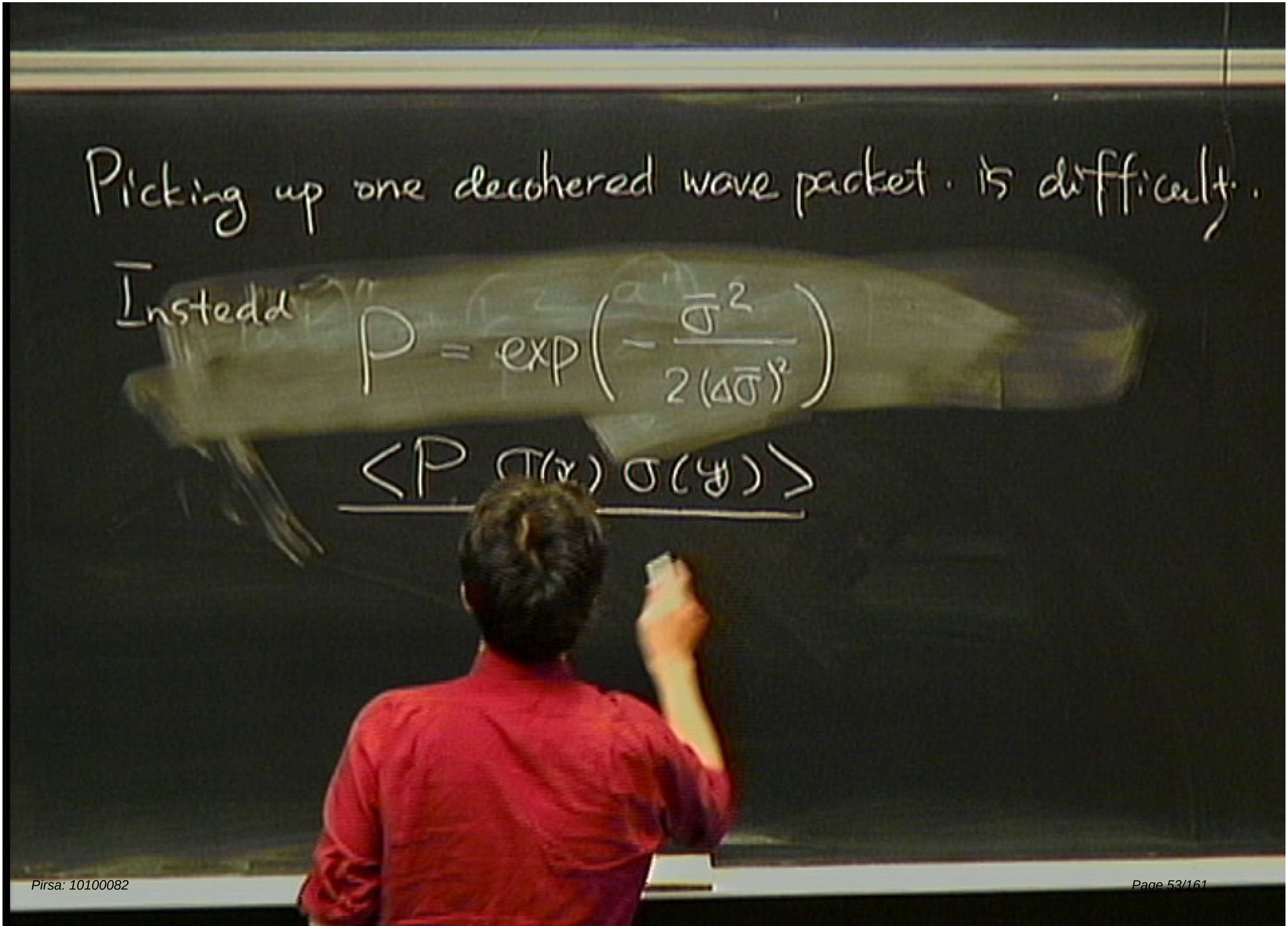
Insted


Picking up one decohered wave packet. is difficult.
Instead
$\rho = \exp\left(-\frac{\bar{\sigma}^2}{2(\Delta\bar{\sigma})^2}\right)$


Picking up one decohered wave packet. is difficult.
Insteadd
$P = \exp\left(-\frac{\bar{\sigma}^2}{2(\Delta\bar{\sigma})^2}\right)$
$\langle P\, \sigma(x)\, \sigma(y) \rangle$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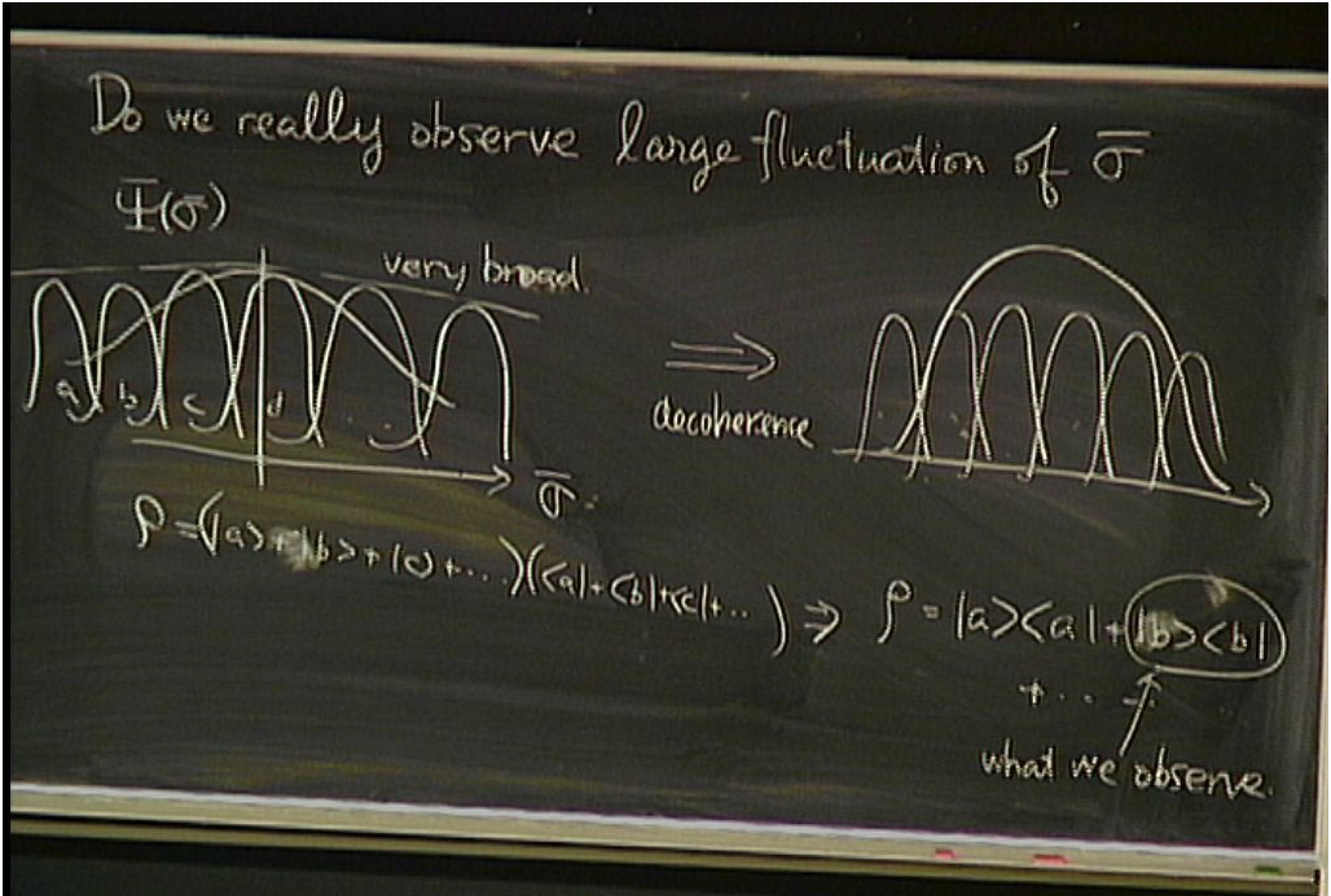
Picking up one decohered wave packet. is difficult.

Instedd

$$P = \exp\left(- \frac{\bar{\sigma}^2}{2(\Delta\bar{\sigma})^2} \right)$$

$$\frac{\langle P\, \sigma(x)\, \sigma(y) \rangle}{\langle P \rangle}$$


Do we really observe large fluctuation of $\bar{\sigma}$
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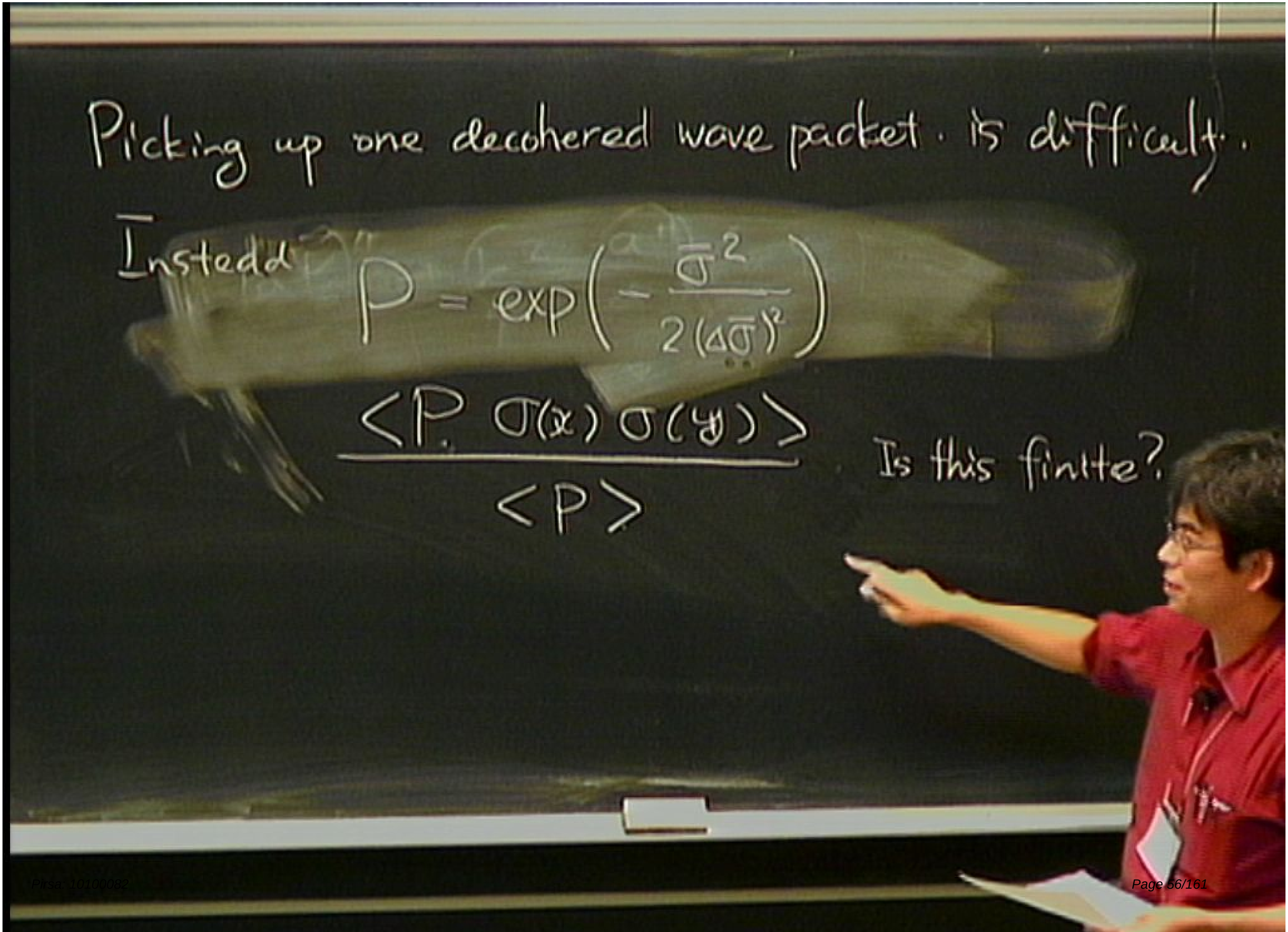
what we observe.


Picking up one decohered wave packet is difficult.
Instead
$P = \exp\left(-\frac{\bar{\sigma}^2}{2(\Delta\bar{\sigma})^2}\right)$
$\frac{\langle P\, \sigma(x)\, \sigma(y) \rangle}{\langle P \rangle}$
Is this finite?

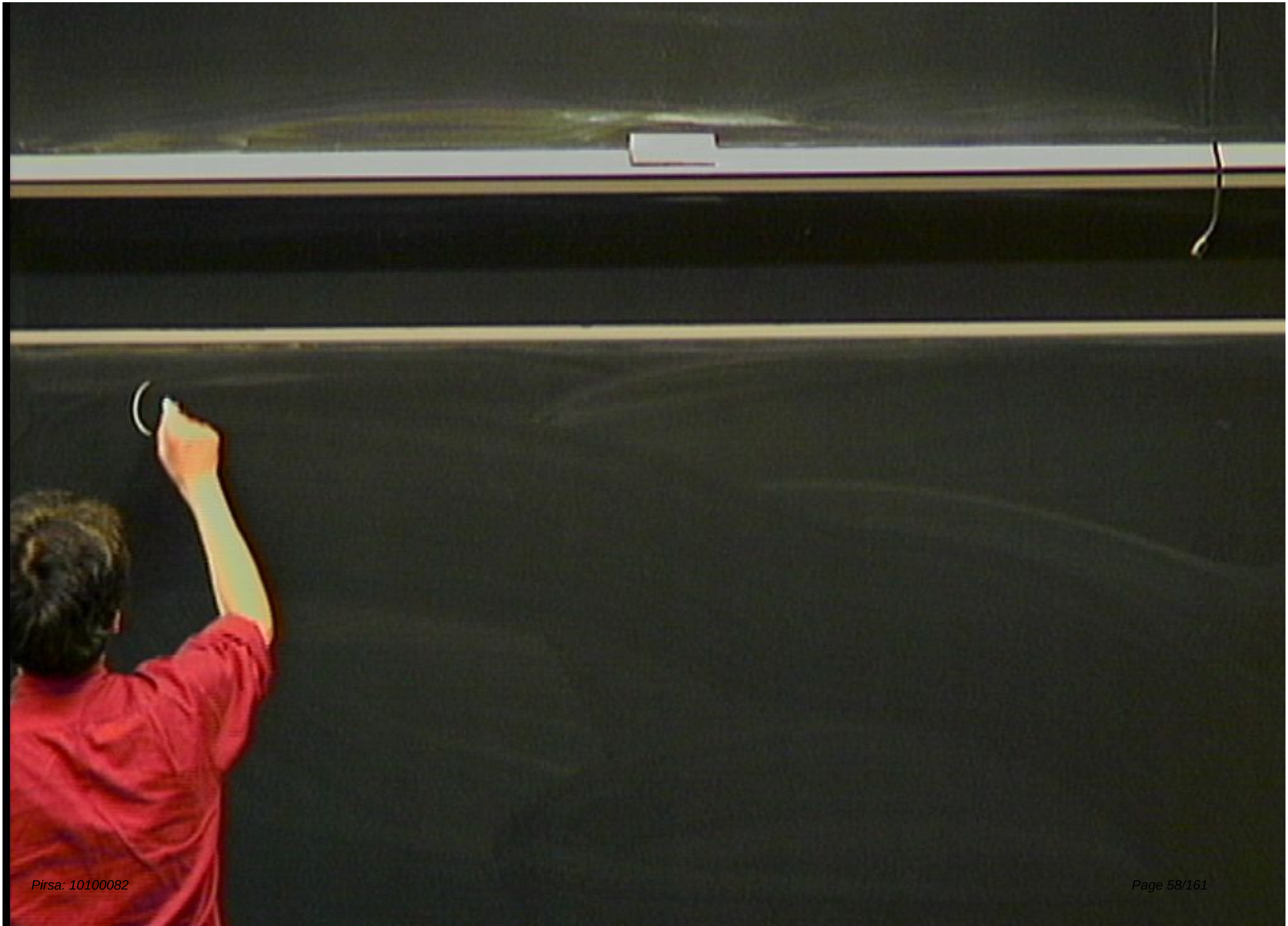
Picking up one decohered wave packet is difficult.

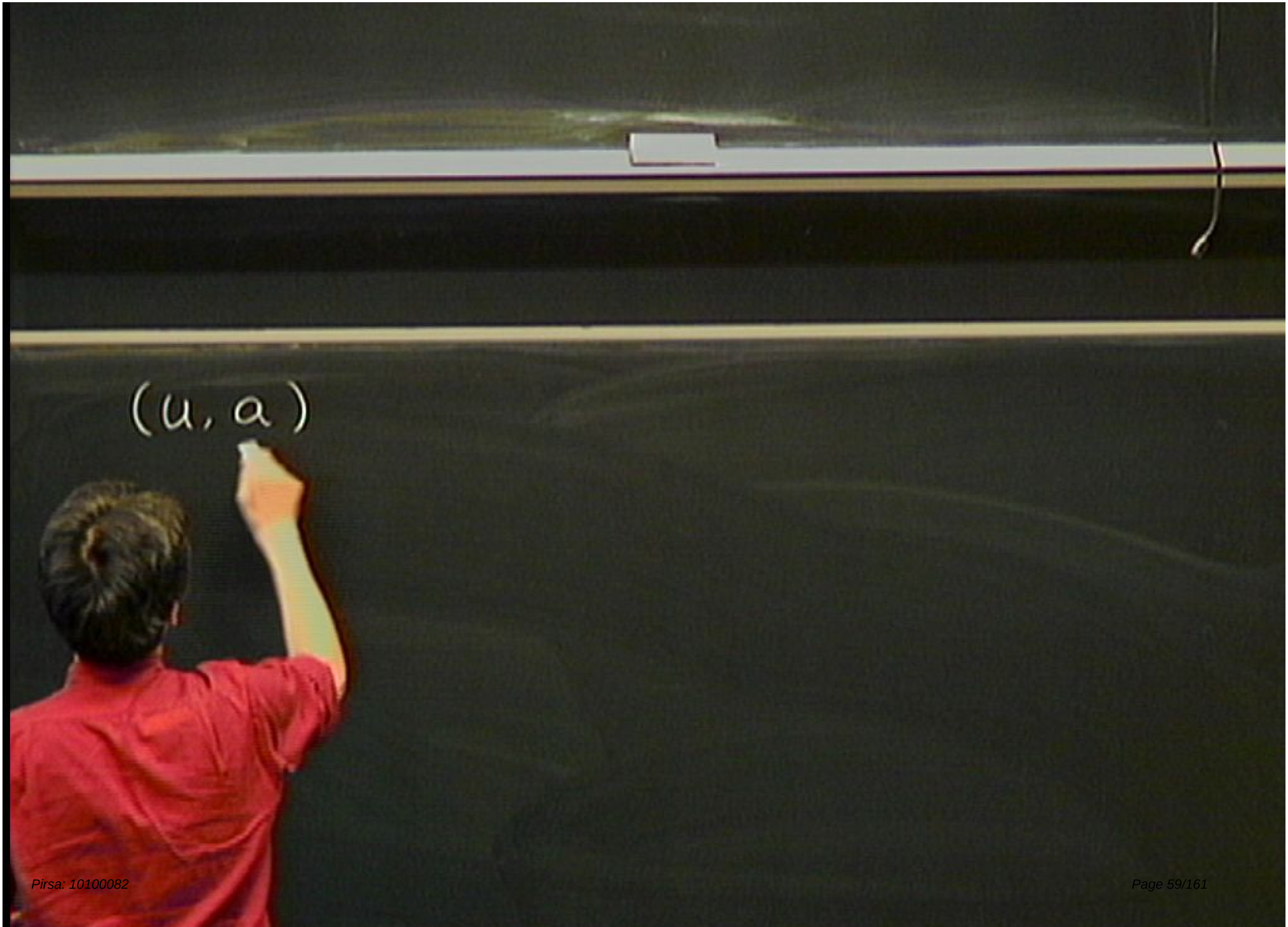
Instead

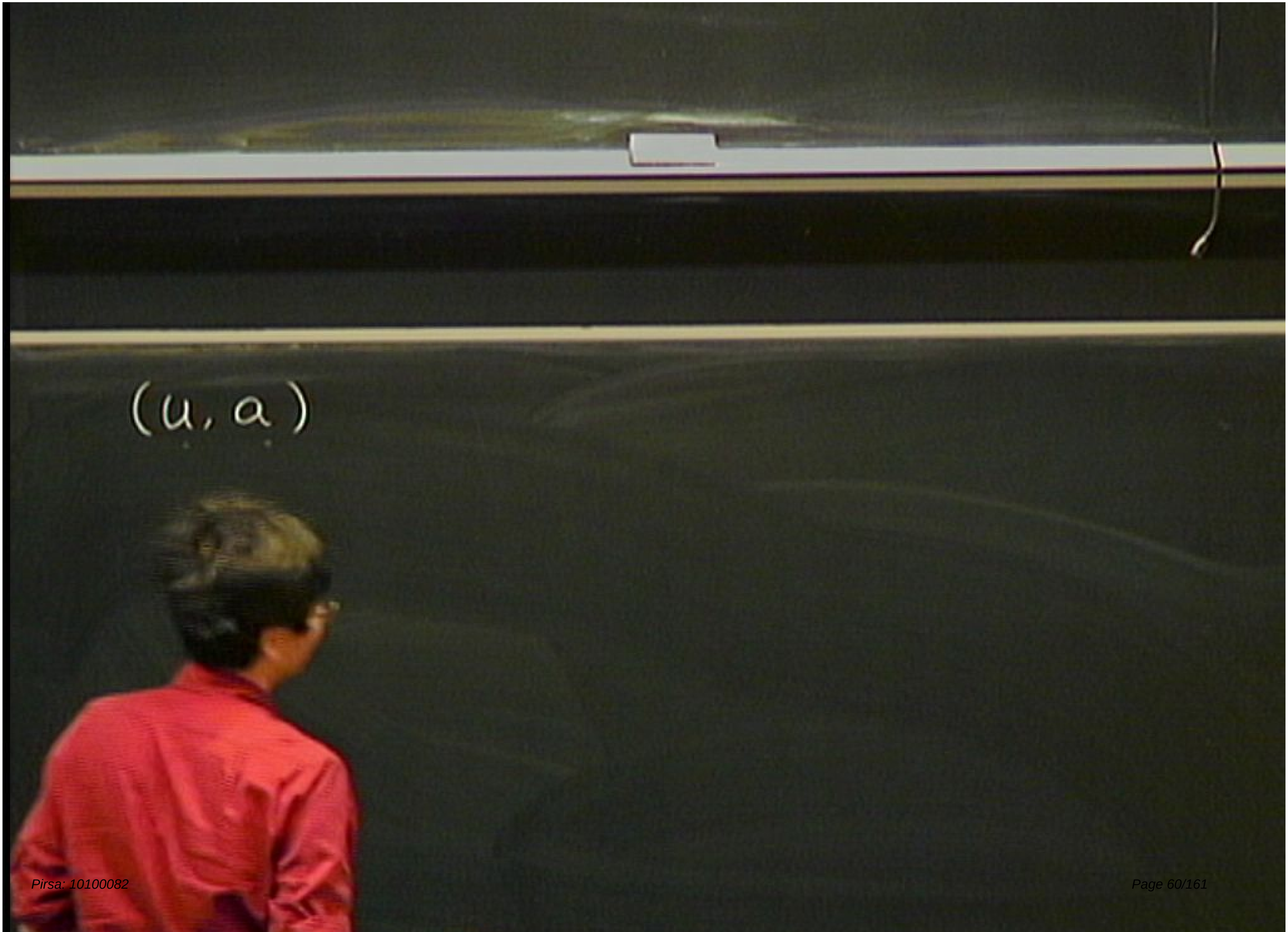
$$P = \exp\left(- \frac{\bar{\sigma}^2}{2(\Delta\bar{\sigma})^2} \right)$$

$$\frac{\langle P\, \sigma(x)\, \sigma(y) \rangle}{\langle P \rangle}$$

Is this finite?

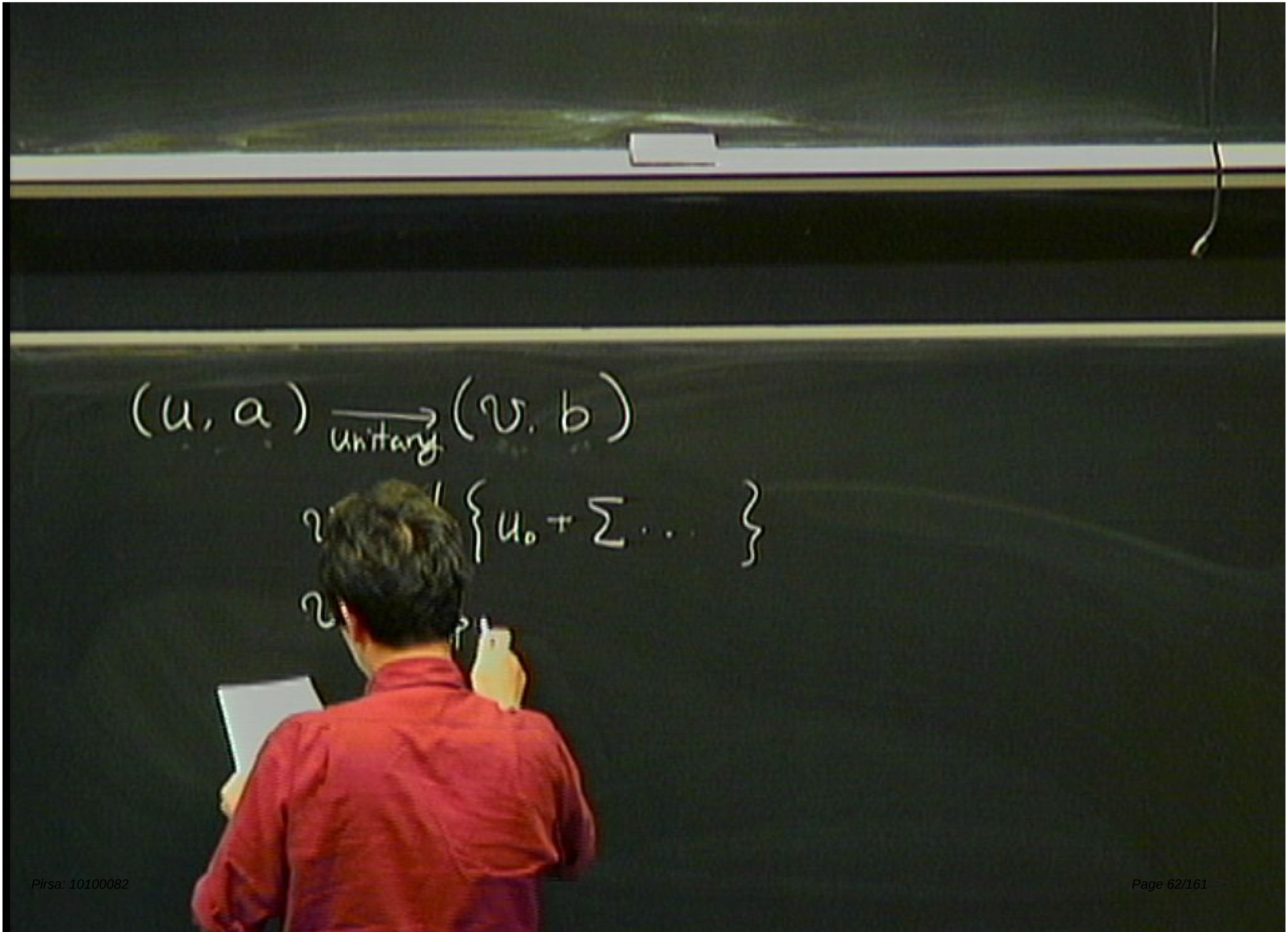


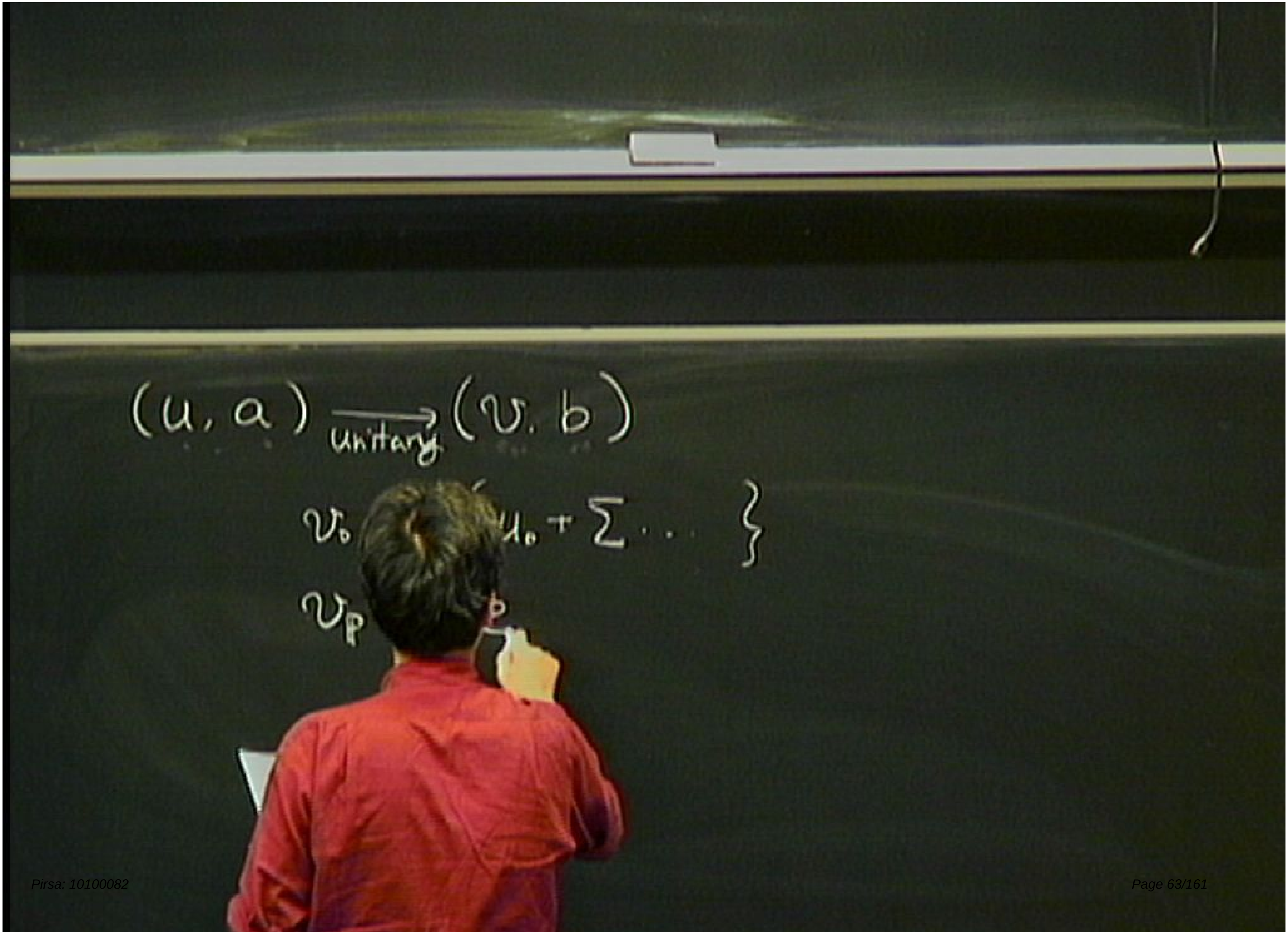

(u, a)


(u, a)

$$(u, a) \xrightarrow[\text{unitary}]{} (v, b)$$

$$v_0 = \frac{1}{N}\left\{ u_0 + \sum \cdots \right\}$$


(u, a) → (v, b)
unitary
{ u₀ + Σ . . . }


(u, a) →unitary (v, b)
v₀ u₀ + Σ . . . }
v_p

$$(u, a) \xrightarrow[\text{unitary}]{} (v, b)$$

$$v_0 = \frac{1}{N}\left\{ u_0 + \sum \cdots \right\}$$

$$v_p = u_p e^{ip\cdot x} - \frac{W_{-p}}{W_0}\frac{C(0)}{C(p)} u_0$$

$$\frac{1}{C(\cdot} \cdots u_p$$

$$(u, a) \xrightarrow[\text{unitary}]{} (v, b)$$

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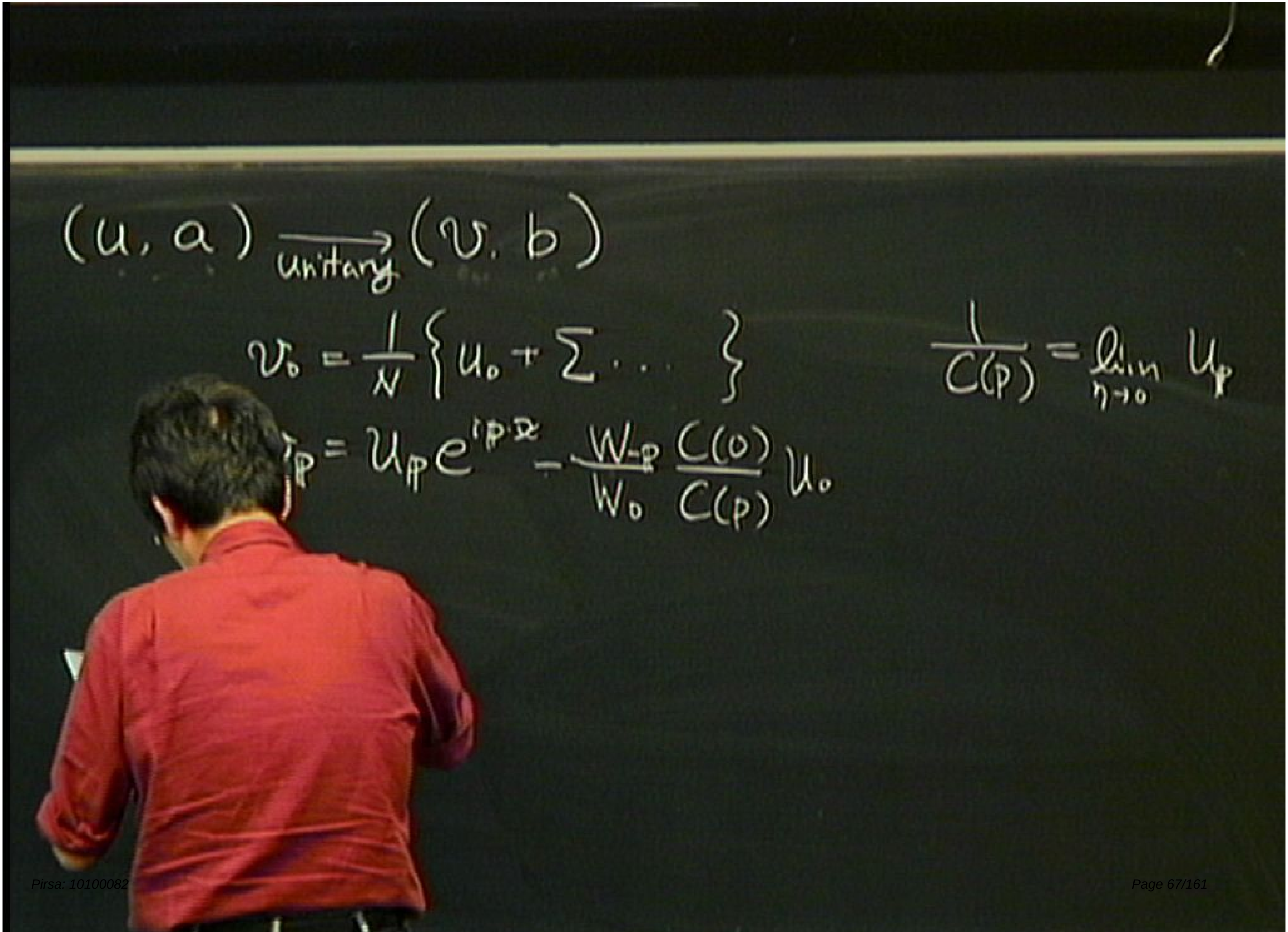
$$\frac{1}{C(p)} = \lim u_p$$

$$(u, a) \xrightarrow[\text{unitary}]{} (v, b)$$

$$v_0 = \frac{1}{N}\left\{ u_0 + \sum \cdots \right\}$$

$$\frac{1}{C(p)} = \lim_{\eta \to 0} u_p$$

$$v_p = u_p e^{ip\cdot x} - \frac{W_{-p}}{W_0}\frac{C(0)}{C(p)} u_0$$



$(u, a) \xrightarrow[\text{unitary}]{} (v, b)$
$v_0 = \frac{1}{N}\{u_0 + \sum \cdots \}$
$\frac{1}{C(p)} = \lim_{\eta \to 0} u_p$
$v_p = u_p e^{ip\cdot x} - \frac{W_{-p}}{W_0}\frac{C(0)}{C(p)} u_0$

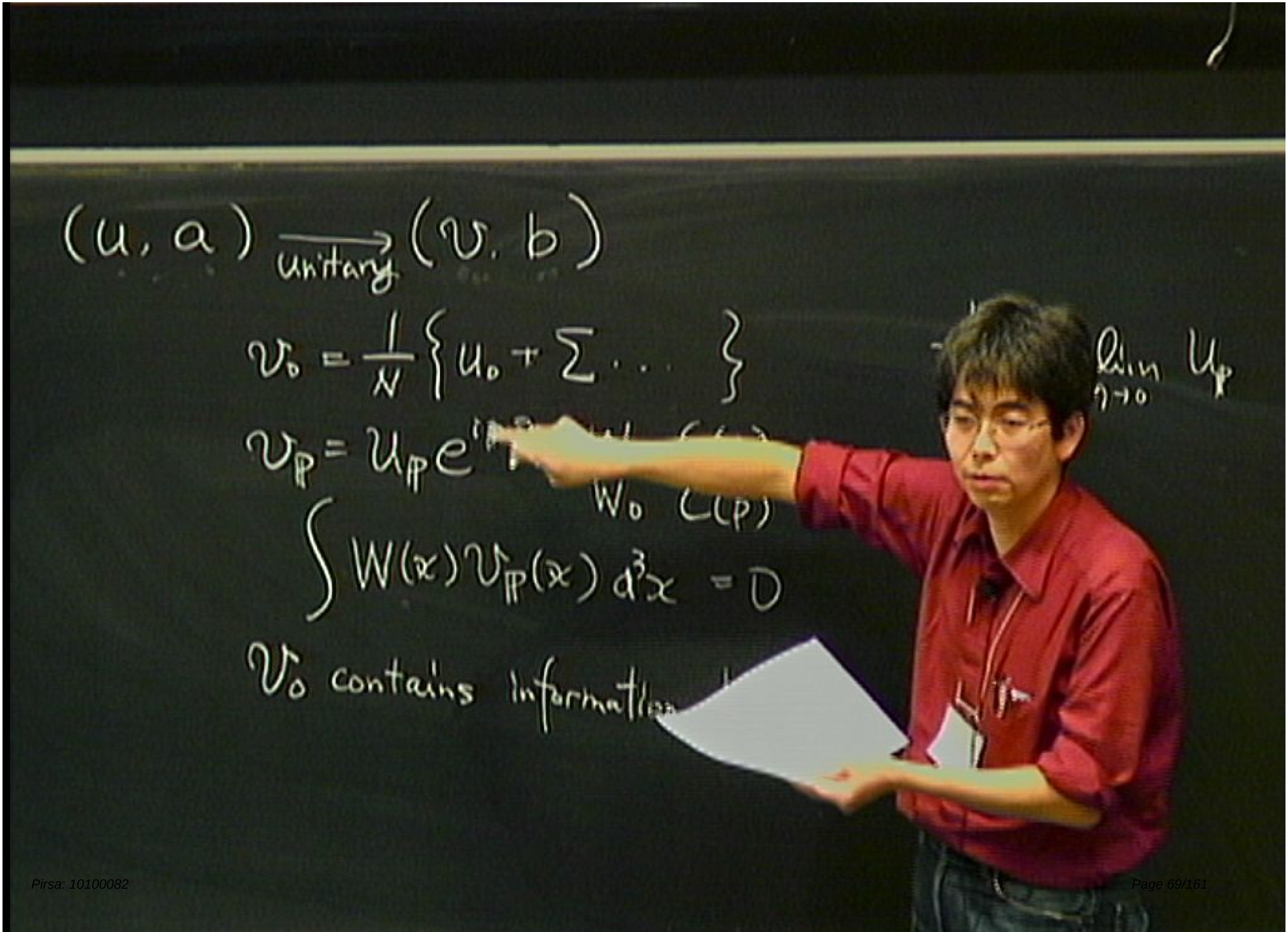
$$(u, a) \xrightarrow[\text{unitary}]{} (v, b)$$

$$v_0 = \frac{1}{N}\left\{ u_0 + \sum \dots \right\}$$

$$\frac{1}{C(p)} = \lim_{\eta \to 0} u_p$$

$$v_p = u_p e^{ip\cdot x} - \frac{W_{-p}}{W_0} \frac{C(0)}{C(p)} u_0$$

$$\int W(x)\, v_p(x)\, d^3x = 0$$


$(u, a) \xrightarrow[\text{unitary}]{} (v, b)$
$v_0 = \frac{1}{N}\{u_0 + \sum \ldots\}$
$v_p = u_p e$
$W_0 \; C(p)$
$\int W(x) v_p(x) \, d^3x = 0$
v_0 contains information
$\lim_{\eta \to 0} u_p$

$$(u, a) \xrightarrow[\text{unitary}]{} (v, b)$$

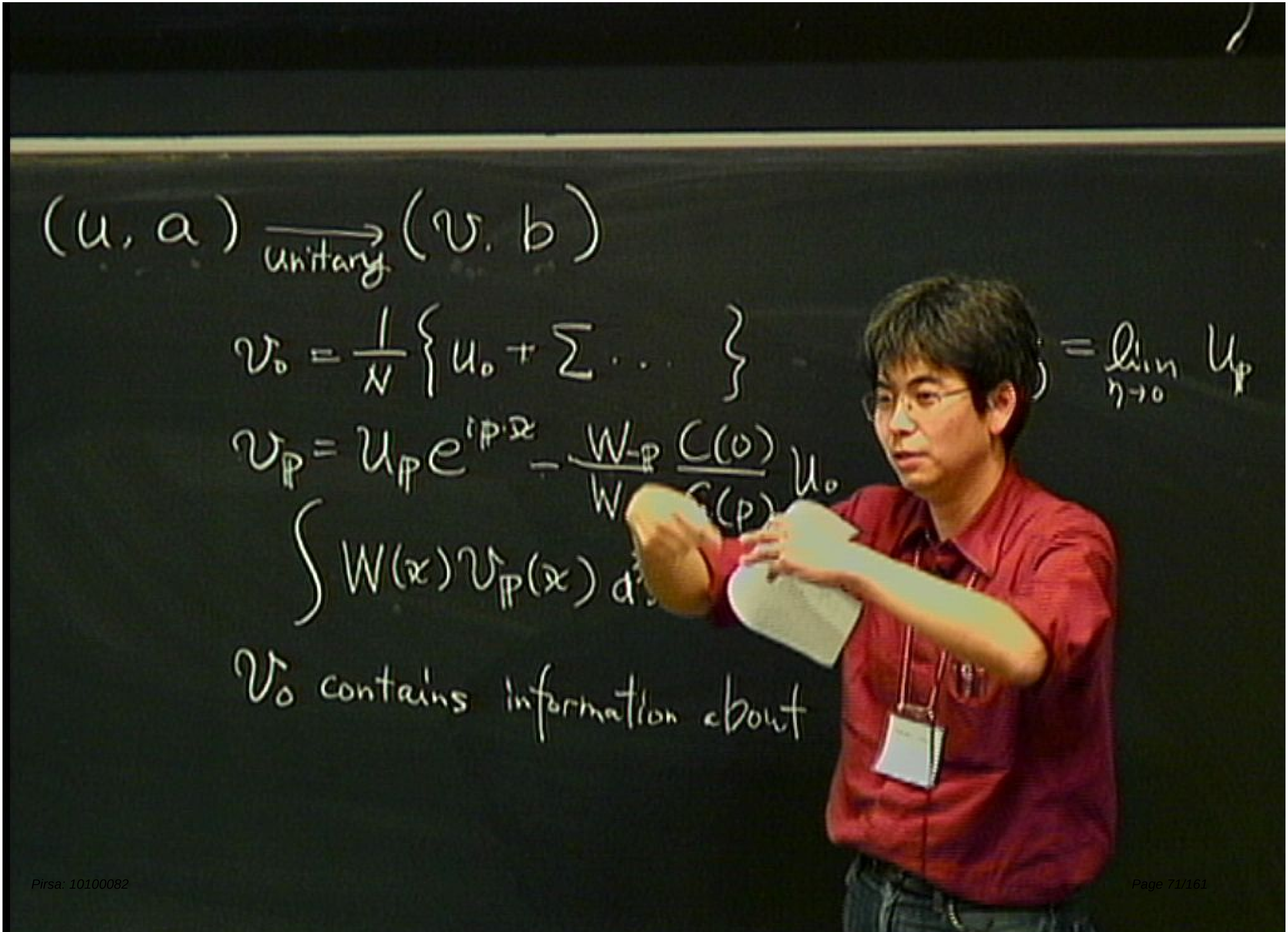
$$v_0 = \frac{1}{N}\left\{ u_0 + \sum \cdots \right\}$$

$$\frac{1}{C(p)} =$$

$$v_p = u_p e^{ip\cdot x} - \frac{W_{-p}}{W_0}\frac{C(0)}{C(p)} u_0$$

$$\int W(x)\, v_p(x)\, d^3x = 0$$

v_0 contains information about


$(u, a) \xrightarrow[\text{unitary}]{} (v, b)$
$v_0 = \frac{1}{N}\{u_0 + \sum \dots\}$
$= \lim_{\eta \to 0} u_p$
$v_p = u_p e^{ip\cdot x} - \frac{W_{-p}}{W} \frac{C(0)}{C(p)} u_0$
$\int W(x) v_p(x) d$
v_0 contains information about

$$(u, a) \xrightarrow[\text{unitary}]{} (v, b)$$

$$v_0 = \frac{1}{N}\left\{ u_0 + \sum \ldots \right\}$$

$$v_{\mathbb{p}} = u_{\mathbb{p}} e^{i\mathbb{p}\cdot x} - \frac{W_{-\mathbb{p}}}{W_0} \frac{C(0)}{C(\mathbb{p})} u_0$$

$$\int W(x)\, v_{\mathbb{p}}(x)\, d^3x = 0$$

v_0 contains information about

$$(u, a) \xrightarrow[\text{unitary}]{} (v, b)$$

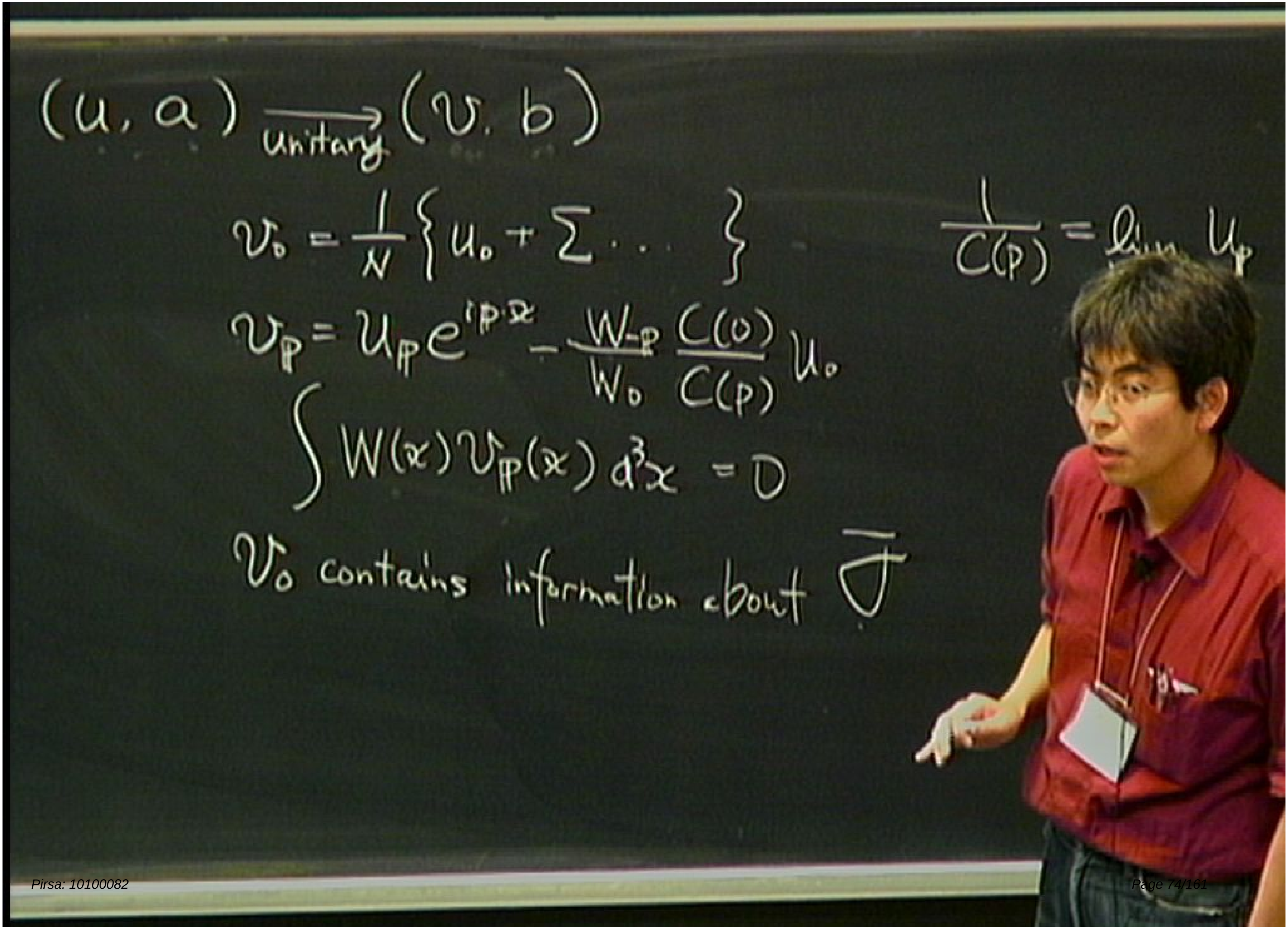
$$v_0 = \frac{1}{N}\left\{ u_0 + \sum \cdots \right\}$$

$$\frac{1}{C(p)} = \lim \; U$$

$$v_p = u_p e^{ip\cdot x} - \frac{W_{-p}}{W_0}\frac{C(0)}{C(p)} u_0$$

$$\int W(x)\, v_p(x)\, d^3x = 0$$

v_0 contains information about $\bar{J}$


$(u, a) \xrightarrow[\text{unitary}]{} (v, b)$
$v_0 = \frac{1}{N}\{u_0 + \Sigma \cdots \}$
$\frac{1}{C(p)} = \lim u_p$
$v_p = u_p e^{ip\cdot x} - \frac{W_{-p}}{W_0}\frac{C(0)}{C(p)} u_0$
$\int W(x) v_p(x)\, d^3x = 0$
v_0 contains information about $\bar{J}$

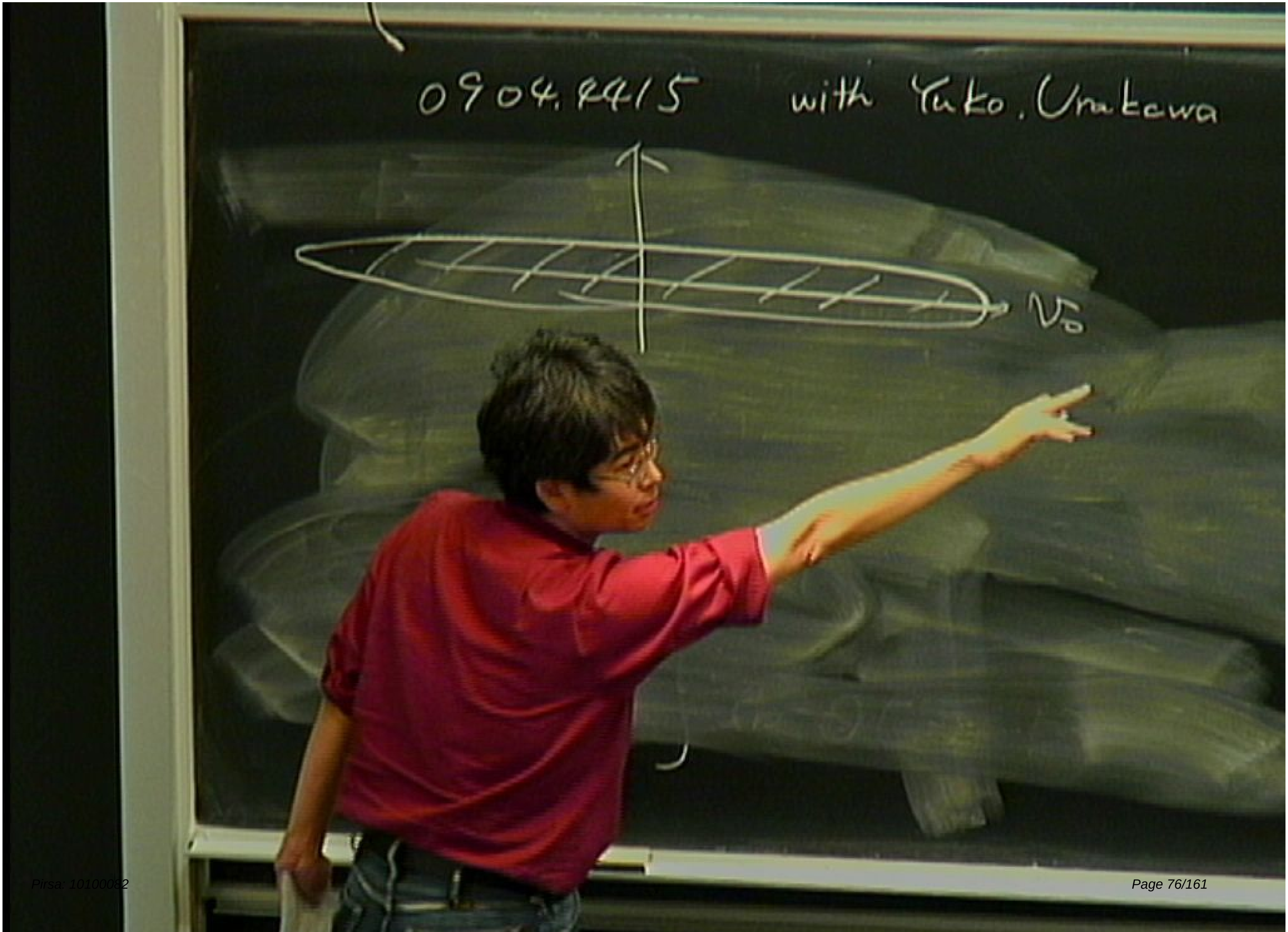
$$(u, a) \xrightarrow[\text{unitary}]{} (v, b)$$

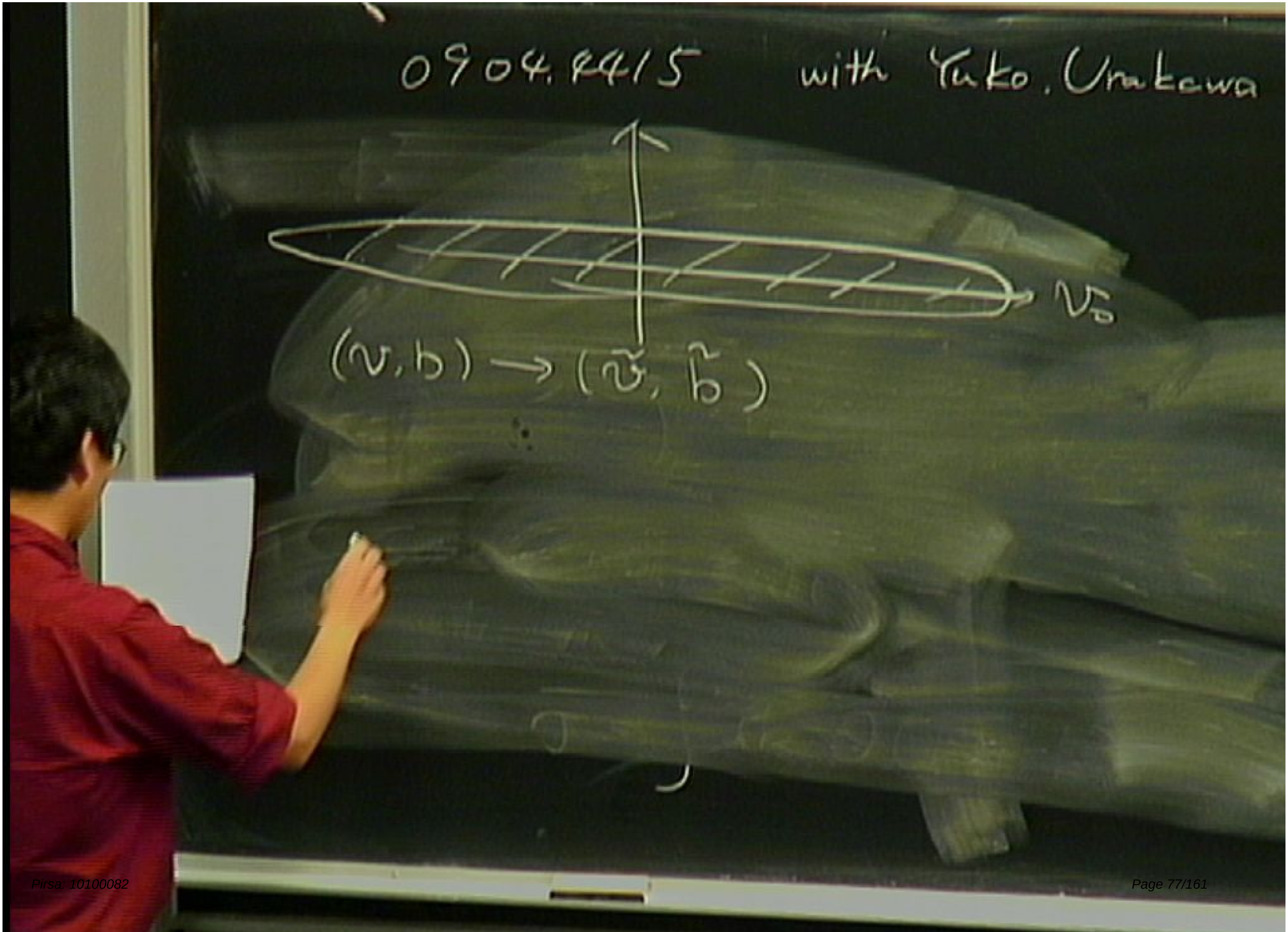
$$v_0 = \frac{1}{N}\left\{u_0 + \sum \cdots \right\} \qquad \frac{1}{C(p)} = \lim_{\eta\to 0} U_p$$

$$v_{\mathbb{p}} = u_{\mathbb{p}} e^{i\mathbb{p}\cdot x} - \frac{W_{-\mathbb{p}}}{W_0}\frac{C(0)}{C(p)} u_0$$

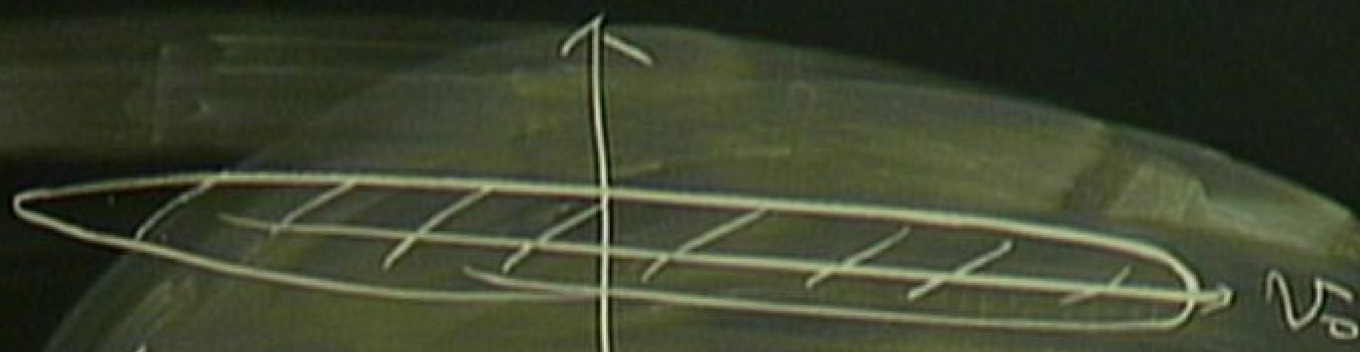
$$\int W(x)\, v_{\mathbb{p}}(x)\, d^3x = 0 \quad \mathbb{p} \neq 0$$

v_0 contains information about $\bar{J}$


0904.4415 with Yuko Urakawa
v_0

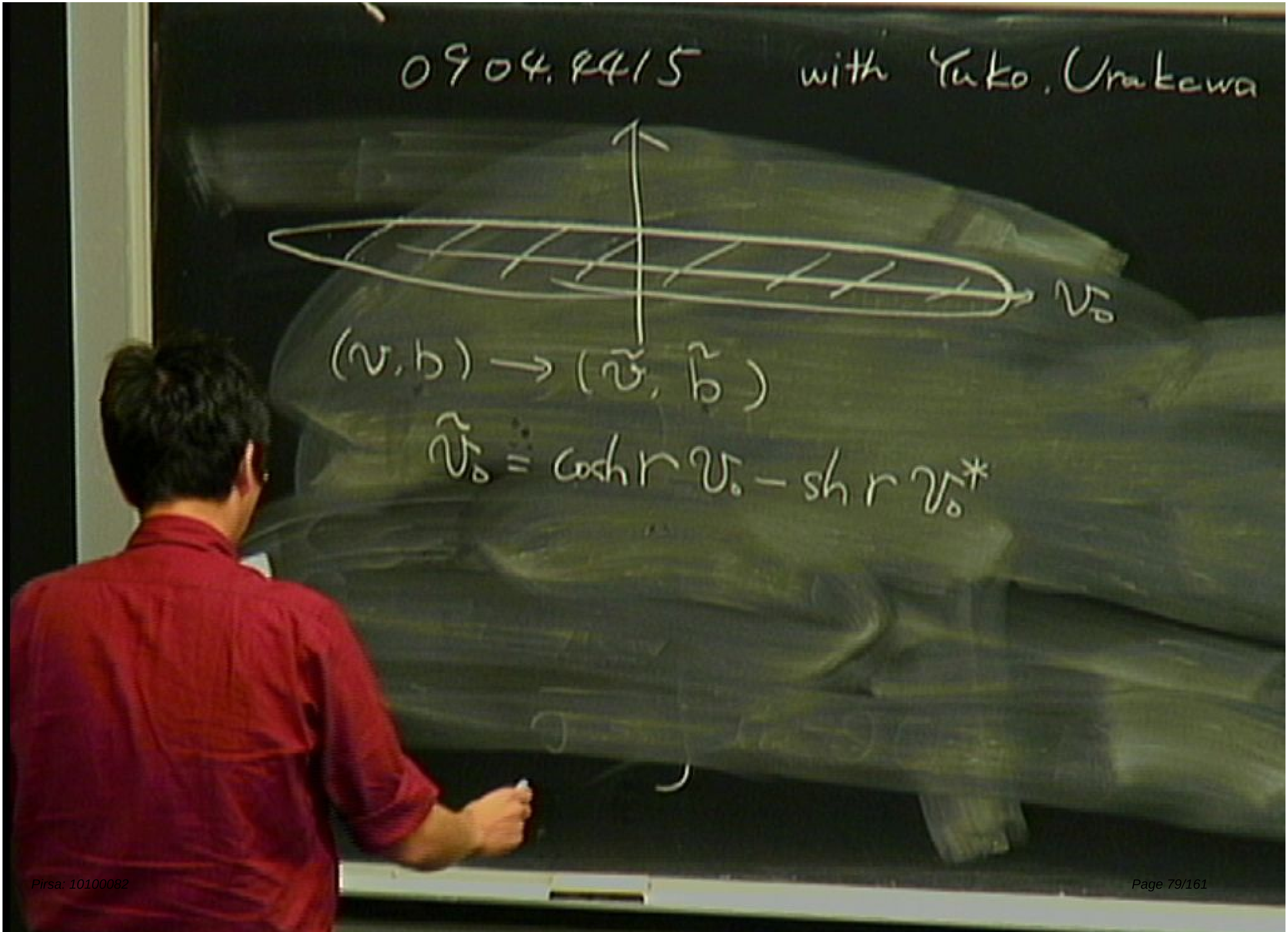

0904.4415 with Yuko Urakawa
v_0
$(v, b) \to (\tilde{v}, \tilde{b})$

0904.4415 with Yuko Urakawa



$(v, b) \longrightarrow (\tilde{v}, \tilde{b})$

$\tilde{v}_0 = \cosh r \, v_0 - \mathrm{sh}\, r \, v_0^*$


0904.4415 with Yuko Urakawa
v_0
$(v, b) \to (\tilde{v}, \tilde{b})$
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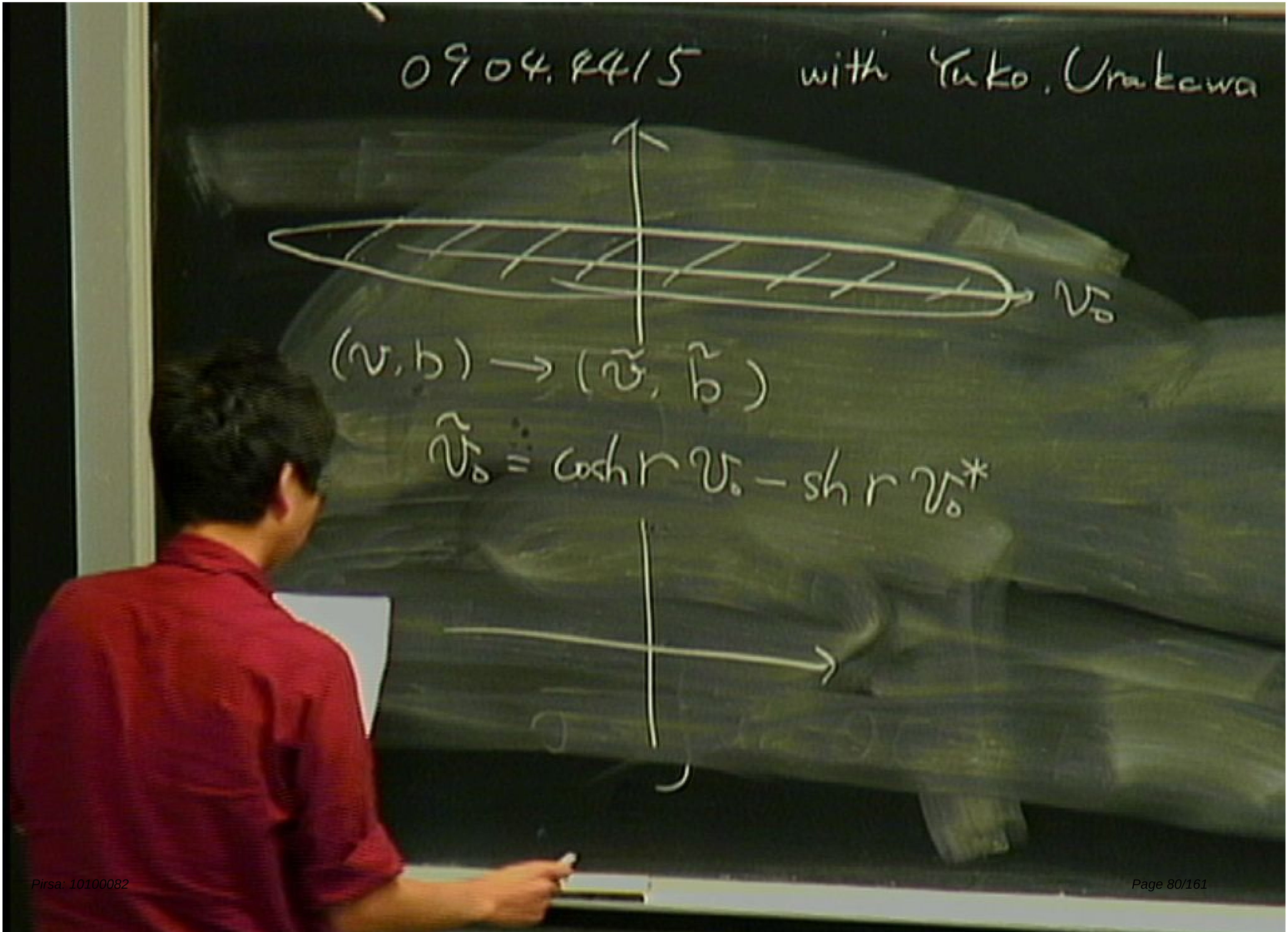
0904.4415 with Yuko Urakawa
v_0
$(v, b) \to (\tilde{v}, \tilde{b})$
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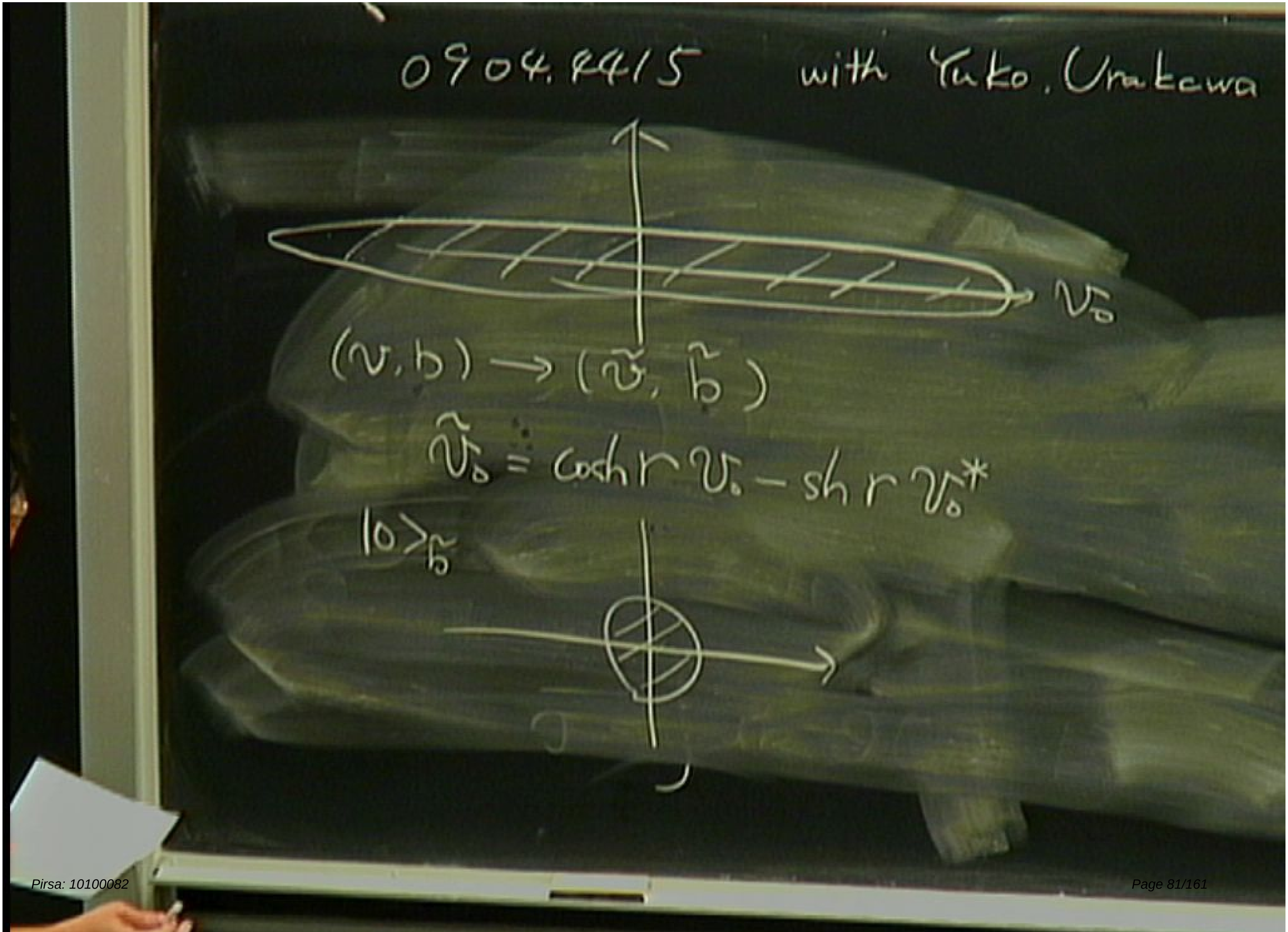
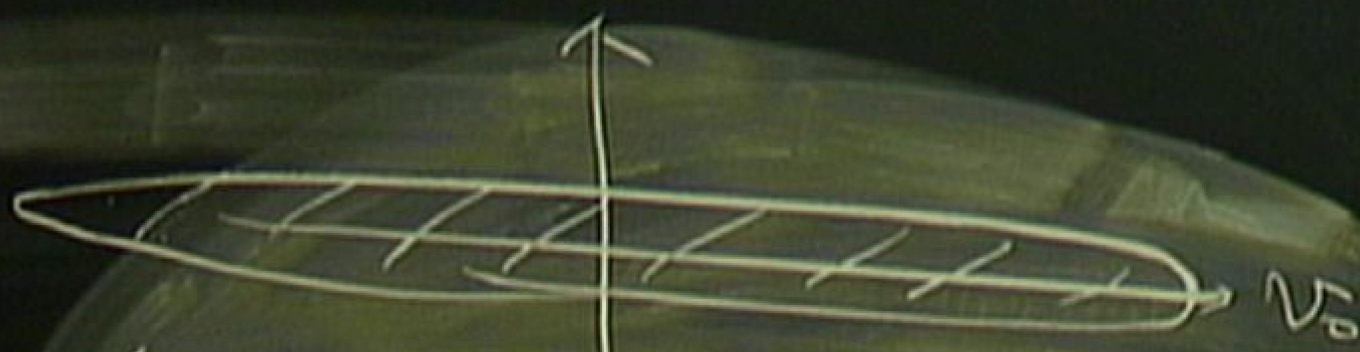

0904.4415 with Yuko Urakawa
v_0
$(v, b) \to (\tilde{v}, \tilde{b})$
$\tilde{v}_0 = \cosh r \, v_0 - \sinh r \, v_0^*$
$|0\rangle_{\tilde{b}}$

0904.4415 with Yuko Urakawa



$(v, b) \longrightarrow (\tilde{v}, \tilde{b})$

$$\tilde{v}_0 = \cosh r \, v_0 - \sinh r \, v_0^*$$

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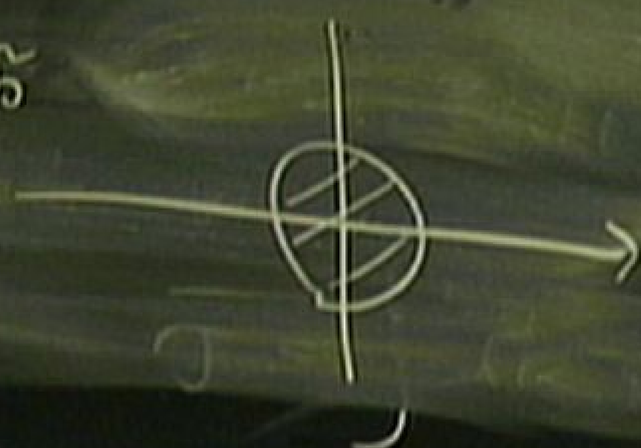
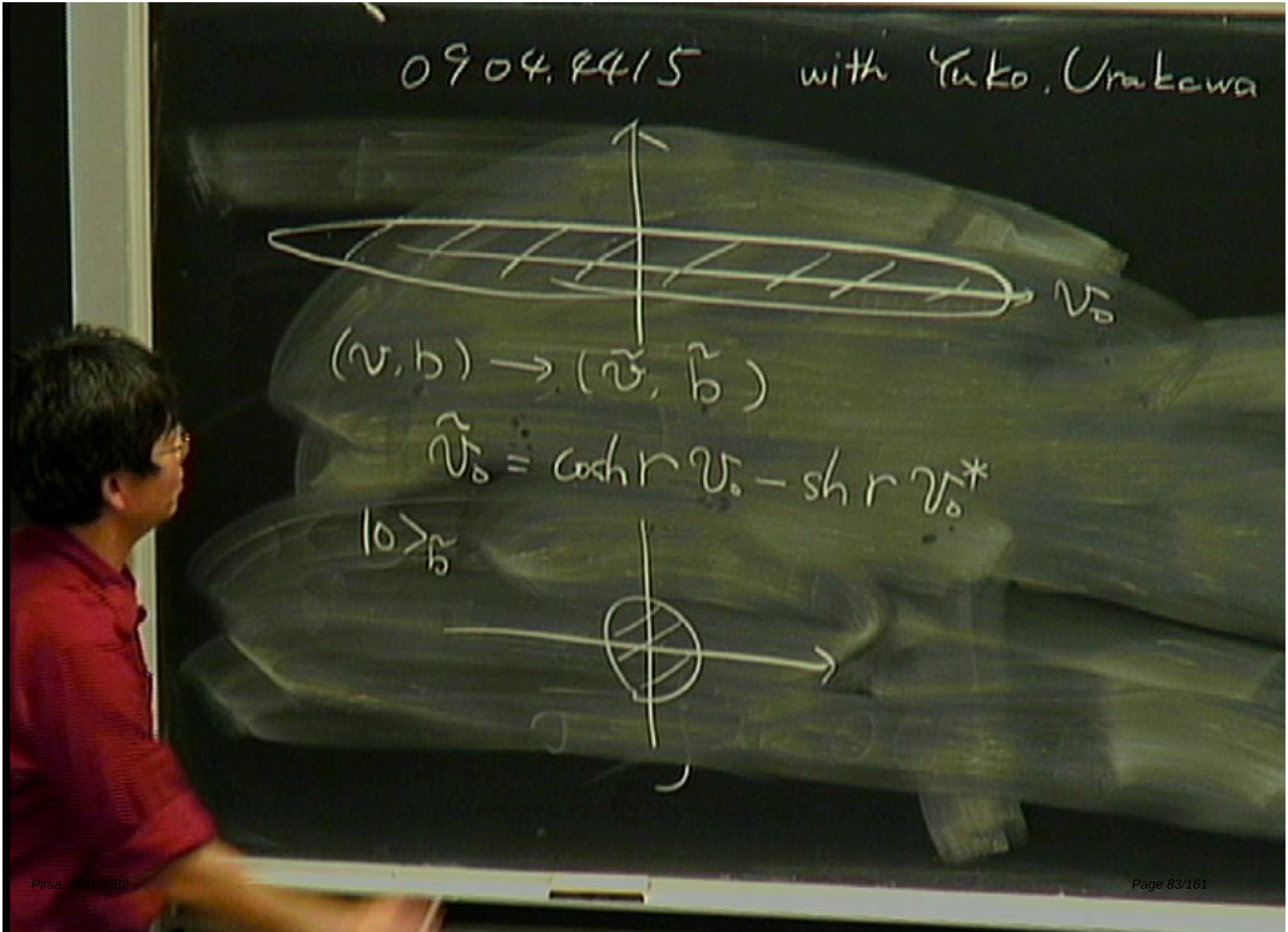
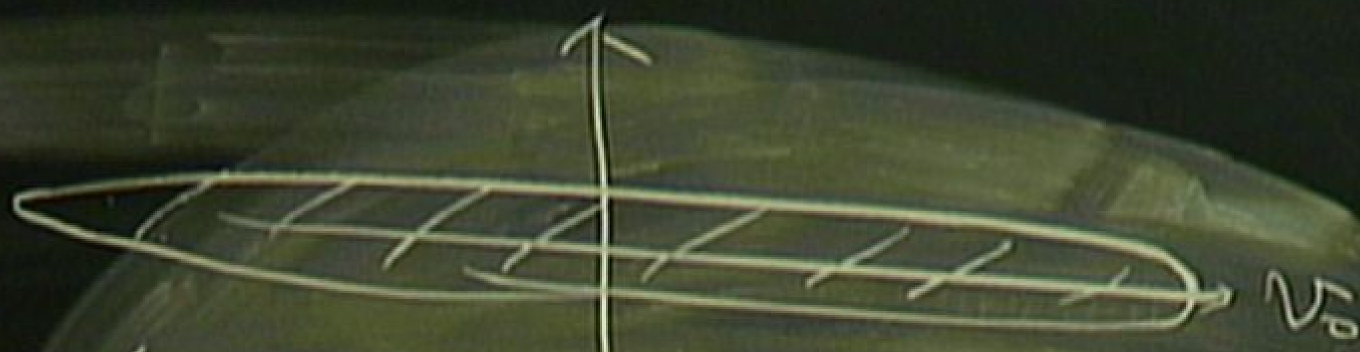



0904.4415 with Yuko Urakawa
v₀
(v, b) → (ṽ, b̃)
ṽ₀ = cosh r v₀ − sh r v₀*
|0⟩b̃

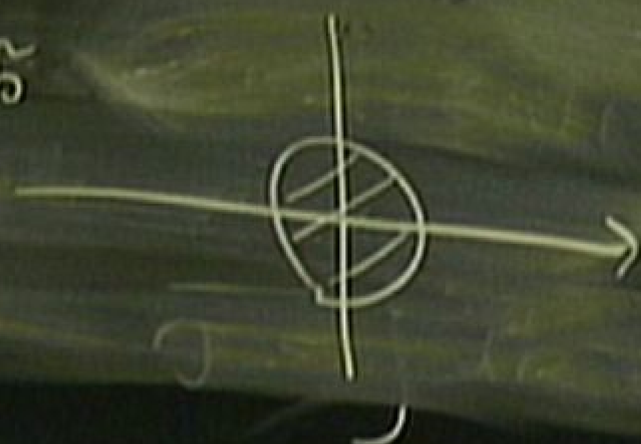
0904.4415 with Yuko Urakawa



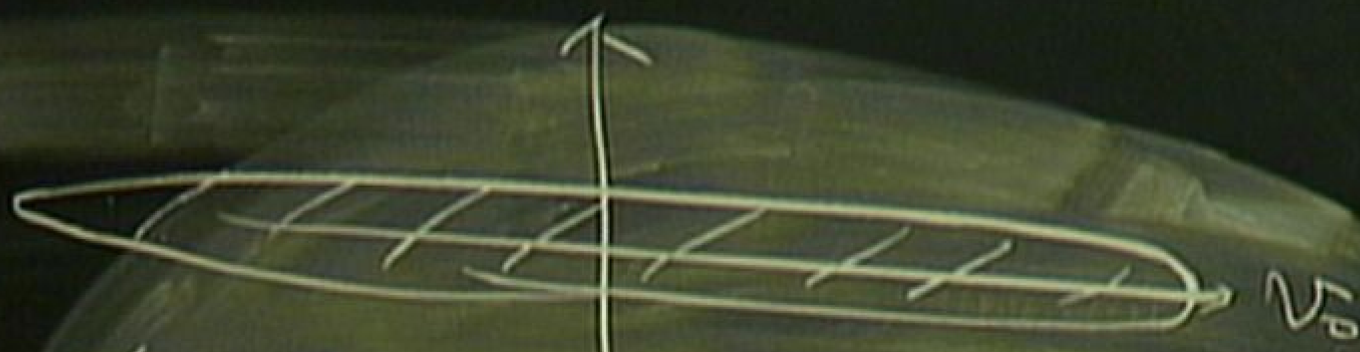
$$(v, b) \to (\tilde{v}, \tilde{b})$$

$$\tilde{v}_0 = \cosh r\, v_0 - \mathrm{sh}\, r\, v_0^*$$

$|0\rangle_{\tilde{b}}$



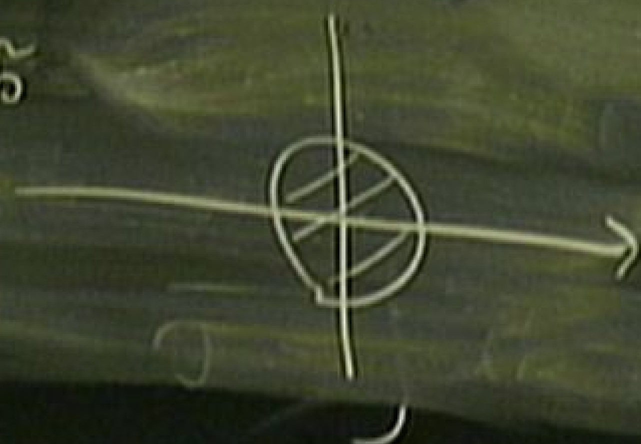
0904.4415 with Yuko Urakawa

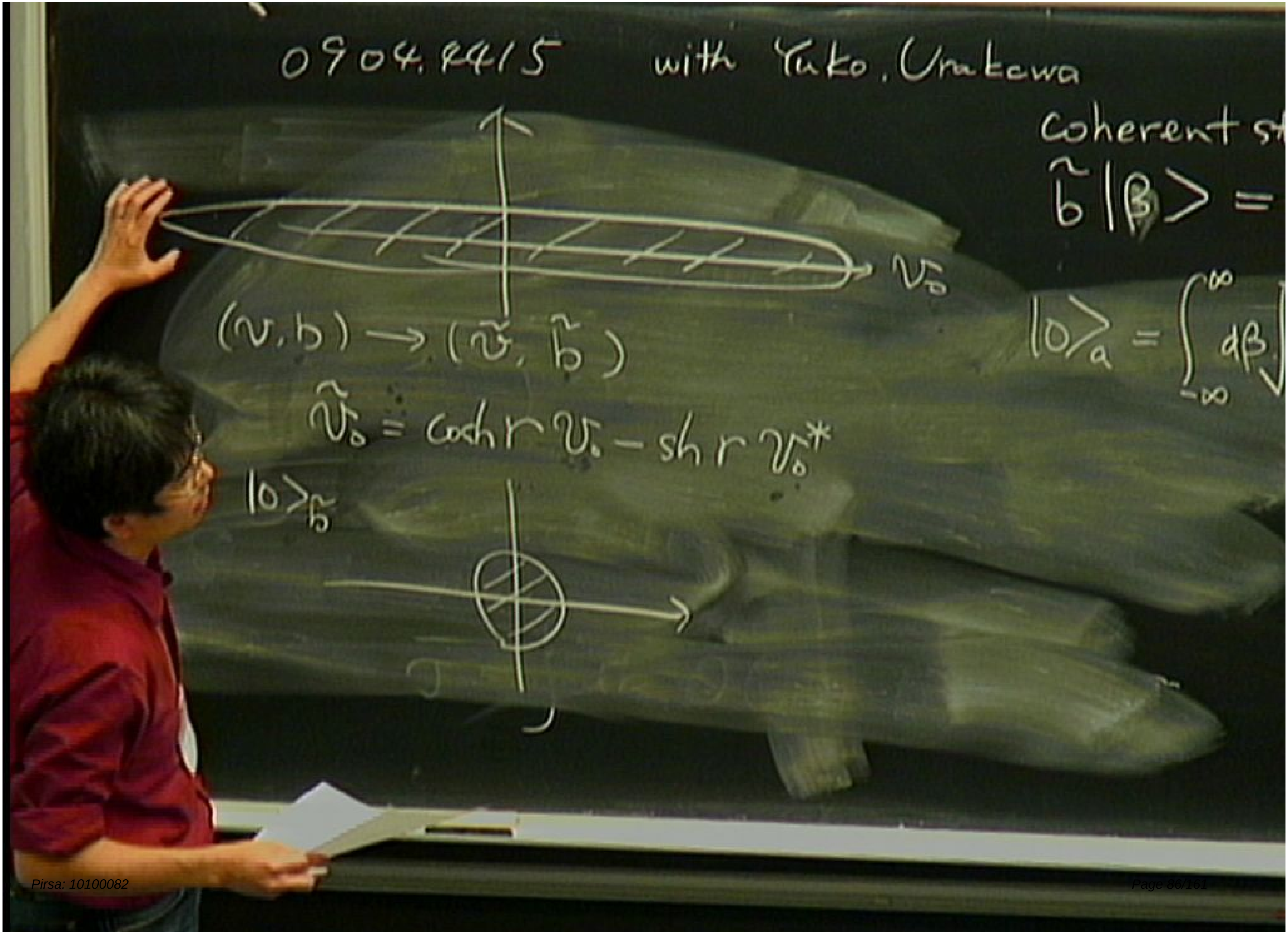


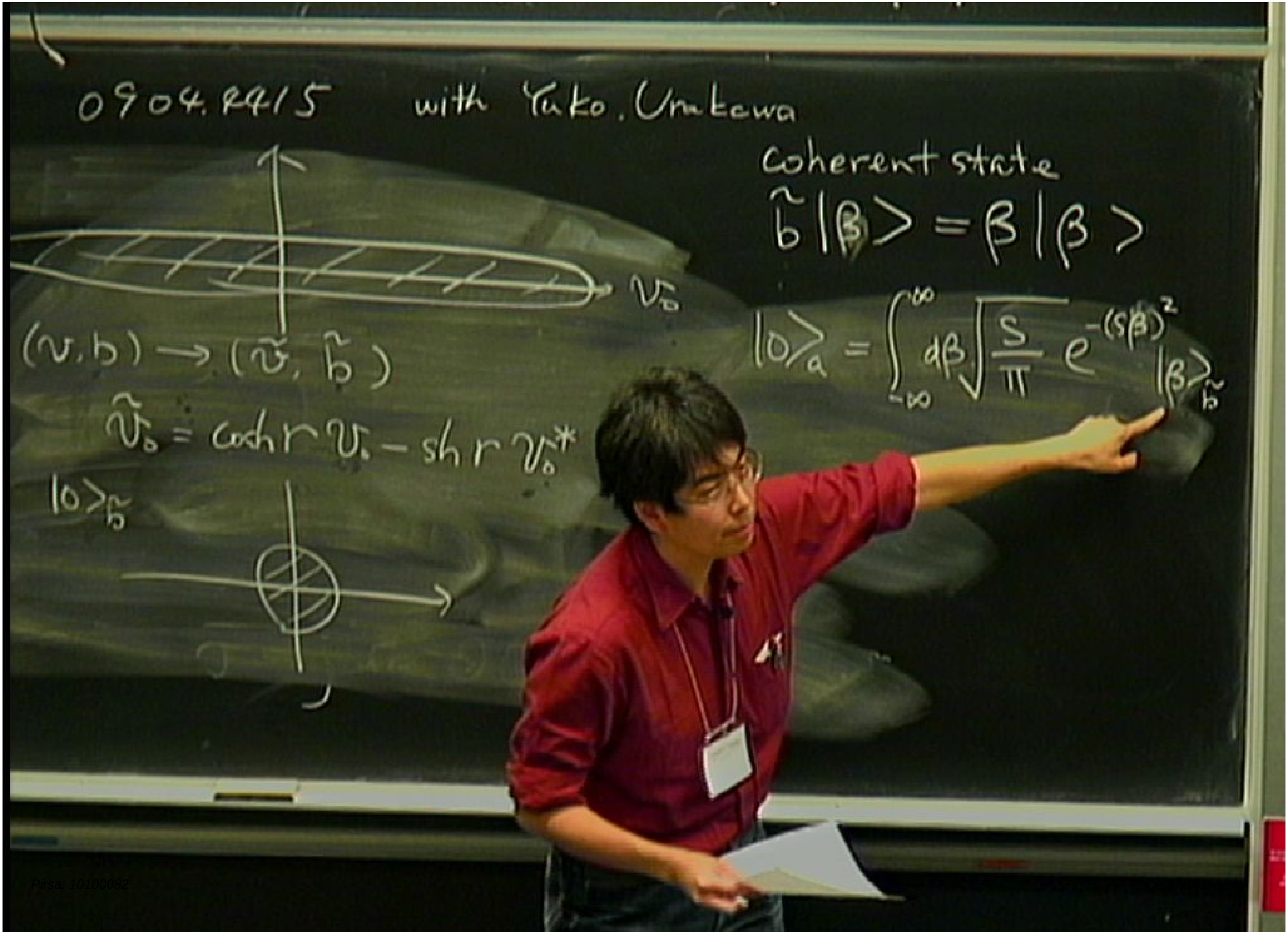
$$(v, b) \to (\tilde{v}, \tilde{b})$$

$$\tilde{v}_0 = \cosh r \, v_0 - \operatorname{sh} r \, v_0^*$$

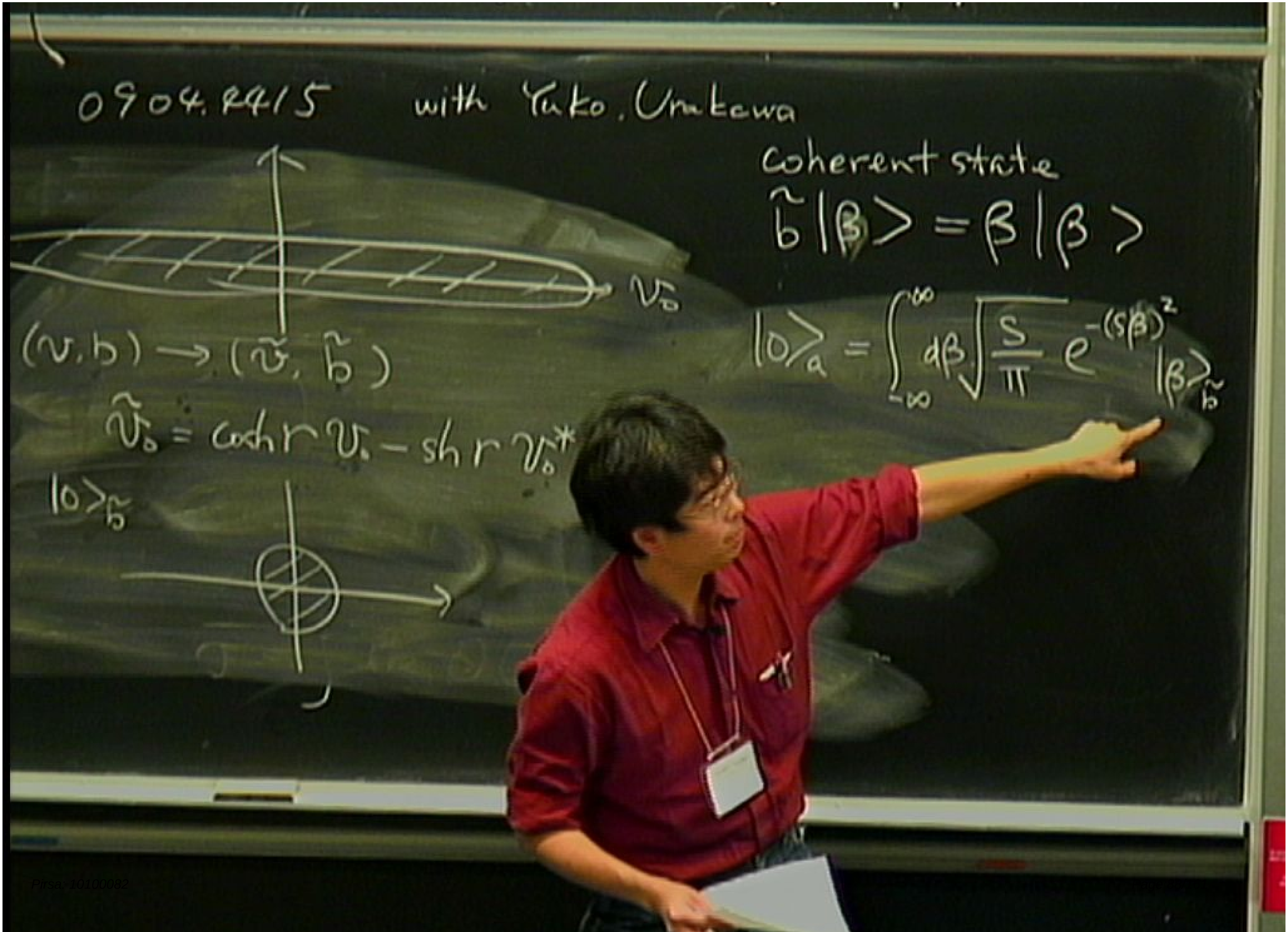
$|0\rangle_{\tilde{b}}$

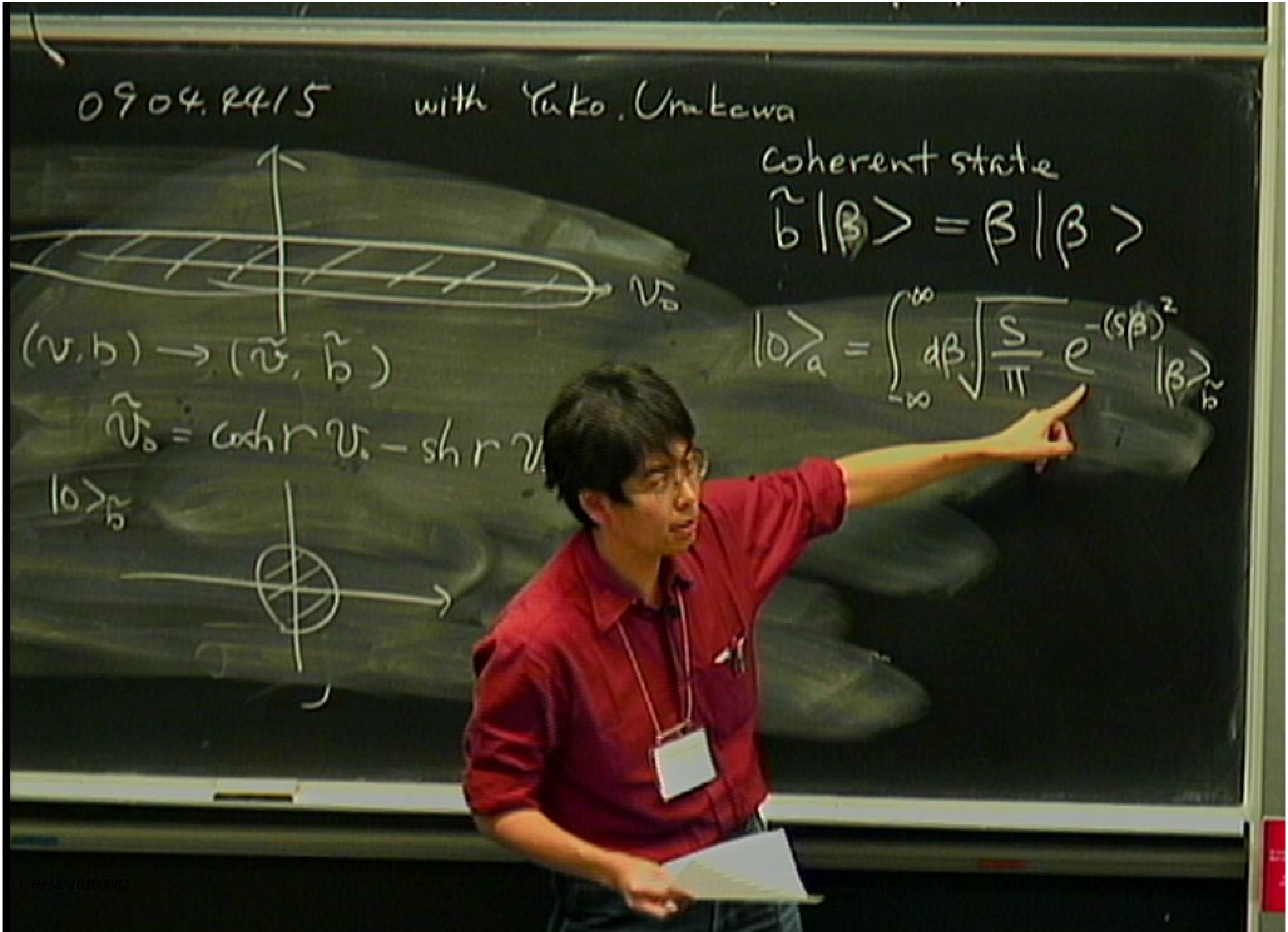



0904.4415 with Yuko Urakawa
coherent st
$\tilde{b}|\beta\rangle =$
$|0\rangle_a = \int_{-\infty}^{\infty} d\beta$
$(v, b) \rightarrow (\tilde{v}, \tilde{b})$
$\tilde{v}_0 = \cosh r\, v_0 - \sh r\, v_0^*$
$|0\rangle_{\tilde{b}}$

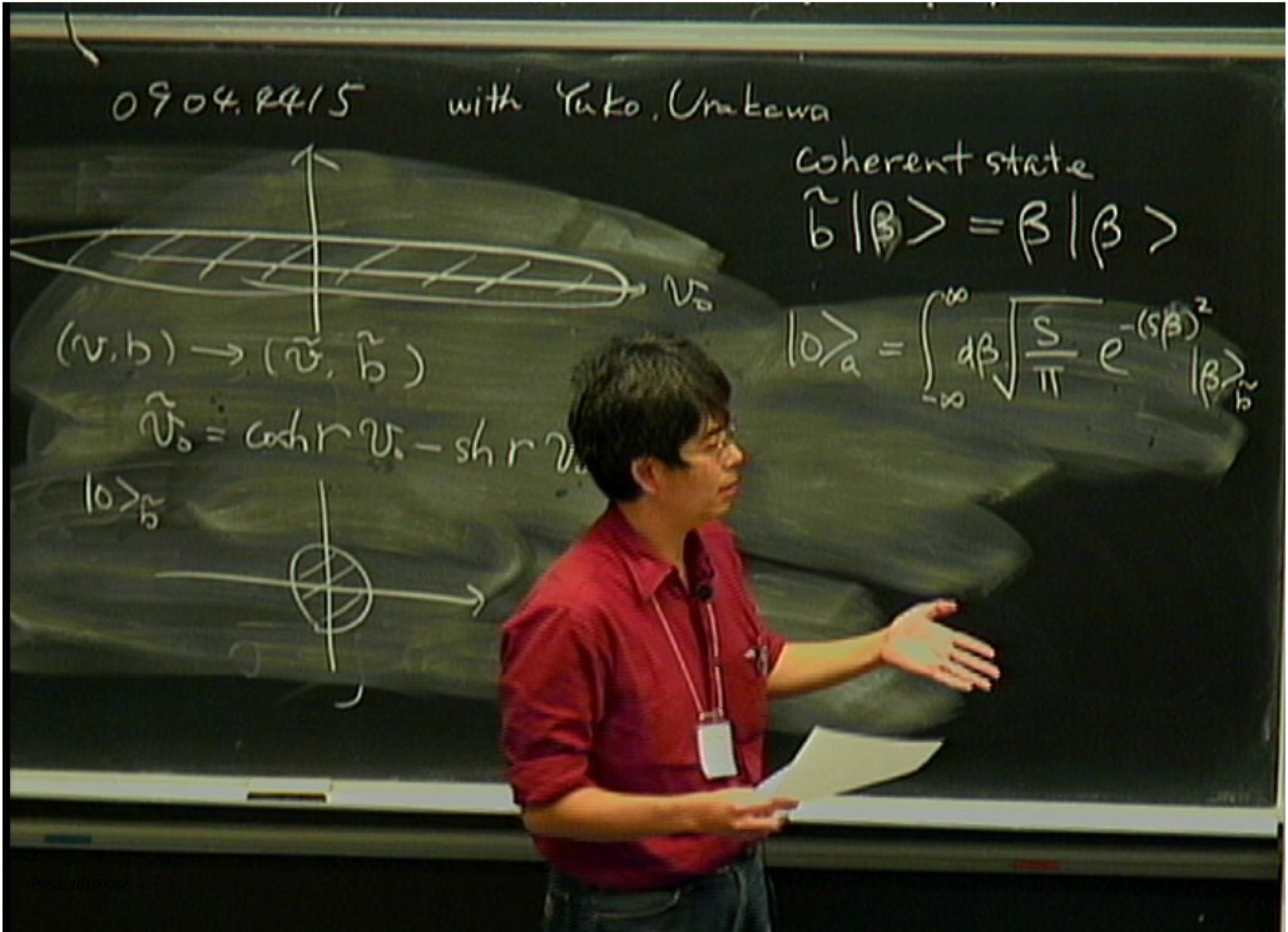


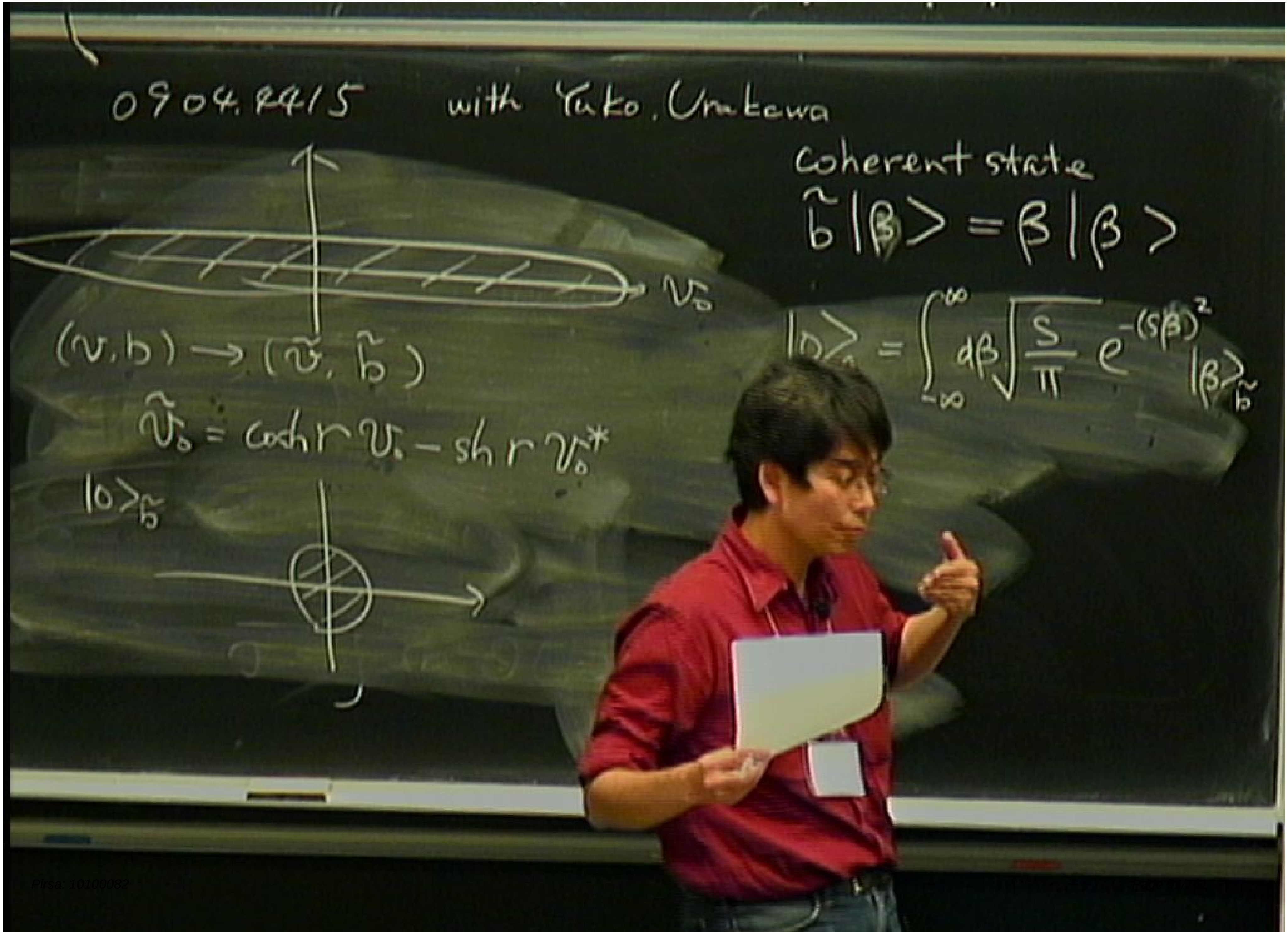
0904.2415 with Yuko Urakawa
coherent state
$\tilde{b}|\beta\rangle = \beta|\beta\rangle$
$|0\rangle_a = \int_{-\infty}^{\infty} d\beta \sqrt{\frac{s}{\pi}}\, e^{-(s\beta)^2} |\beta\rangle_{\tilde{b}}$
v_0
$(v, b) \to (\tilde{v}, \tilde{b})$
$\tilde{v}_0 = \cosh r\, v_0 - \mathrm{sh}\, r\, v_0^*$
$|0\rangle_{\tilde{b}}$


0904.2415
with Yuko Urakawa
coherent state
$\tilde{b}|\beta\rangle = \beta|\beta\rangle$
$|0\rangle_a = \int_{-\infty}^{\infty} d\beta \sqrt{\frac{s}{\pi}}\, e^{-(s\beta)^2} |\beta\rangle_{\tilde{b}}$
v_0
$(v, b) \to (\tilde{v}, \tilde{b})$
$\tilde{v}_0 = \cosh r\, v_0 - \mathrm{sh}\, r\, v_0^*$
$|0\rangle_{\tilde{b}}$

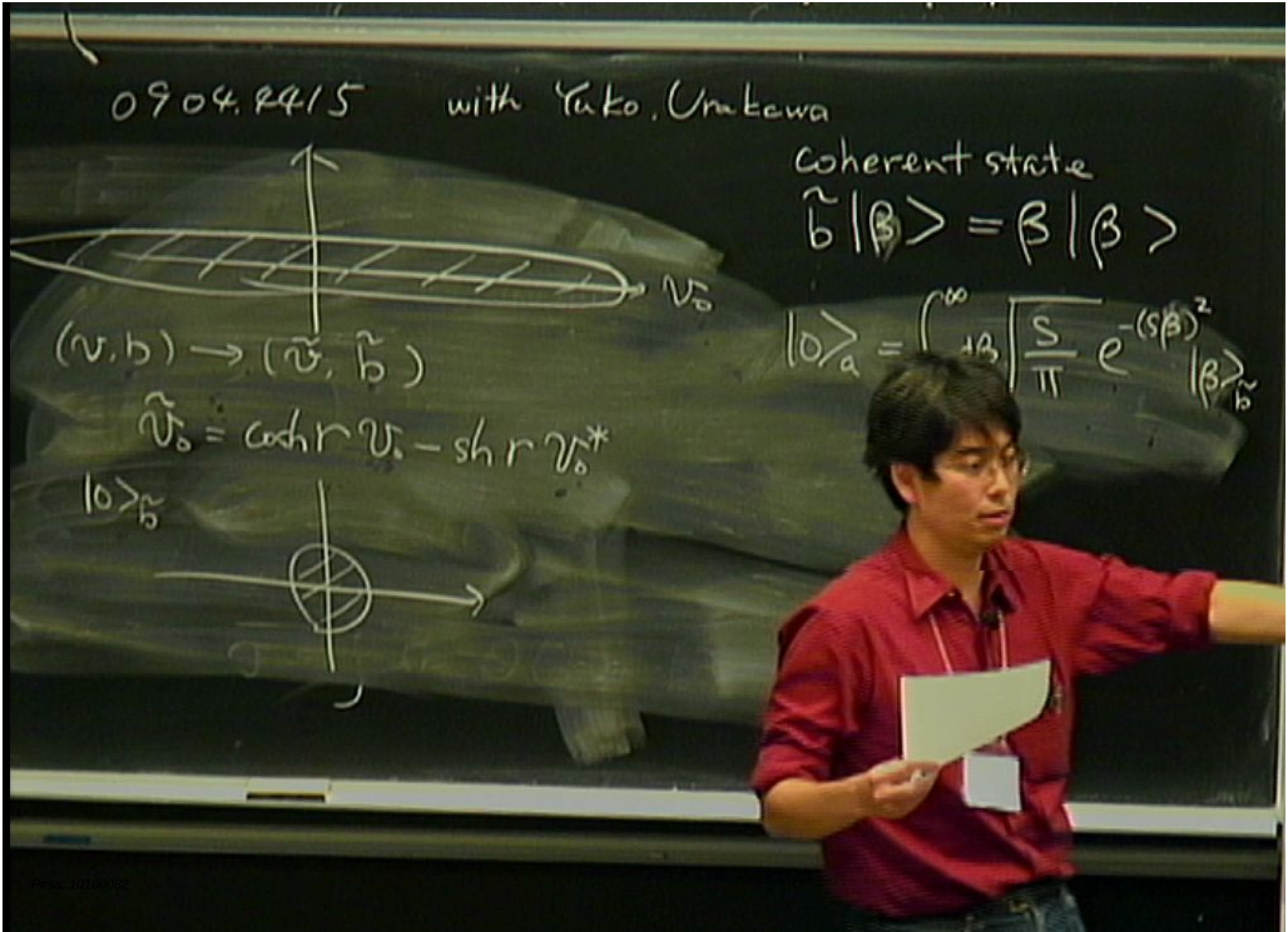


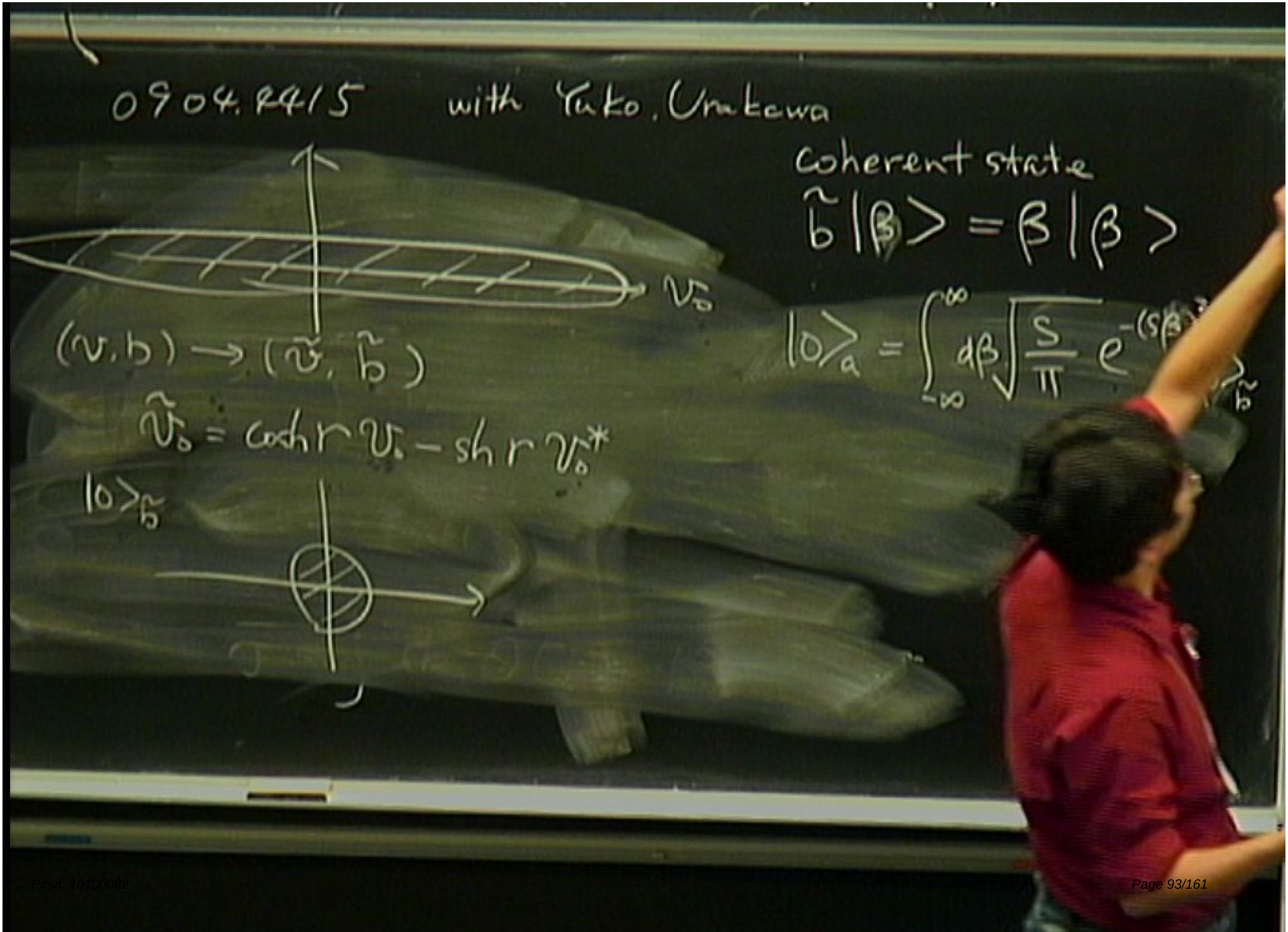
0904.2415 with Yuko. Urakawa
coherent state
$\tilde{b}|\beta\rangle = \beta|\beta\rangle$
v_0
$|0\rangle_a = \int_{-\infty}^{\infty} d\beta \sqrt{\frac{S}{\pi}}\, e^{-(S\beta)^2} |\beta\rangle_{\tilde{b}}$
$(v, b) \to (\tilde{v}, \tilde{b})$
$\tilde{v}_0 = \cosh r\, v_0 - \mathrm{sh}\, r\, v$
$|0\rangle_{\tilde{b}}$


0904.2415 with Yuko, Urakawa
coherent state
$\tilde{b}|\beta\rangle = \beta|\beta\rangle$
$|0\rangle_a = \int_{-\infty}^{\infty} d\beta \sqrt{\frac{s}{\pi}}\, e^{-(s\beta)^2} |\beta\rangle_{\tilde{b}}$
v_0
$(v, b) \to (\tilde{v}, \tilde{b})$
$\tilde{v}_0 = \cosh r\, v_0 - \sinh r\, v_0$
$|0\rangle_{\tilde{b}}$

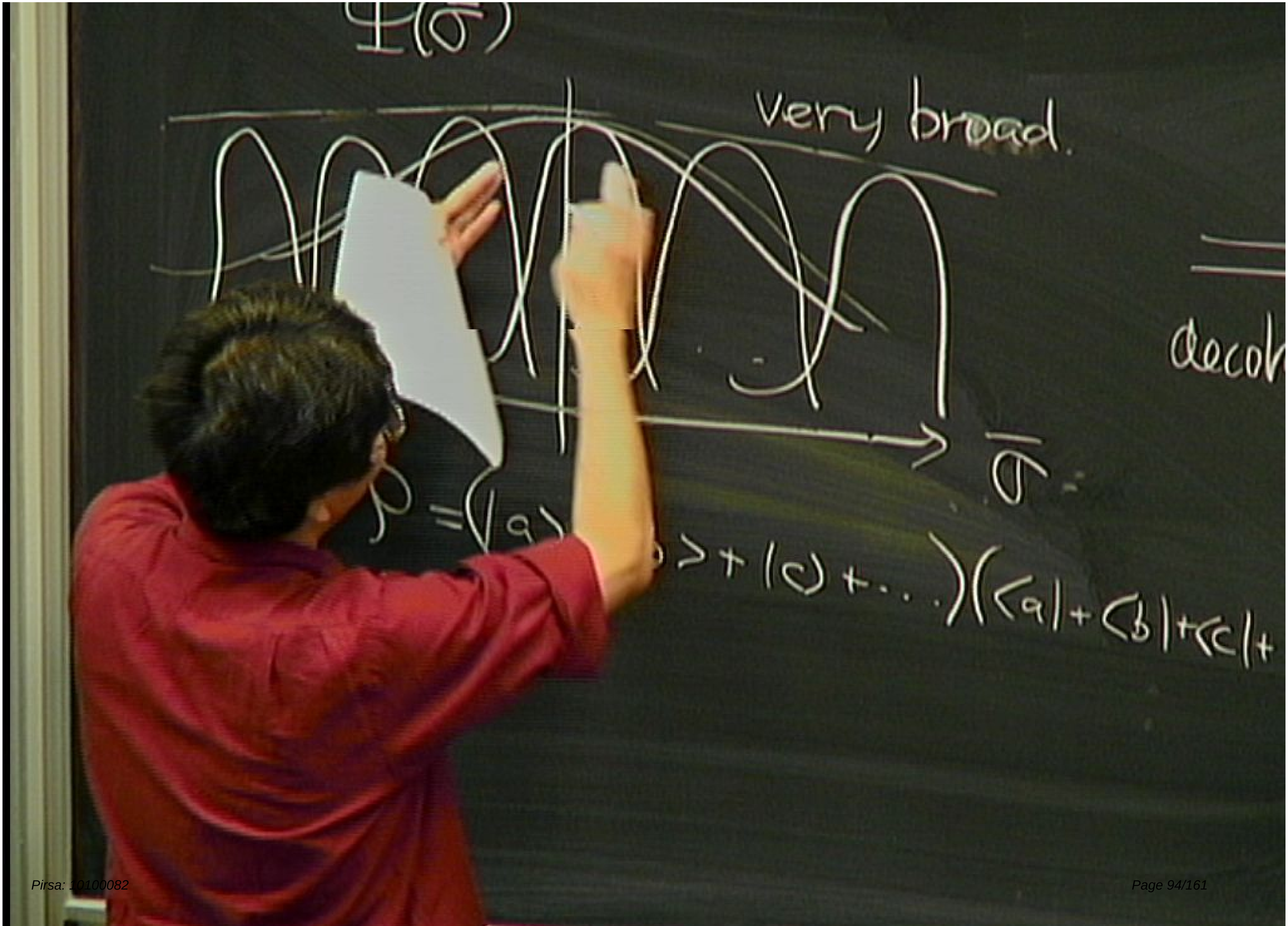


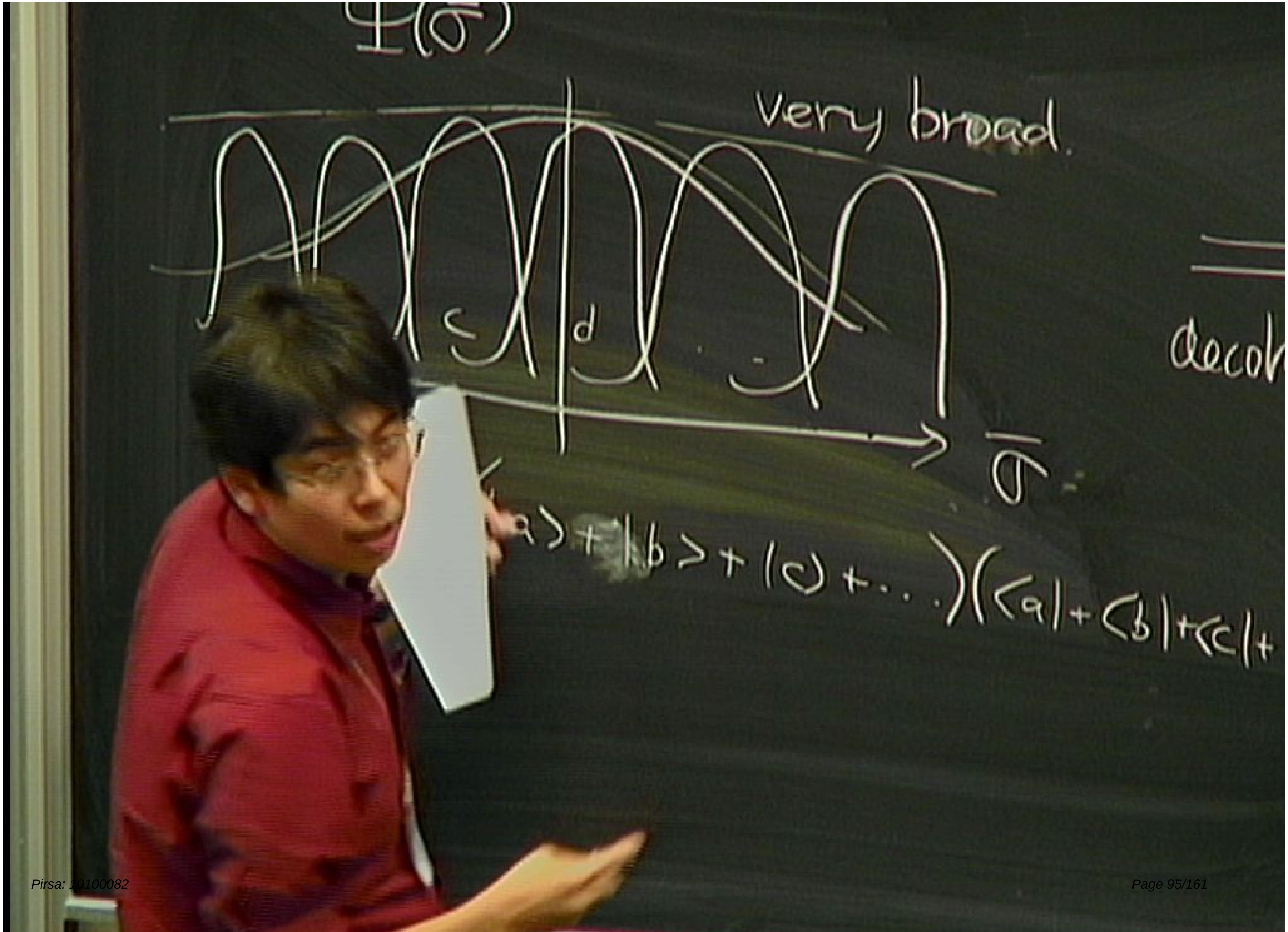
0904.2415 with Yuko Urakawa
coherent state
$\tilde{b}|\beta\rangle = \beta|\beta\rangle$
v_0
$(v, b) \rightarrow (\tilde{v}, \tilde{b})$
$\tilde{v}_0 = \cosh r\, v_0 - \sinh r\, v_0^*$
$|0\rangle_{\tilde{b}}$
$|0\rangle_b = \int_{-\infty}^{\infty} d\beta \sqrt{\frac{s}{\pi}}\, e^{-(s\beta)^2} |\beta\rangle_{\tilde{b}}$
Pirsa: 10100082

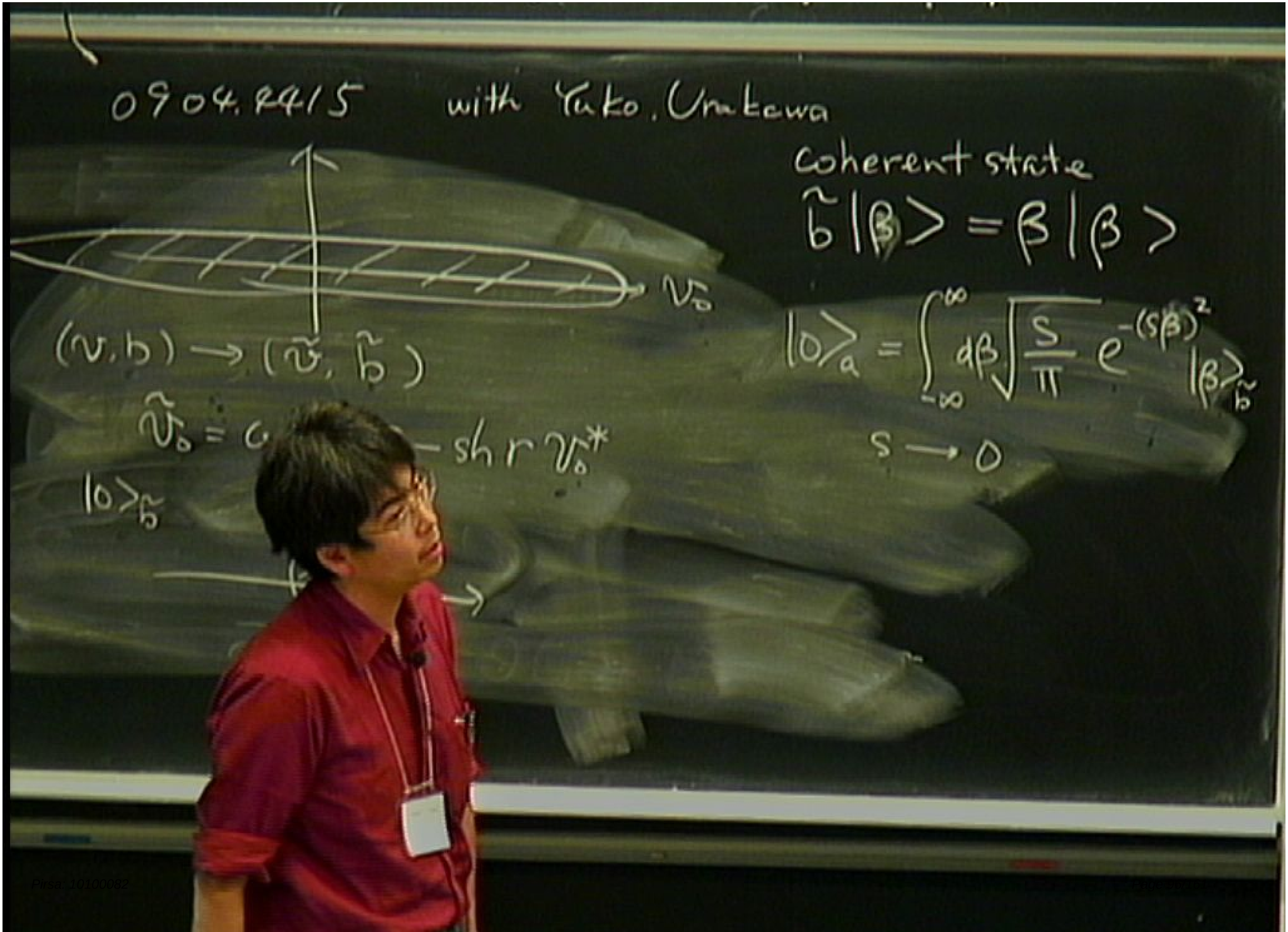

0904.2415 with Yuko Urakawa
coherent state
$\tilde{b}|\beta\rangle = \beta|\beta\rangle$
v_0
$(v, b) \rightarrow (\tilde{v}, \tilde{b})$
$|0\rangle_a = \int^{\infty} d\beta \sqrt{\frac{s}{\pi}}\, e^{-(s\beta)^2} |\beta\rangle_{\tilde{b}}$
$\tilde{v}_0 = \cosh r\, v_0 - \sinh r\, v_0^*$
$|0\rangle_{\tilde{b}}$

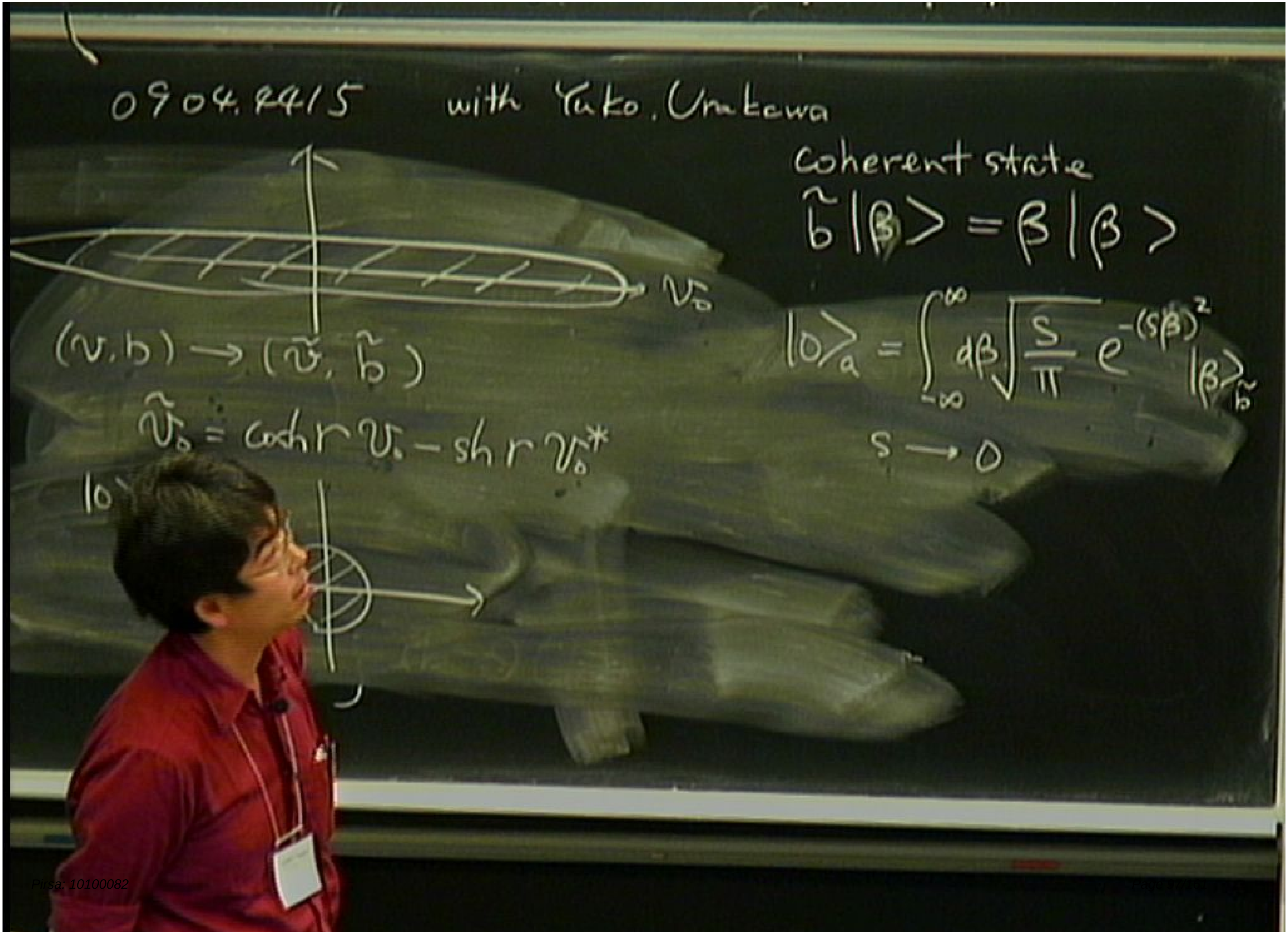


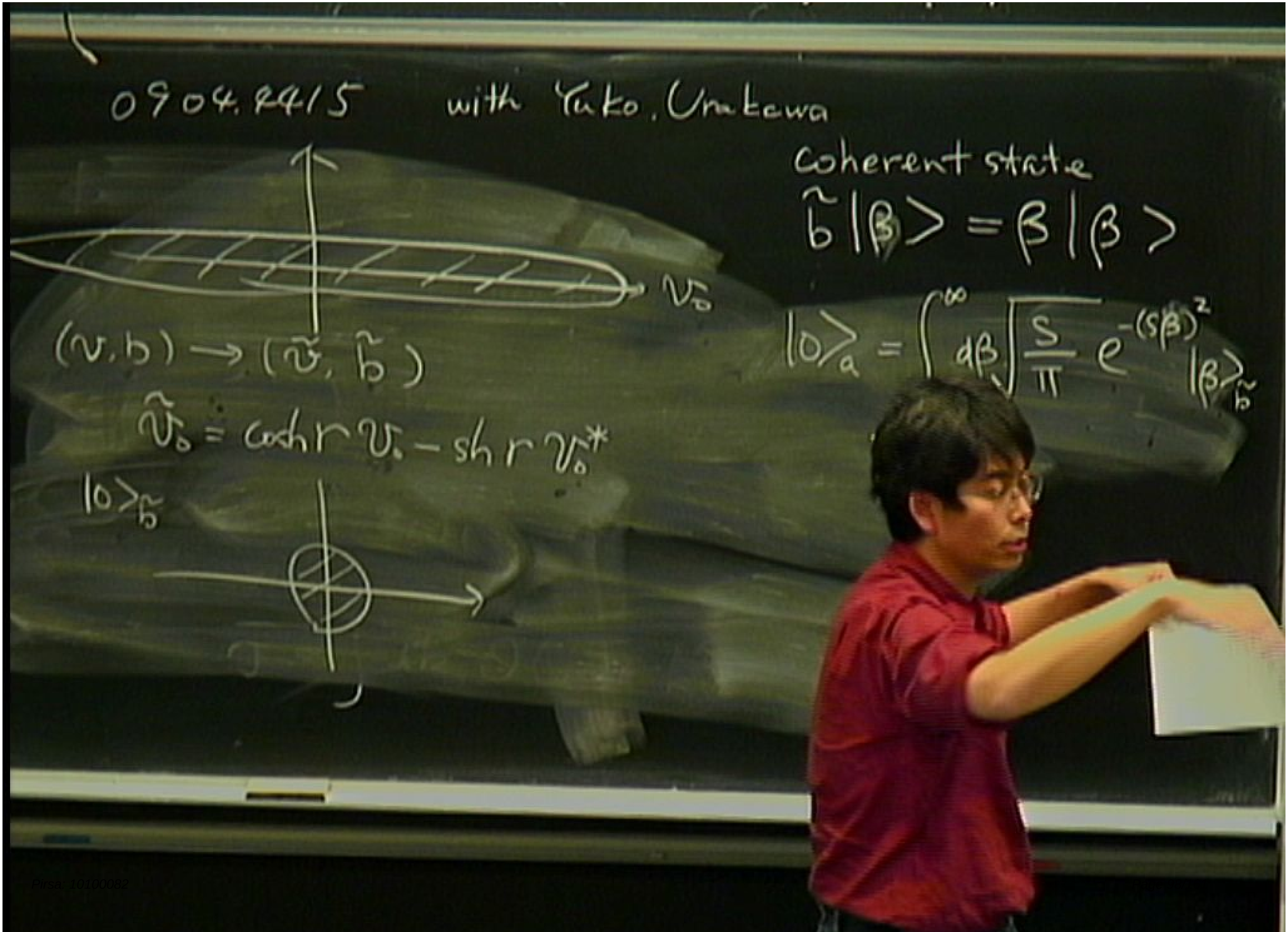
0904.2415 with Yuko Urakawa
coherent state
$\tilde{b}|\beta\rangle = \beta|\beta\rangle$
v_0
$|0\rangle_a = \int_{-\infty}^{\infty} d\beta \sqrt{\frac{s}{\pi}}\, e^{-(s\beta)^2}$
$(v, b) \to (\tilde{v}, \tilde{b})$
$\tilde{v}_0 = \cosh r\, v_0 - \sh r\, v_0^*$
$|0\rangle_{\tilde{b}}$

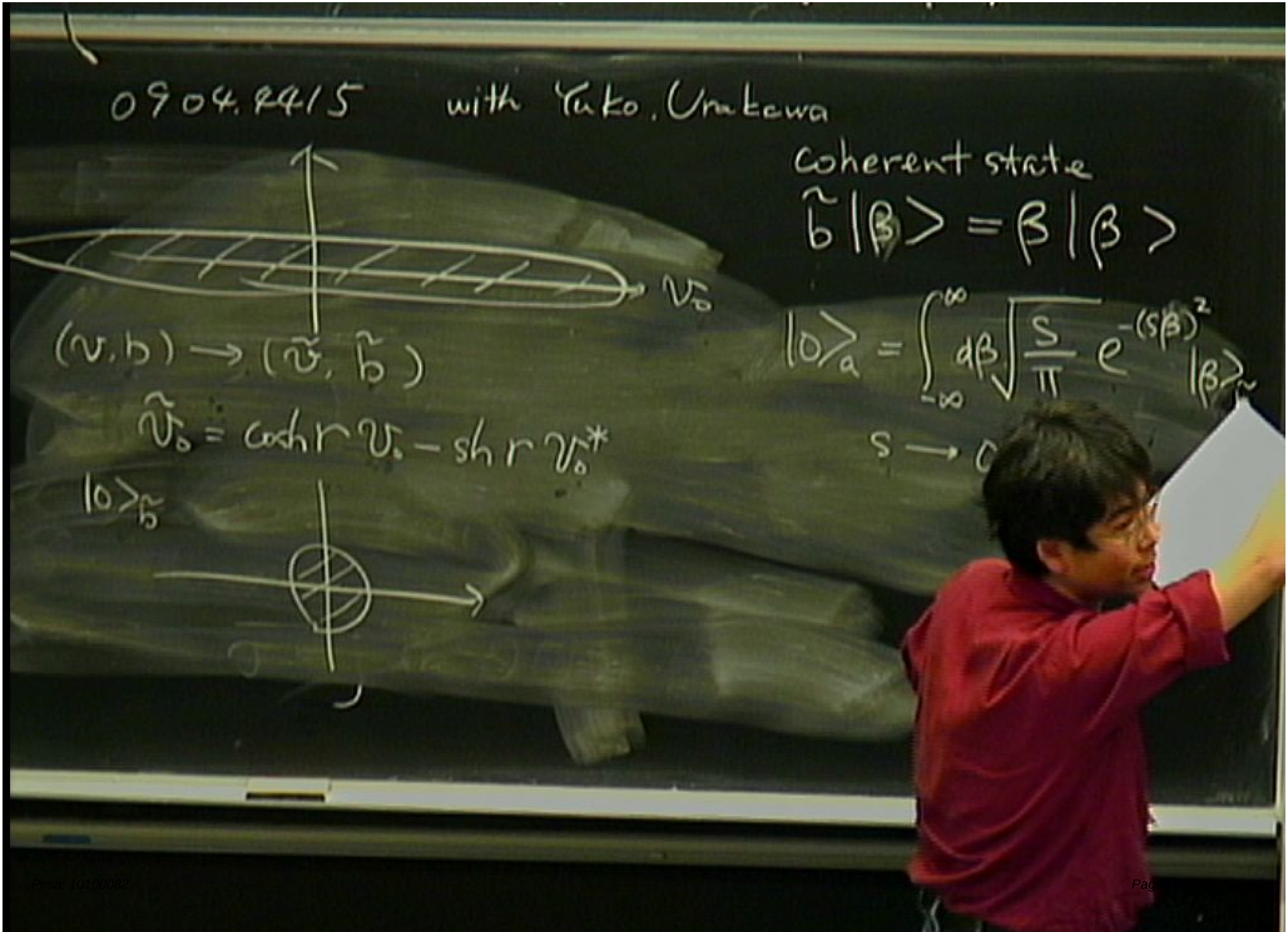

very broad


very broad
c
d
decoh
$|a\rangle + |b\rangle + |c\rangle + \ldots)(\langle a| + \langle b| + \langle c| +$


0904.2415 with Yuko Urakawa
coherent state
$\tilde{b}|\beta\rangle = \beta|\beta\rangle$
$(v, b) \to (\tilde{v}, \tilde{b})$
$\tilde{v}_0 = c$ … $- \mathrm{sh}\, r\, v_0^*$
$|0\rangle_{\tilde{b}}$
$|0\rangle_a = \int_{-\infty}^{\infty} d\beta \sqrt{\frac{s}{\pi}}\, e^{-(s\beta)^2} |\beta\rangle_{\tilde{b}}$
$s \to 0$
Pirsa: 10100082


0904.4415 with Yuko Urakawa
coherent state
$\tilde{b}|\beta\rangle = \beta|\beta\rangle$
$|0\rangle_a = \int_{-\infty}^{\infty} d\beta \sqrt{\frac{s}{\pi}}\, e^{-(s\beta)^2} |\beta\rangle_{\tilde{b}}$
$s \to 0$
v_0
$(v, b) \to (\tilde{v}, \tilde{b})$
$\tilde{v}_0 = \cosh r\, v_0 - \mathrm{sh}\, r\, v_0^*$


0904.2415 with Yuko Urakawa
coherent state
$\tilde{b}|\beta\rangle = \beta|\beta\rangle$
$|0\rangle_a = \int^{\infty} d\beta \sqrt{\frac{s}{\pi}}\, e^{-(s\beta)^2} |\beta\rangle_{\tilde{b}}$
v_0
$(v, b) \rightarrow (\tilde{v}, \tilde{b})$
$\tilde{v}_0 = \cosh r\, v_0 - \sinh r\, v_0^*$
$|0\rangle_{\tilde{b}}$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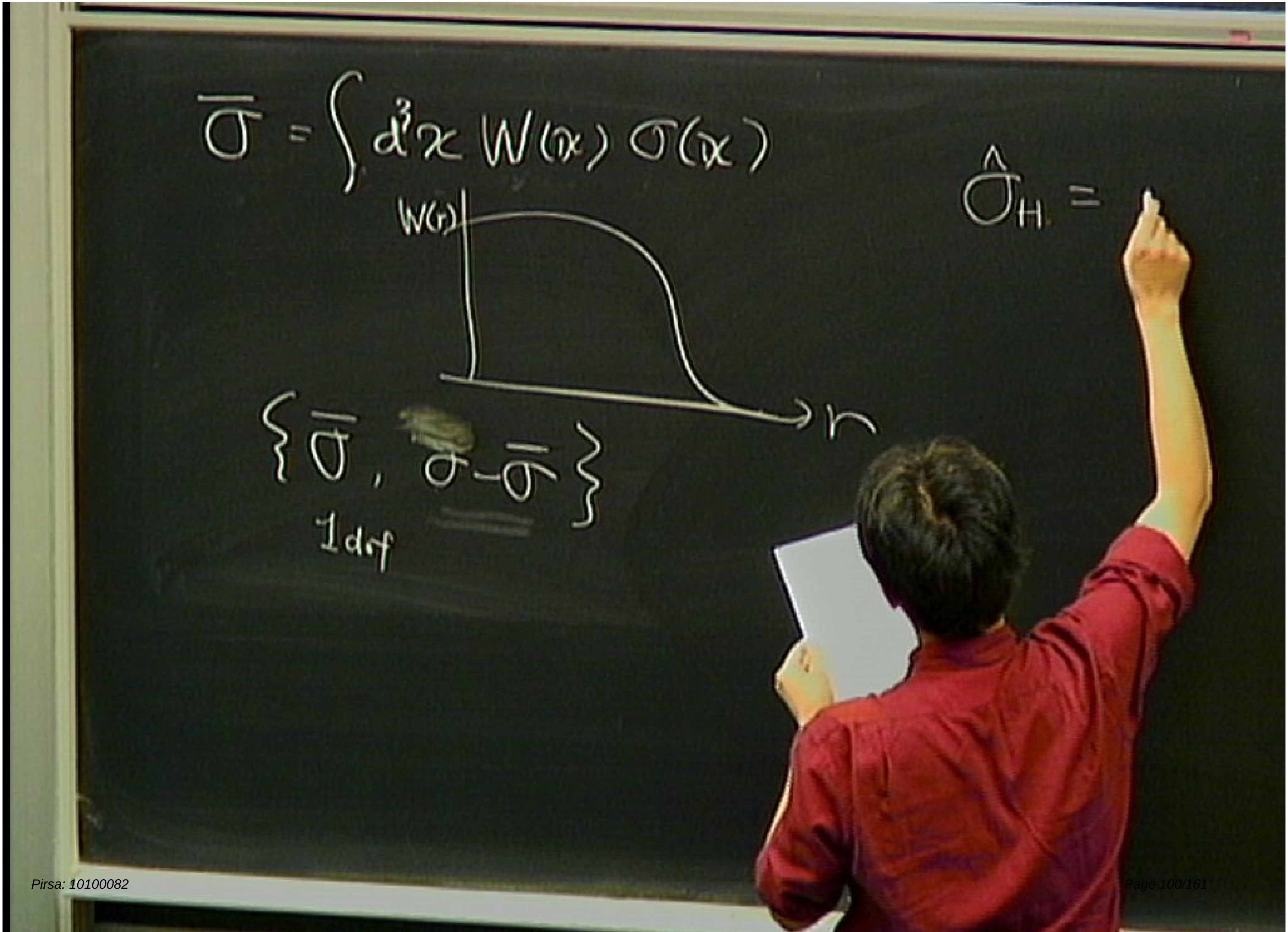
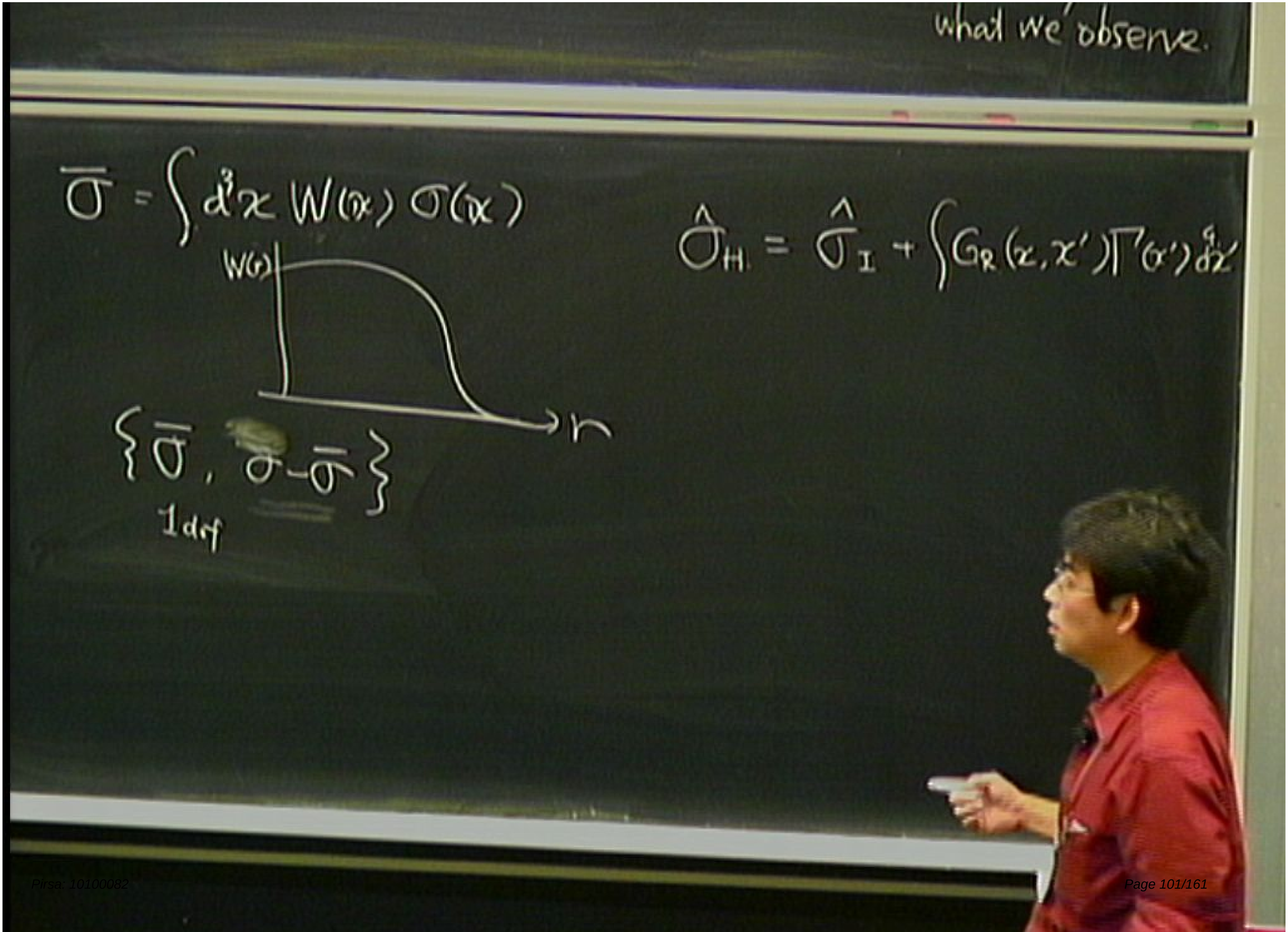
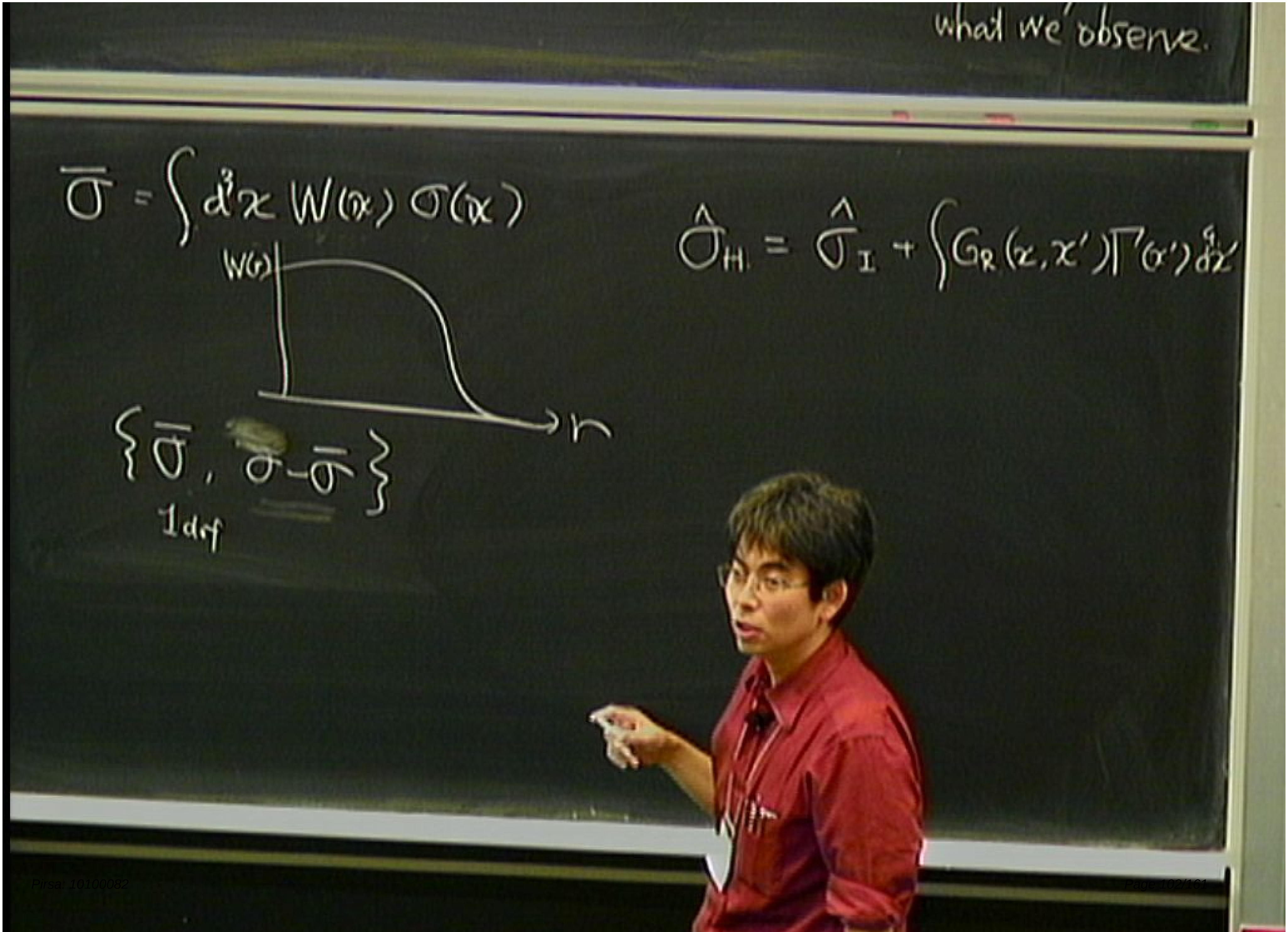
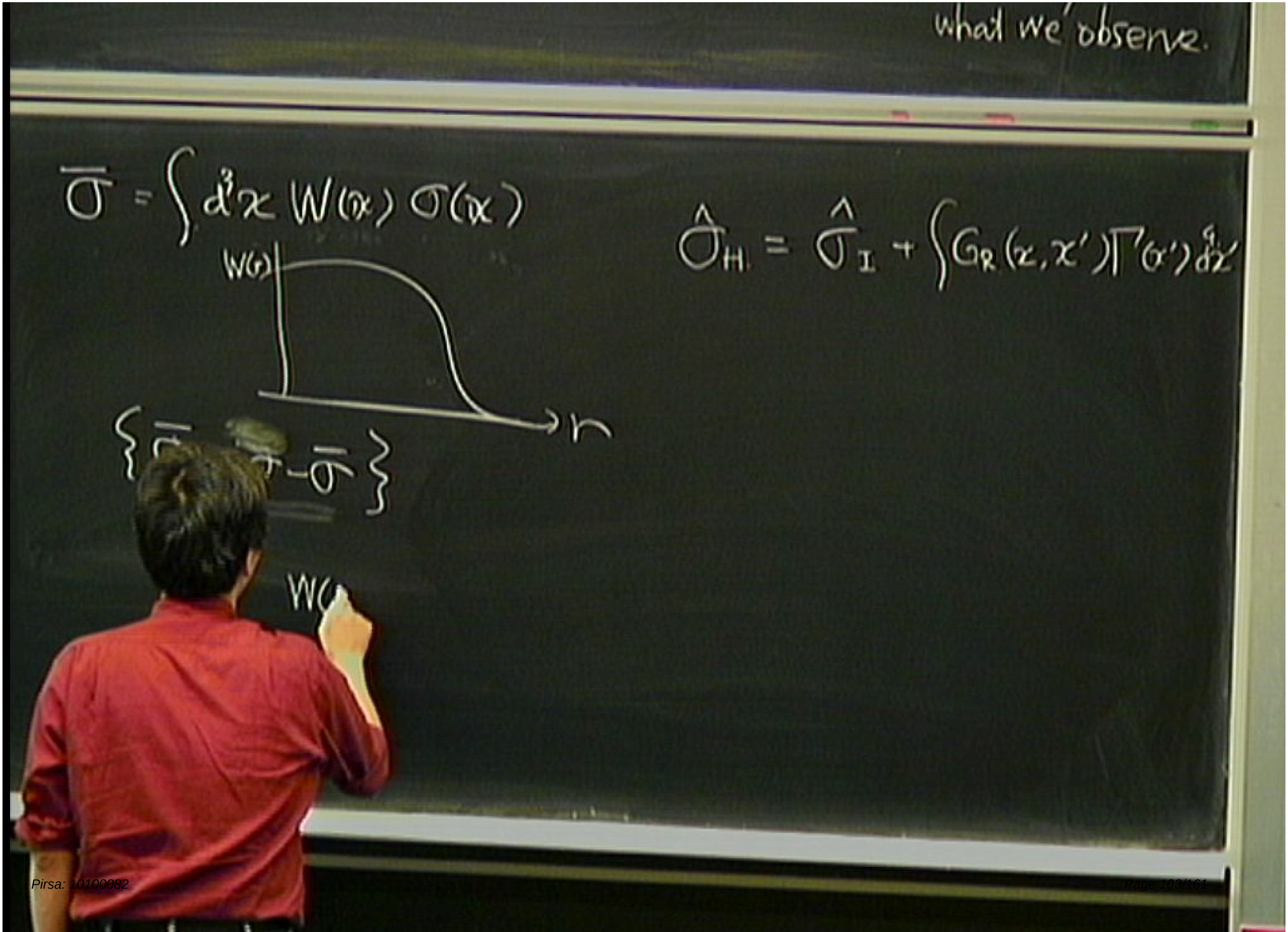
$|0\rangle_a = \int_{-\infty}^{\infty} d\beta \sqrt{\frac{s}{\pi}}\, e^{-(s\beta)^2} |\beta\rangle_{\sim}$
$s \to 0$

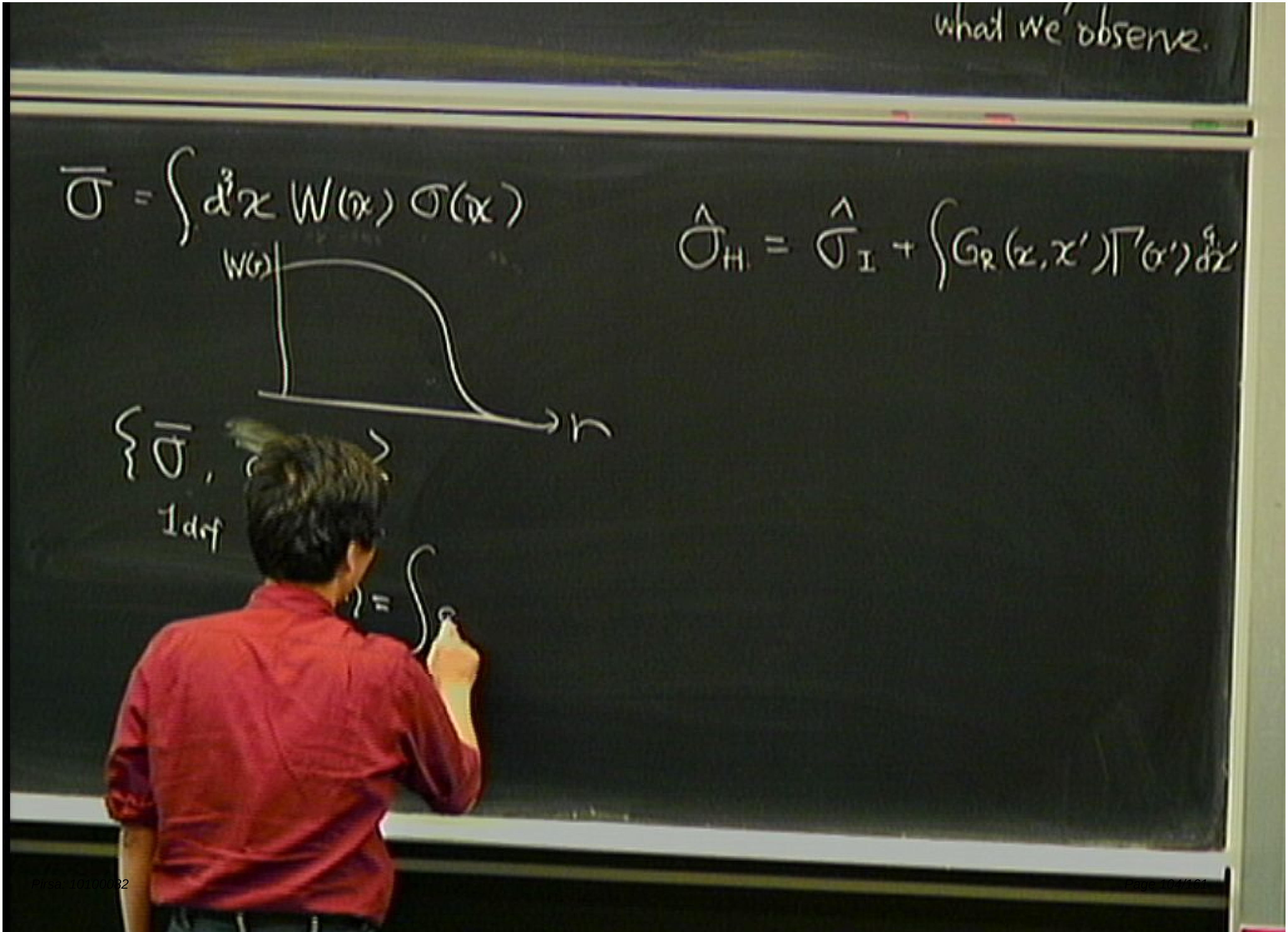


$\bar{\sigma} = \int d^3x\, W(x)\, \sigma(x)$
$\hat{\sigma}_H =$
W(r)
r
$\{ \bar{\sigma},\ \sigma - \bar{\sigma} \}$
1 dof


what we observe.
$\bar{\sigma} = \int d^3x\, W(x)\, \sigma(x)$
$W(r)$
r
$\{ \bar{\sigma},\ \sigma - \bar{\sigma} \}$
1 dof
$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x, x') \Gamma(\sigma') d^4x'$

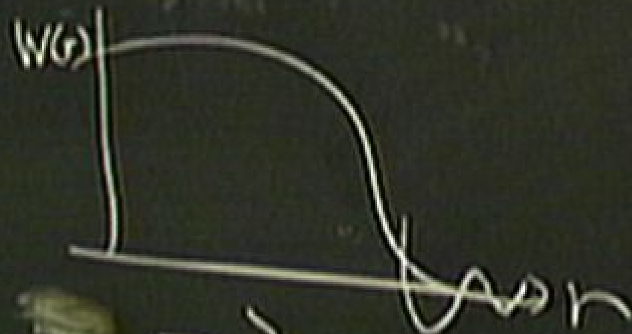

what we observe.
$\bar{\sigma} = \int d^3x \, W(x) \, \sigma(x)$
$W(r)$
r
$\{ \bar{\sigma}, \; \sigma - \bar{\sigma} \}$
1 dof
$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x, x') \Gamma(x') d^4x'$


what we observe.
$\bar{\sigma} = \int d^3x \, W(x) \, \sigma(x)$
$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x, x') \Gamma(x') d^4x'$
W(r)
r
$\{ \bar{\sigma} \quad \bar{\sigma} - \bar{\sigma} \}$
W(


what we observe.
$\overline{\sigma} = \int d^3x \, W(x) \, \sigma(x)$
$W(r)$
r
$\{ \overline{\sigma}, \ldots \}$
1 dof
$) = \int$
$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x, x') \Gamma(\sigma') d^4x'$

what we observe.

$$\bar{\sigma} = \int d^3x \, W(x) \, \sigma(x)$$

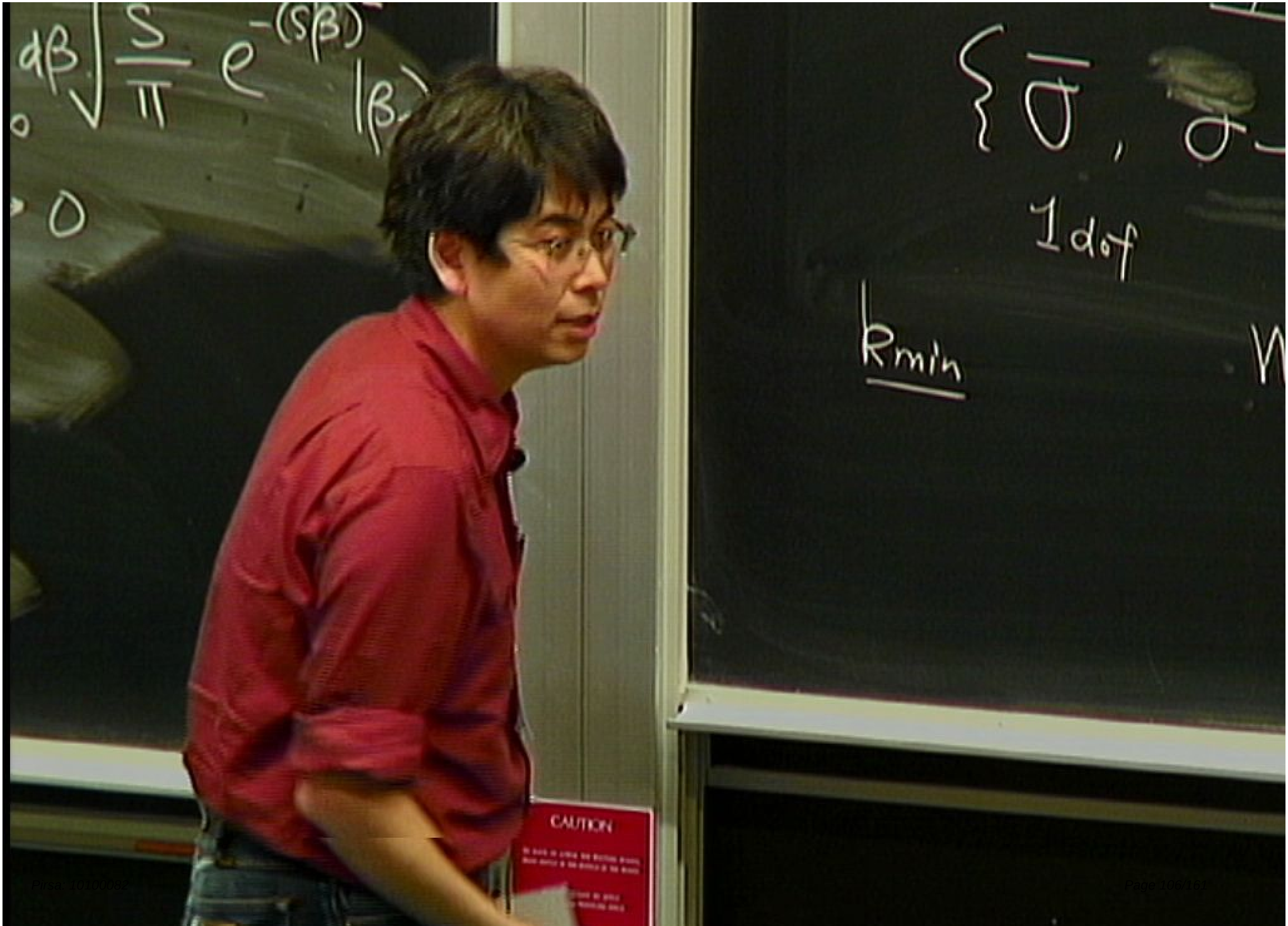


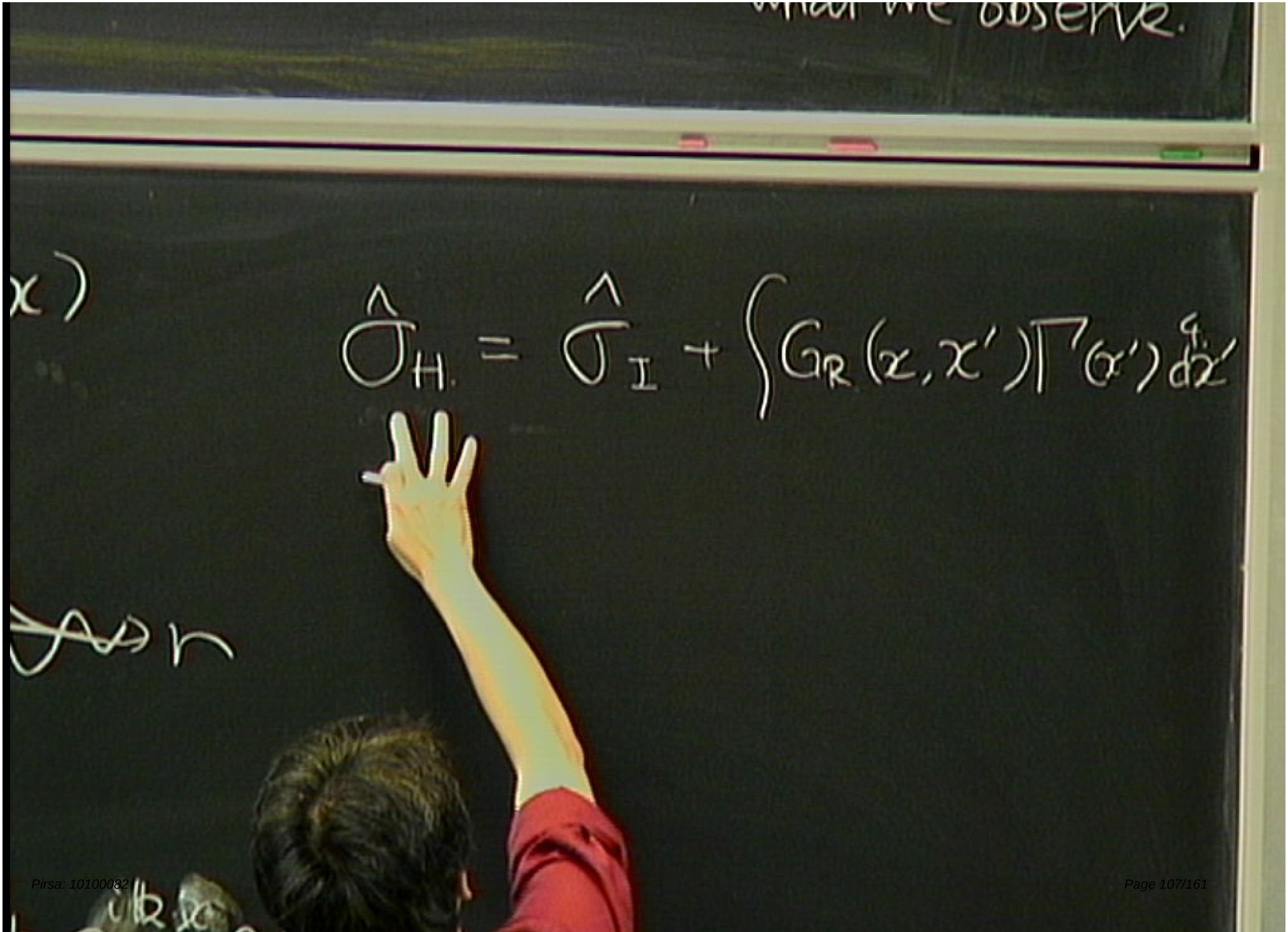
$$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x, x') \Gamma(\sigma') \, d^4x'$$

$$\{ \bar{\sigma}, \; \sigma - \bar{\sigma} \}$$

1 dof

$$W(r) = \int d^3k \, e^{ik \cdot x} \, \theta(k_{cut} - k)$$


1 dof
kmin
CAUTION


what we observe.
$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x, x')\Gamma(x')\,d^4x'$

what we observe.

$$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x,x')\,\Gamma(x')\,d^4x'$$

$$= \hat{\sigma}_I + \hat{\sigma}_I^2 + \dots$$

$${}_a\langle 0 | P\,\Theta | 0 \rangle_a$$

what we observe.

$x)$

$$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x,x')\,\Gamma(x')\,d^4x'$$

$$= \hat{\sigma}_I + \hat{\sigma}_I^2 + \dots$$

$${}_a\langle 0|\,P\,\Theta\,|0\rangle_a$$

what we observe.

x)

$$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x,x')\,\Gamma(x')\,d^4x'$$

$$= \hat{\sigma}_I + \hat{\sigma}_I^2 + \dots$$

on

$${}_a\langle 0 | P\,\Theta | 0 \rangle_a$$

$$\approx \int d\alpha \int d\beta \; {}_b\langle \alpha | P\,\Theta | \beta \rangle_{\tilde{b}}$$

what we observe.

$x)$

$$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x,x')\Gamma(x')\,d^4x'$$

$$= \hat{\sigma}_I + \hat{\sigma}_I^2 + \ldots$$

~~tion~~

$${}_a\langle 0|P\,\Theta|0\rangle_a$$

$$\approx \int d\alpha \int d\beta \; \underline{{}_b\langle \alpha|P\,\Theta|\beta\rangle_{\tilde{b}}}$$

what we observe.

$x)$

$$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x,x')\,\Gamma(x')\,d^4x'$$

$$= \hat{\sigma}_I + \hat{\sigma}_I^2 + \ldots$$

$${}_a\langle 0 | P\,\Theta | 0 \rangle_a$$

$$\int d\alpha \int d\beta \; {}_b\langle \alpha | P\,\Theta | \beta \rangle_{\tilde{b}}$$

$$\Downarrow$$

$$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x,x')\Gamma(x')\,d^4x'$$

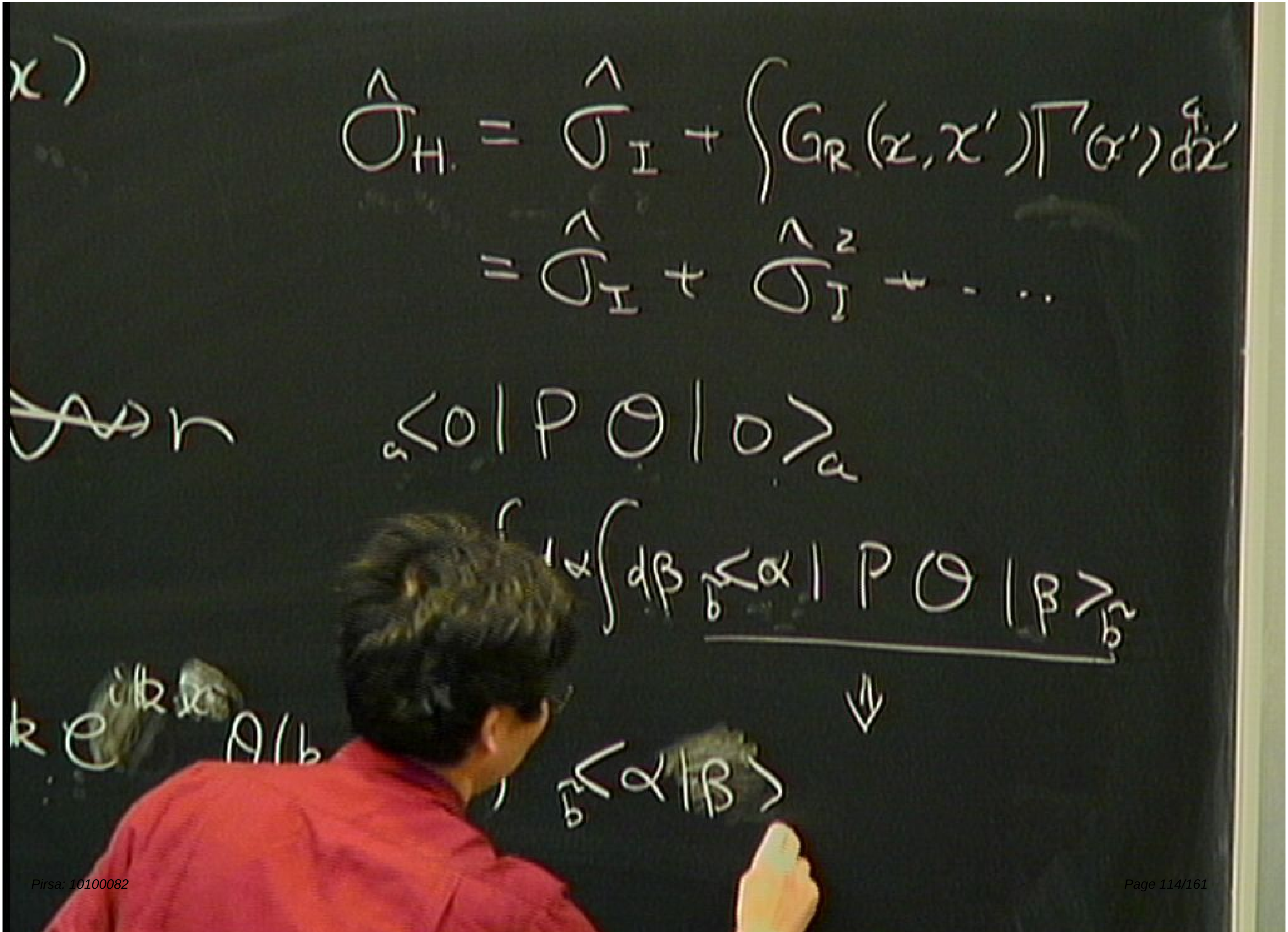
$$= \hat{\sigma}_I + \hat{\sigma}_I^2 + \dots$$

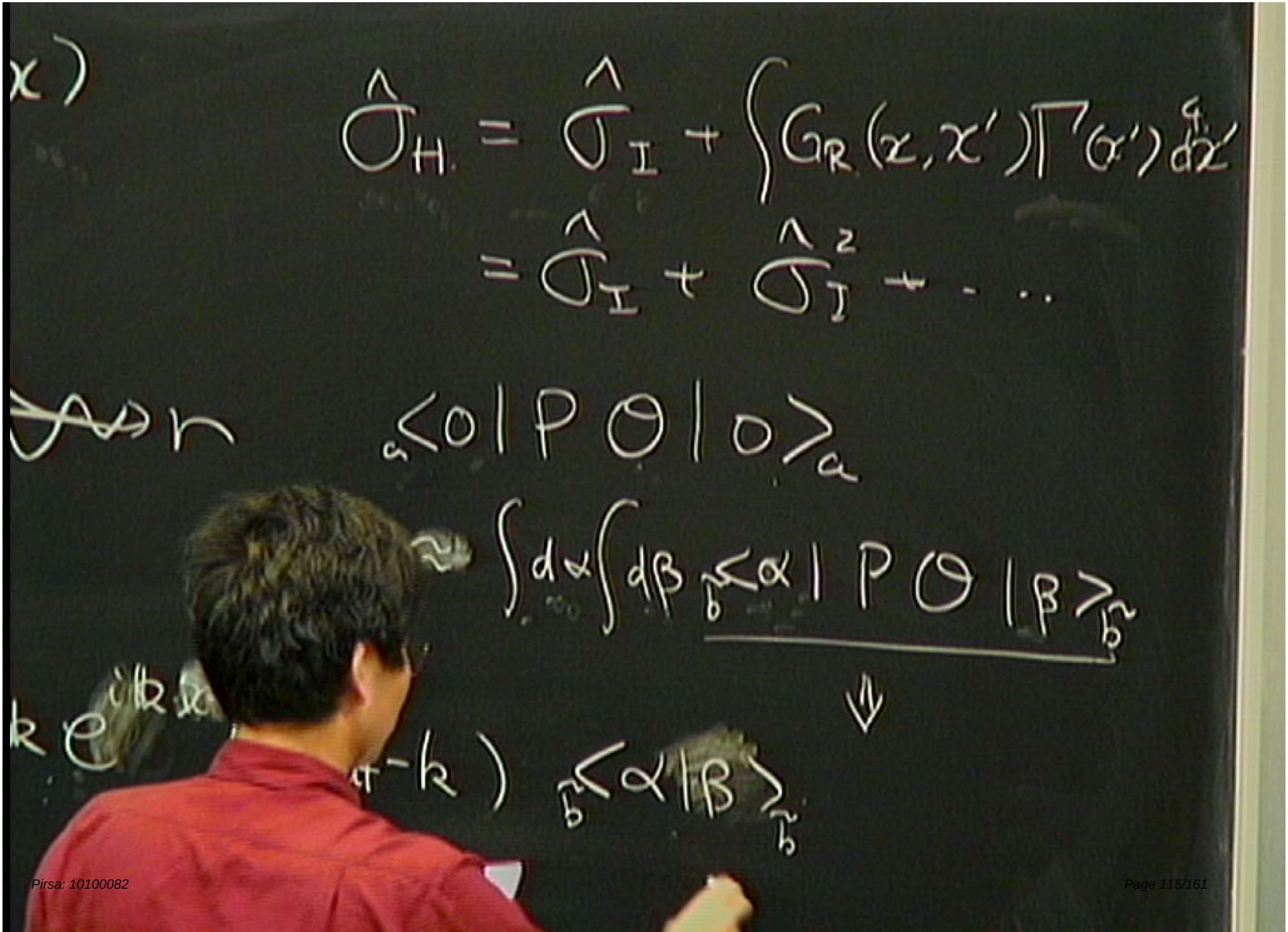
$${}_a\langle 0|\,P\,\Theta\,|0\rangle_a$$

$$\int d\alpha \int d\beta \; \underline{{}_b\langle \alpha|\,P\,\Theta\,|\beta\rangle_{\tilde{b}}}$$

$$\Downarrow$$

$$\langle\alpha|$$


$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x,x')\Gamma(x')d^4x'$
$= \hat{\sigma}_I + \hat{\sigma}_I^2 + \dots$
${}_a\langle 0|P\,O|0\rangle_a$
$\int d\alpha \int d\beta \; {}_b\langle \alpha | P\,O | \beta \rangle_b$
$\Downarrow$
${}_b\langle \alpha | \beta \rangle$



$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x,x')\Gamma(x')\,d^4x'$
$= \hat{\sigma}_I + \hat{\sigma}_I^2 + \dots$
${}_a\langle 0|P\,\Theta|0\rangle_a$
$\approx \int d\alpha \int d\beta\; {}_{\tilde b}\langle \alpha|P\,\Theta|\beta\rangle_{\tilde b}$
$\Downarrow$
${}_{\tilde b}\langle \alpha|\beta\rangle_{\tilde b}$

$x)$

$$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x,x')\Gamma(x')\,d^4x'$$

$$= \hat{\sigma}_I + \hat{\sigma}_I^2 + \cdots$$

~~...~~on

$${}_a\langle 0|P\,\Theta|0\rangle_a$$

$$\approx \int d\alpha \int d\beta\; \underline{{}_{\tilde{b}}\langle \alpha|P\,\Theta|\beta\rangle_{\tilde{b}}}$$

$$\Downarrow$$

$k\, e^{ikx}\;\; \Theta(k_{cut}-k)\;\; {}_{\tilde{b}}\langle\alpha|\beta\rangle_{\tilde{b}} \times {}_{\tilde{b}}\langle 0|(P\Theta)_{\tilde{b}}$

$x)$

$$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x,x')\Gamma(x')\,d^4x'$$

$$= \hat{\sigma}_I + \hat{\sigma}_I^2 + \dots$$

$\sim$on

$${}_a\langle 0 | P\,\Theta | 0 \rangle_a$$

$$\approx \int d\alpha \int d\beta\; \underline{{}_{\tilde{b}}\langle \alpha | P\,\Theta | \beta \rangle_{\tilde{b}}}$$

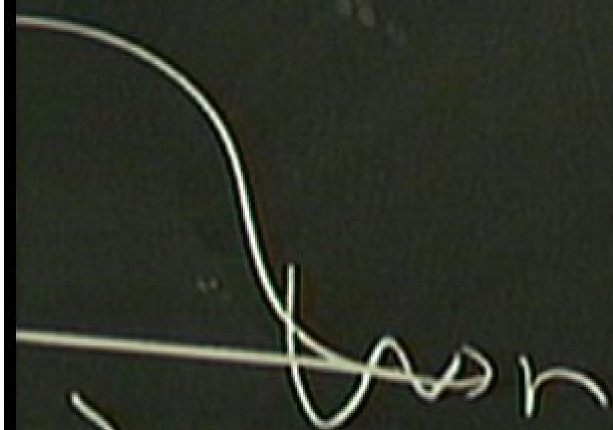
$$\Downarrow$$

$k\,e^{ikx}\;\Theta(k_{cut}-k)\quad {}_{\tilde{b}}\langle \alpha | \beta \rangle_{\tilde{b}} \times {}_{\tilde{b}}\langle 0 | (P\Theta)_{\tilde{b}}$

$x)\ \sigma(x)$

$$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x,x')\Gamma(x')\,d^4x'$$

$$= \hat{\sigma}_I + \hat{\sigma}_I^2 + \dots$$



$$\}$$

$${}_a\langle 0|P\,\Theta|0\rangle_a$$

$$\approx \int d\alpha \int d\beta\ {}_{\tilde{b}}\langle \alpha|P\,\Theta|\beta\rangle_{\tilde{b}}$$

$$\Downarrow$$

$$) = \int d^3k\, e^{ik\cdot x}\,\theta(k_{cut} - k) \qquad {}_{\tilde{b}}\langle \alpha|\beta\rangle_{\tilde{b}} \times {}_{\tilde{b}}\langle 0|(P\Theta)|0\rangle_{\tilde{b}}$$

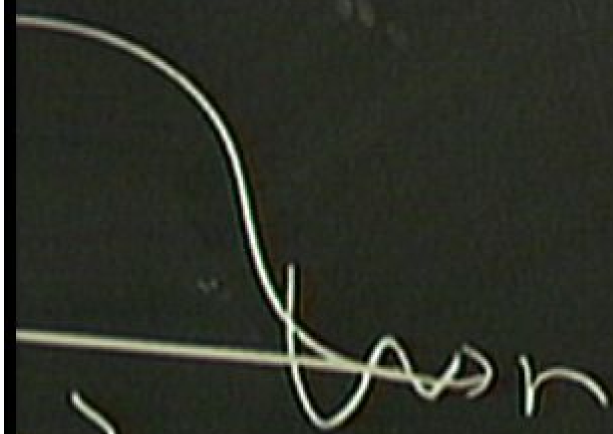
$$\tilde{b} \to \tilde{b} + \alpha$$

$$\tilde{b}^\dagger \to \tilde{b}^\dagger + \beta$$

$(x)\ \sigma(x)$

$$\hat{\sigma}_H = \hat{\sigma}_I + \int G_R(x,x')\,\Gamma(x')\,d^4x'$$

$$= \hat{\sigma}_I + \hat{\sigma}_I^2 + \cdots$$



$$\}$$

$${}_a\langle 0 | P\,\Theta | 0 \rangle_a$$

$$\approx \int d\alpha \int d\beta\ \underline{{}_{\tilde{b}}\langle \alpha | P\,\Theta | \beta \rangle_{\tilde{b}}}$$

$$\Downarrow$$

$$\cdot) = \int d^3k\, e^{ik\cdot x}\,\theta(k_{cut}-k) \qquad {}_{\tilde{b}}\langle \alpha | \beta \rangle_{\tilde{b}} \times {}_{\tilde{b}}\langle 0 | (P\,\Theta) | 0 \rangle_{\tilde{b}}$$

$$\tilde{b} \to \tilde{b} + \alpha$$
$$\tilde{b}^\dagger \to \tilde{b}^\dagger + \beta$$

$$\approx \int d\alpha \int d\beta \; {}_{b}\langle \alpha | P\Theta | \beta \rangle_{\tilde{b}}$$

$$\Downarrow$$

$$\langle \alpha | \beta \rangle_{\tilde{b}} \times \langle 0 | (P\Theta) | 0 \rangle_{\tilde{b}}$$

$$\tilde{b} \to \tilde{b} + \alpha$$

$$\tilde{b}^{\dagger} \to \tilde{b}^{\dagger} + \beta$$

$$\approx \int d\alpha \int d\beta \; {}_{\tilde{b}}\langle \alpha | P \Theta | \beta \rangle_{\tilde{b}}$$

$$\Downarrow$$

$$\text{ut}-k) \quad {}_{\tilde{b}}\langle \alpha | \beta \rangle_{\tilde{b}} \times {}_{\tilde{b}}\langle 0 | (P\Theta) | 0 \rangle_{\tilde{b}}$$

$$\tilde{b} \to \tilde{b} + \alpha$$
$$\tilde{b}^{+} \to \tilde{b}^{+} + \beta$$

$$ {}_a\langle 0 | \;\; \Theta \; | 0 \rangle_a $$

$$ \approx \int d\alpha \int d\beta \; \underline{{}_{\tilde{b}}\langle \alpha | \, P \, \Theta \, | \beta \rangle_{\tilde{b}}} $$

$$ \Downarrow $$

$$ \text{ut} - k \,) \quad {}_{\tilde{b}}\langle \alpha | \beta \rangle_{\tilde{b}} \times {}_{\tilde{b}}\langle 0 | (P\Theta) | 0 \rangle_{\tilde{b}} $$

$$ \tilde{b} \to \tilde{b} + \alpha $$

$$ \tilde{b}^{\dagger} \to \tilde{b}^{\dagger} + \beta $$

. Urakawa

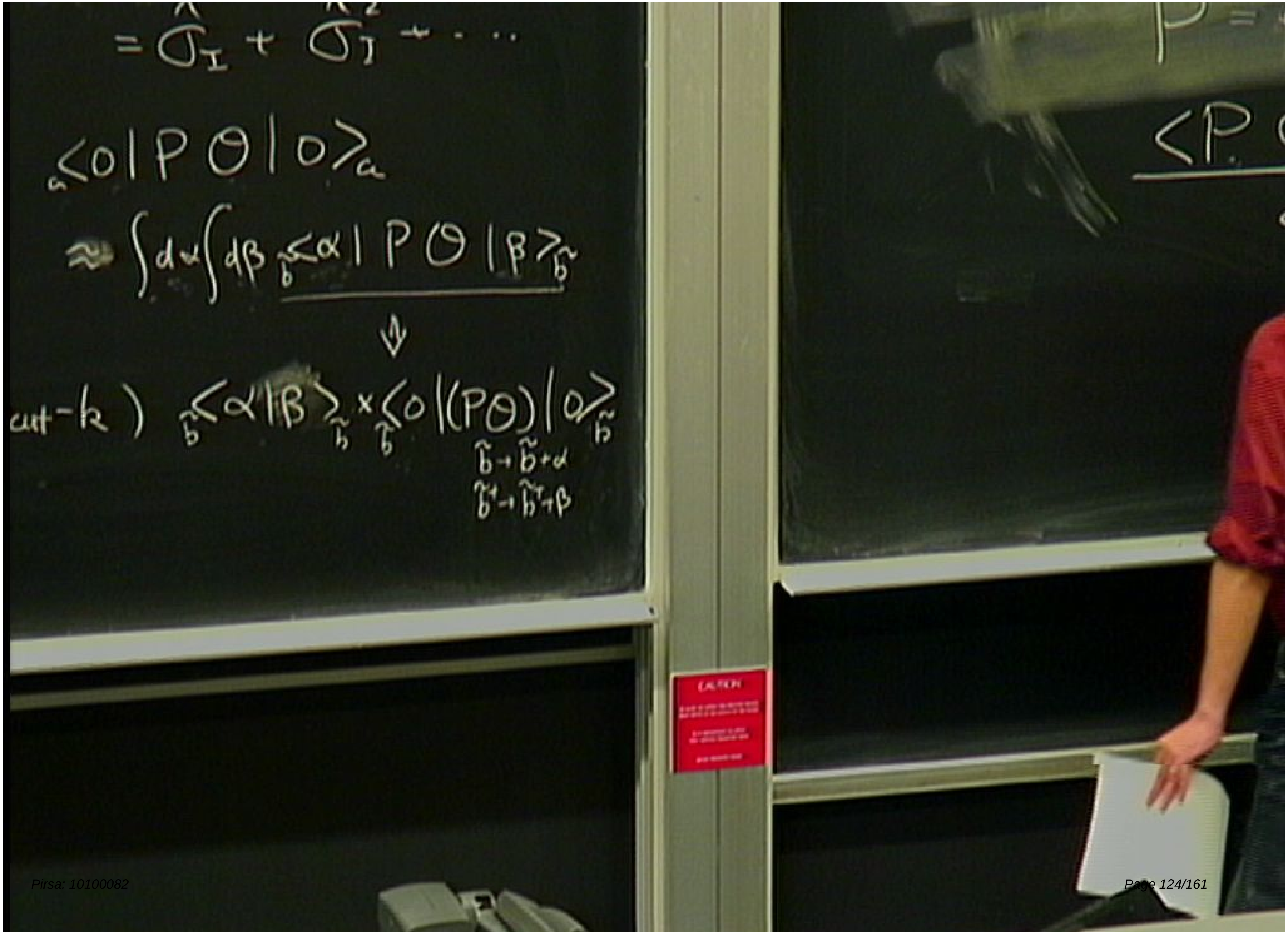
coherent state

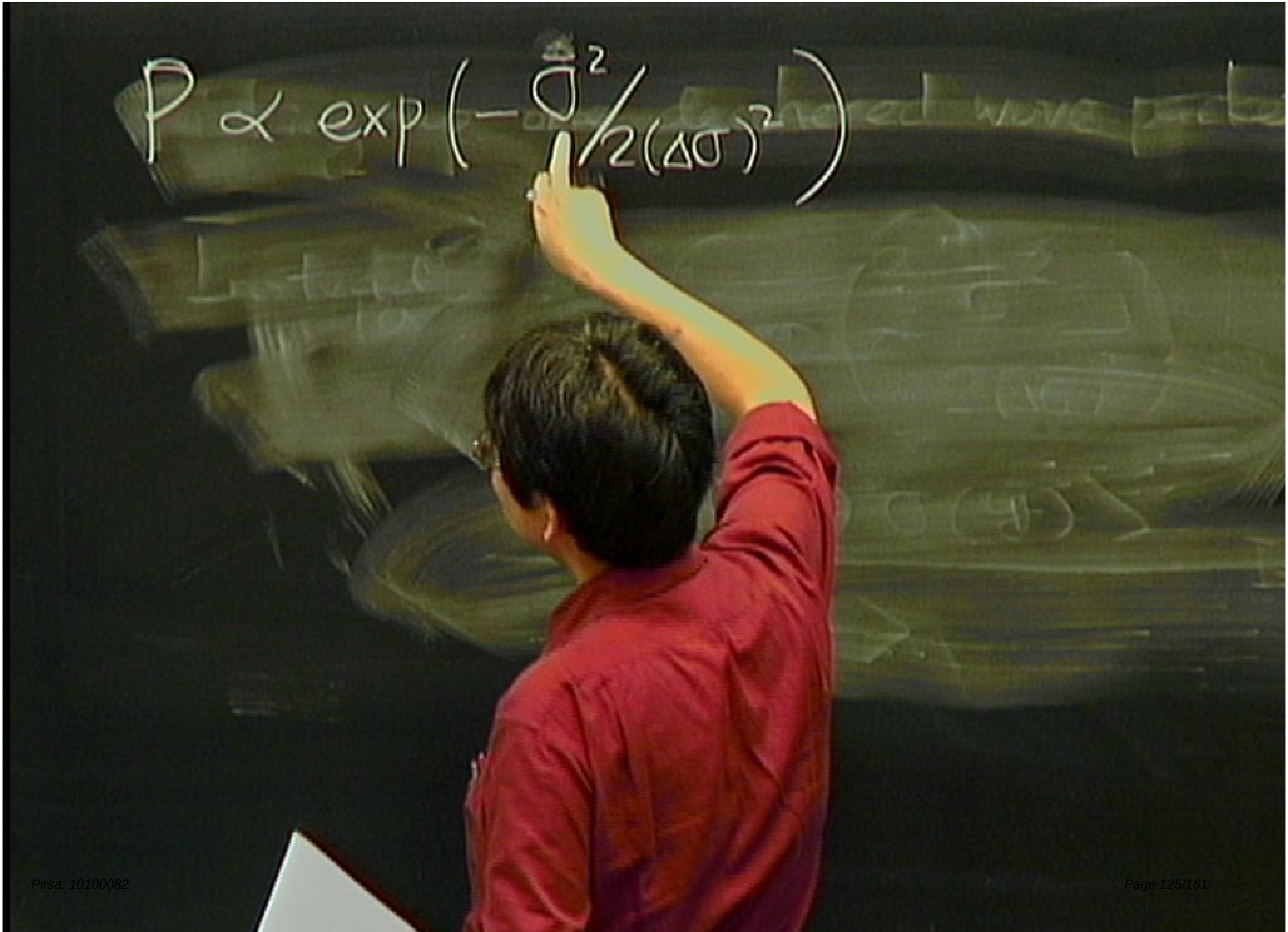
$$\tilde{b}\,|\beta\rangle = \beta\,|\beta\rangle$$

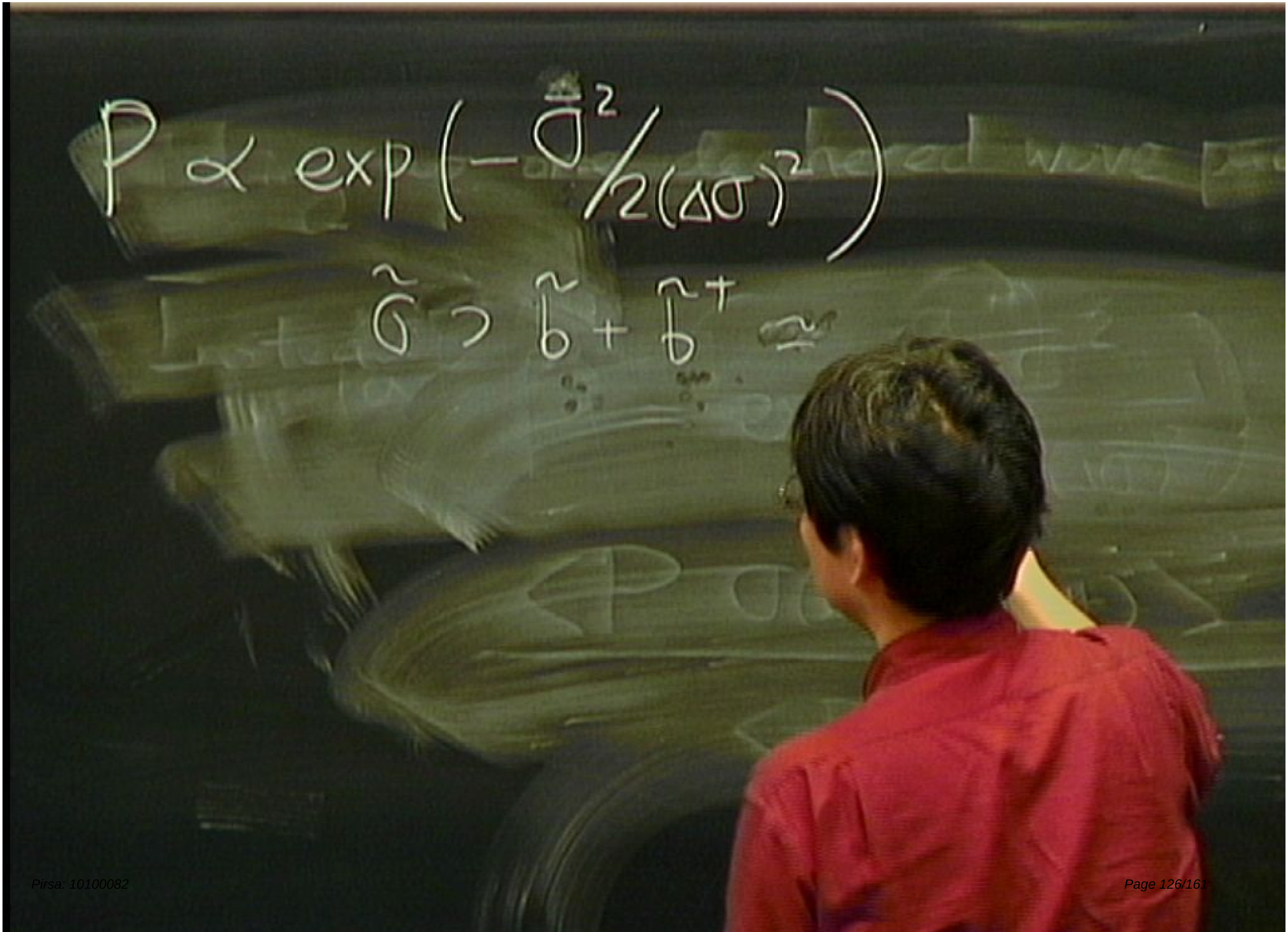
N_0

$$|0\rangle_a = \int_{-\infty}^{\infty} d\beta \sqrt{\frac{s}{\pi}}\, e^{-(s\beta)^2}\, |\beta\rangle_{\tilde{b}}$$

$$s \to 0$$


$= \hat{\sigma}_I + \hat{\sigma}_J + \cdots$
${}_a\langle 0 | P\,\mathcal{O} | 0 \rangle_a$
$\approx \int d\alpha \int d\beta \; {}_{\tilde{b}}\langle \alpha | P\,\mathcal{O} | \beta \rangle_{\tilde{b}}$
$\Downarrow$
cut-k) ${}_{\tilde{b}}\langle \alpha | \beta \rangle_{\tilde{b}} \times {}_{\tilde{b}}\langle 0 | (P\,\mathcal{O}) | 0 \rangle_{\tilde{b}}$
$\tilde{b} \to \tilde{b} + \alpha$
$\tilde{b}^{\dagger} \to \tilde{b}^{\dagger} + \beta$
CAUTION

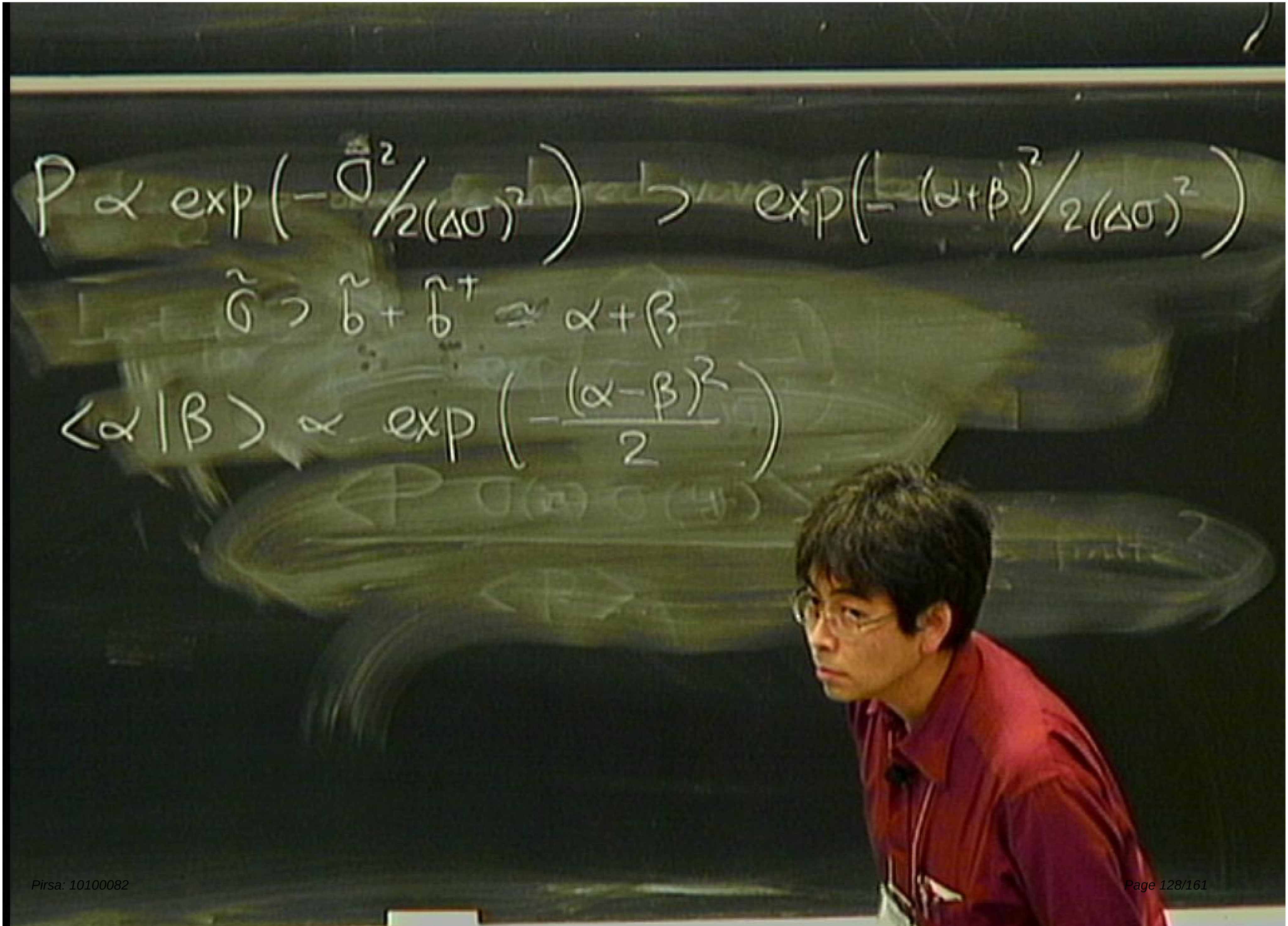

$P \propto \exp\left(-\bar{\sigma}^2 / 2(\Delta\sigma)^2\right)$

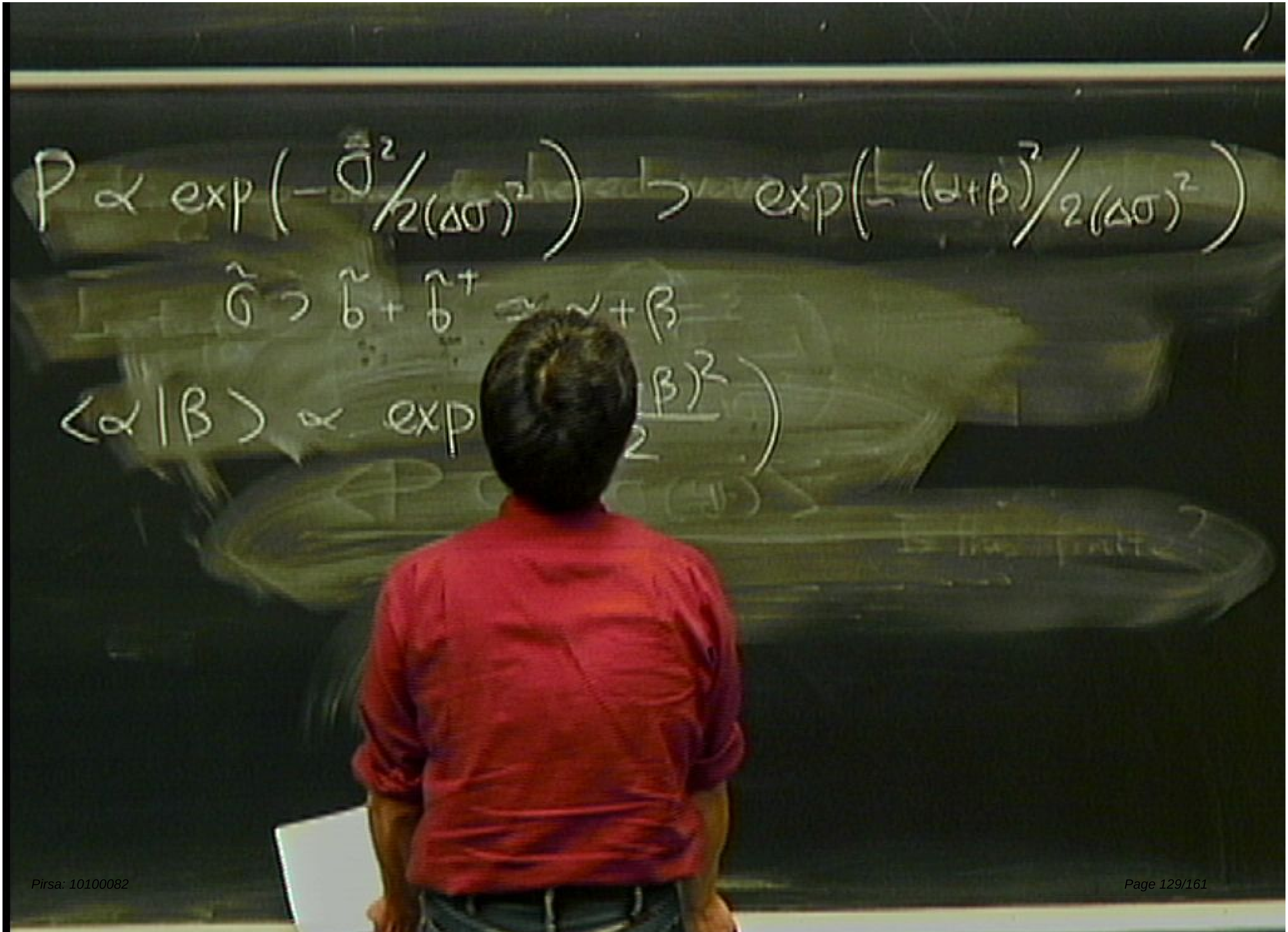

$P \propto \exp\left(-\tilde{\sigma}^2 / 2(\Delta\sigma)^2\right)$
$\tilde{\sigma} \to \tilde{b} + \tilde{b}^\dagger$

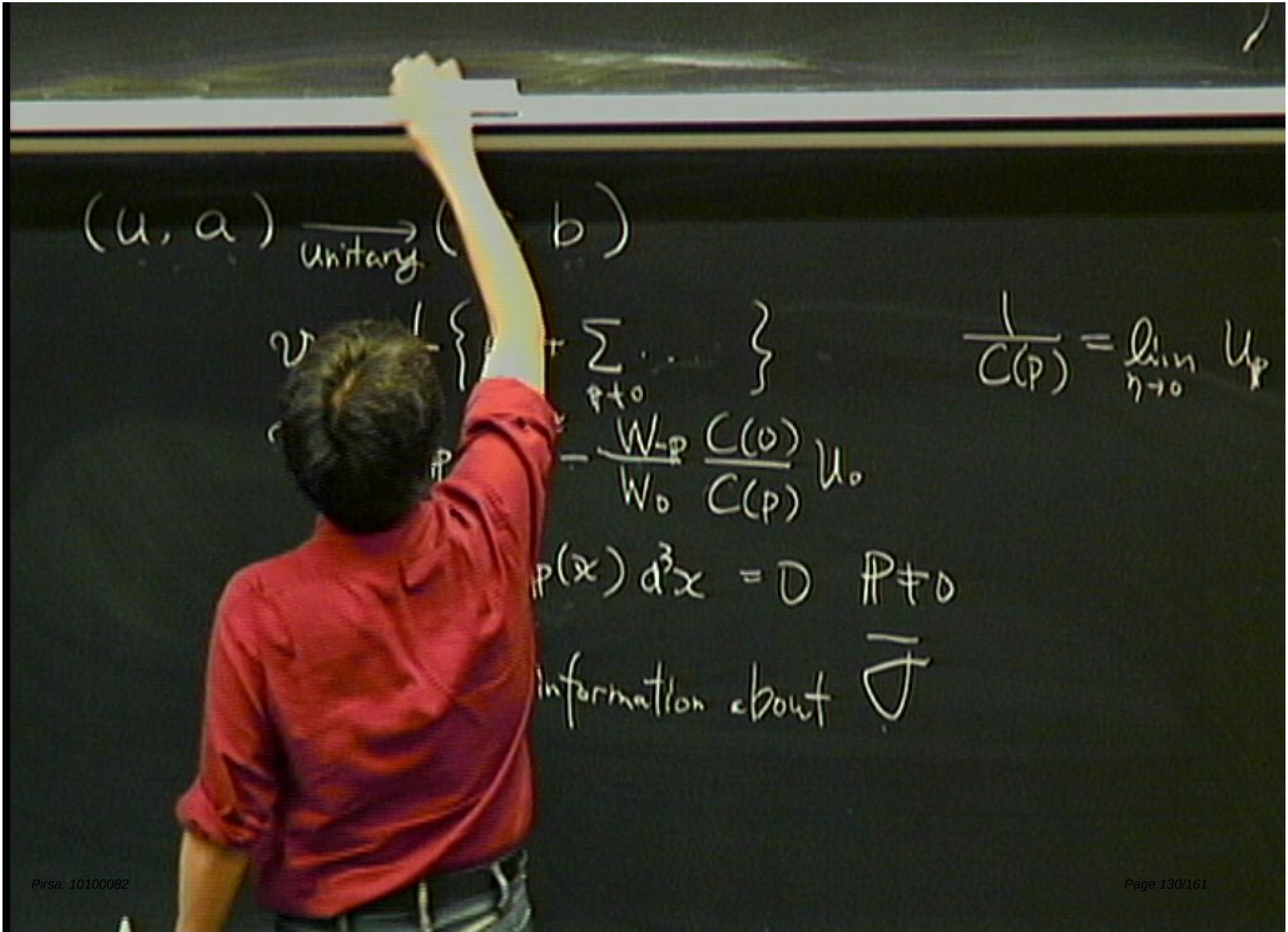
$$P \propto \exp\left(-\tilde{\sigma}^2 / 2(\Delta\sigma)^2\right) \to \exp\left(-(\alpha+\beta)^2 / 2(\Delta\sigma)^2\right)$$

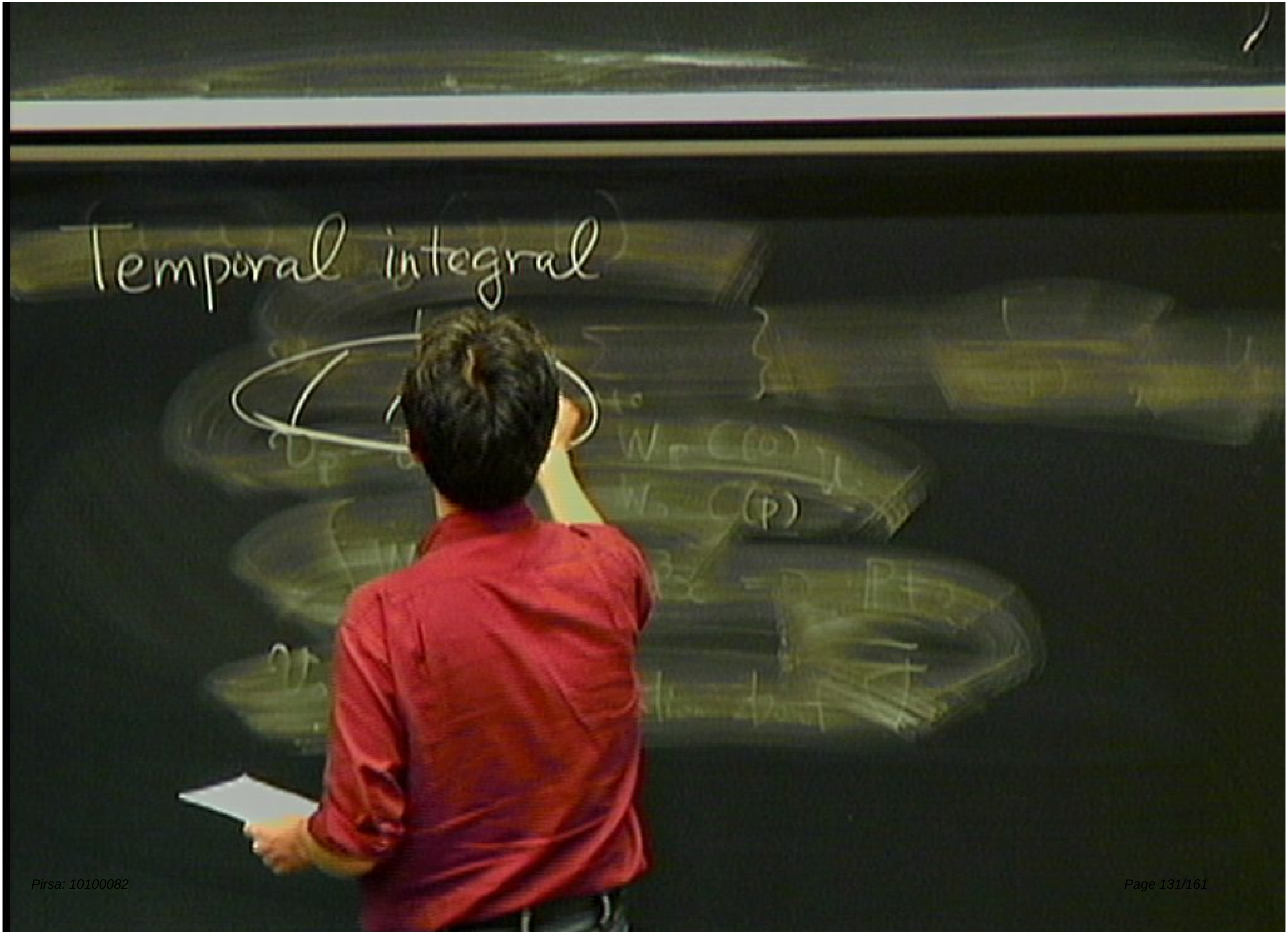
$$\tilde{\sigma} \to \tilde{b} + \tilde{b}^\dagger \approx \alpha + \beta$$

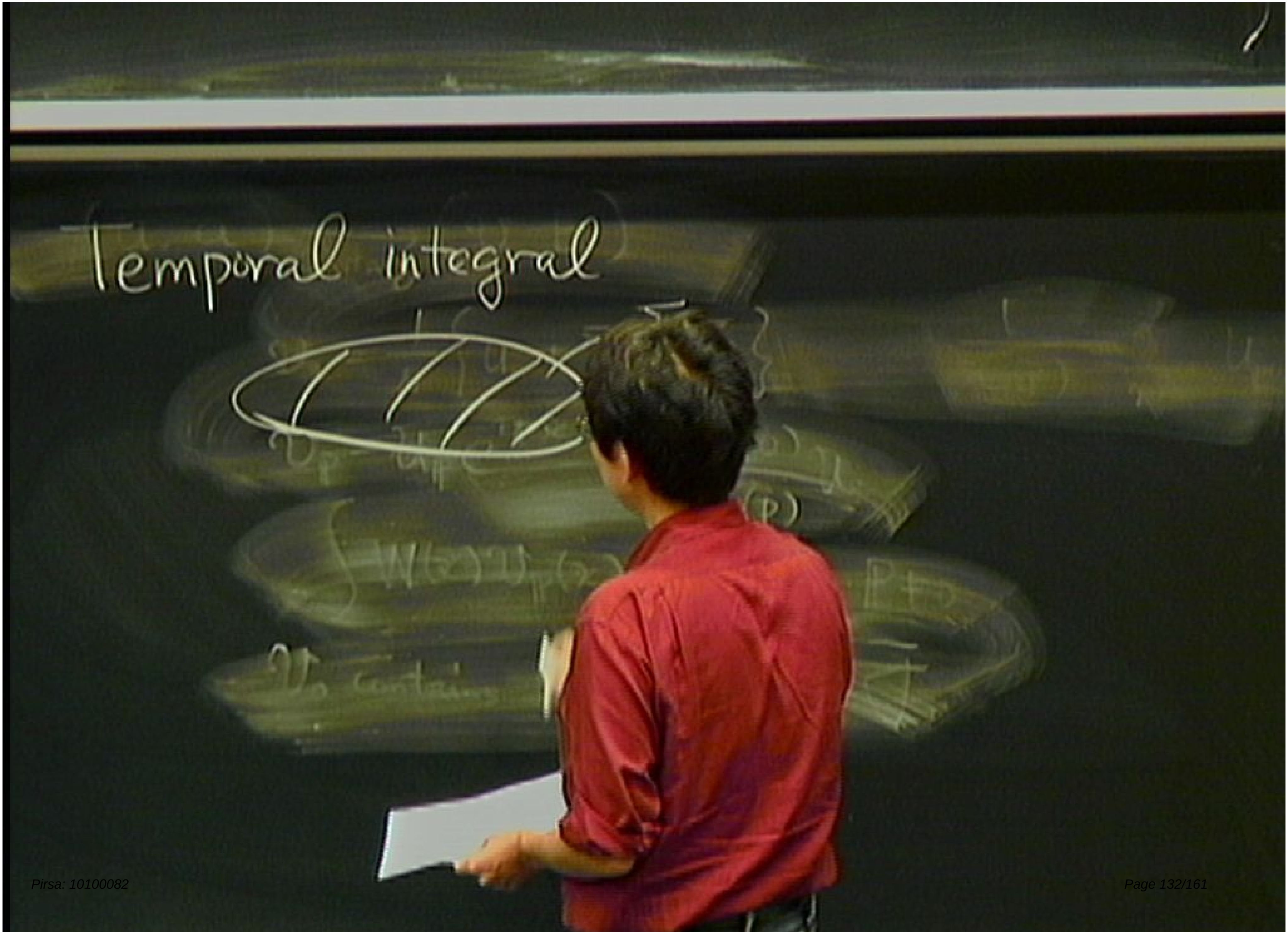
$$\langle \alpha | \beta \rangle \propto \exp\left(-\frac{(\alpha-\beta)^2}{2}\right)$$

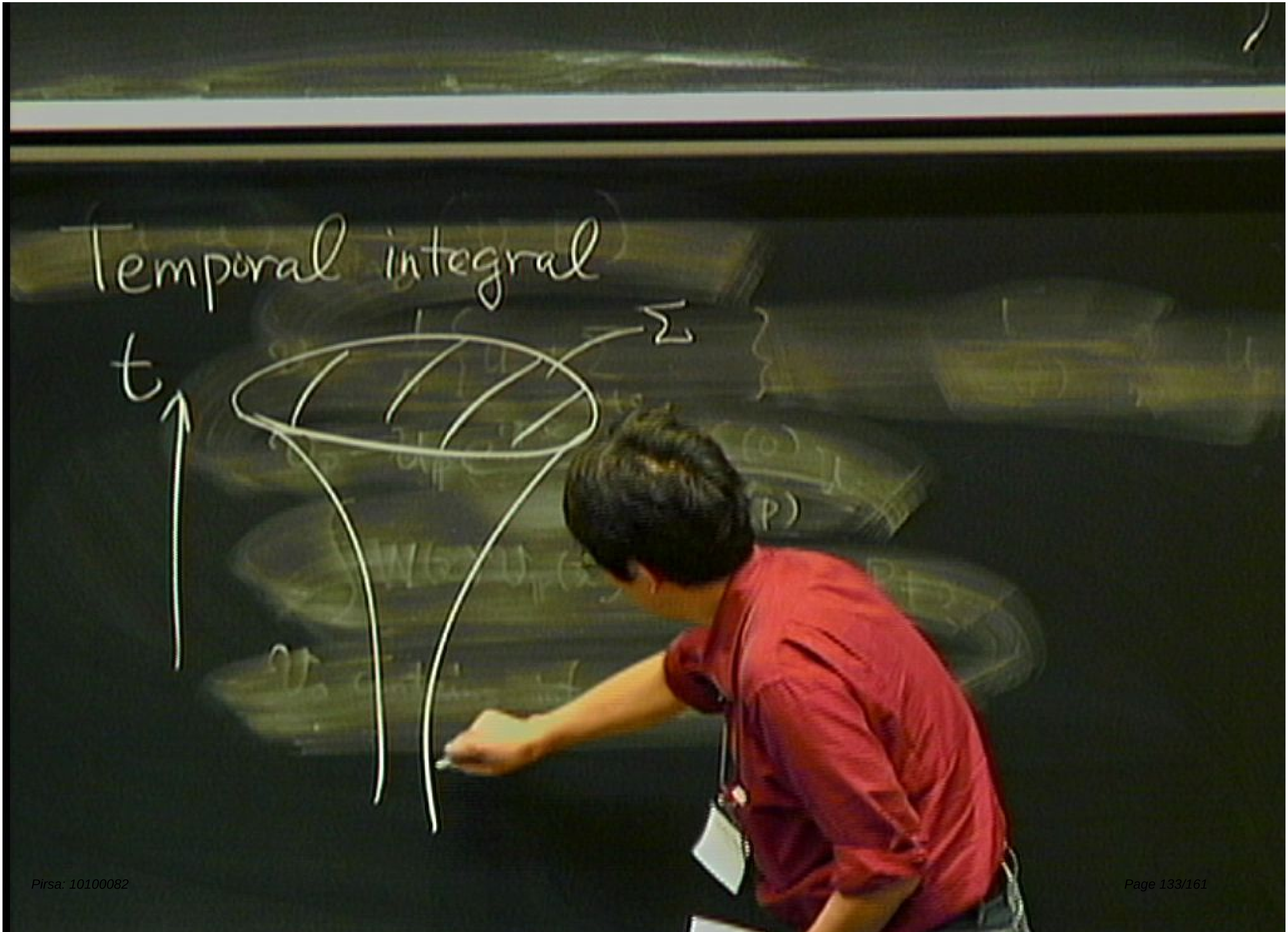

$P \propto \exp\left(-\tilde{\sigma}^2 / 2(\Delta\sigma)^2\right) \rightarrow \exp\left(-(\alpha+\beta)^2 / 2(\Delta\sigma)^2\right)$
$\tilde{\sigma} \rightarrow \tilde{b} + \tilde{b}^\dagger \propto \alpha + \beta$
$\langle \alpha | \beta \rangle \propto \exp\left(-\frac{(\alpha-\beta)^2}{2}\right)$

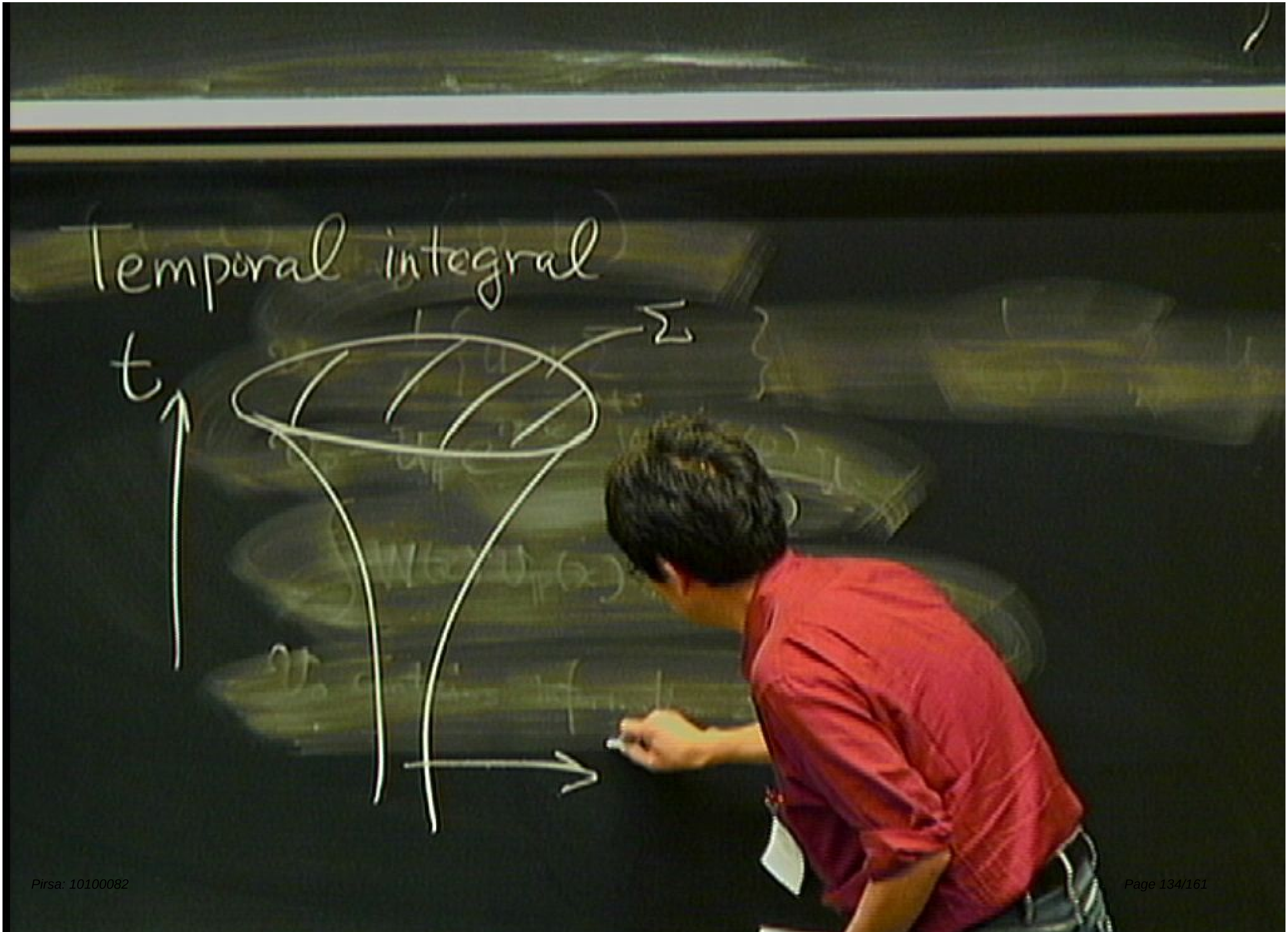

P ∝ exp(−σ̂²/2(Δσ)²) → exp(−(α+β)²/2(Δσ)²)
σ̂ → b̂ + b̂⁺ → α + β
⟨α|β⟩ ∝ exp


(u, a) → (b)
unitary
1/C(p) = lim η→0 u_p
p≠0
W_-p/W_0 C(0)/C(p) u_0
p(x)) d³x = 0 p≠0
information about J


Temporal integral


Temporal integral


Temporal integral
t
Σ


Temporal integral
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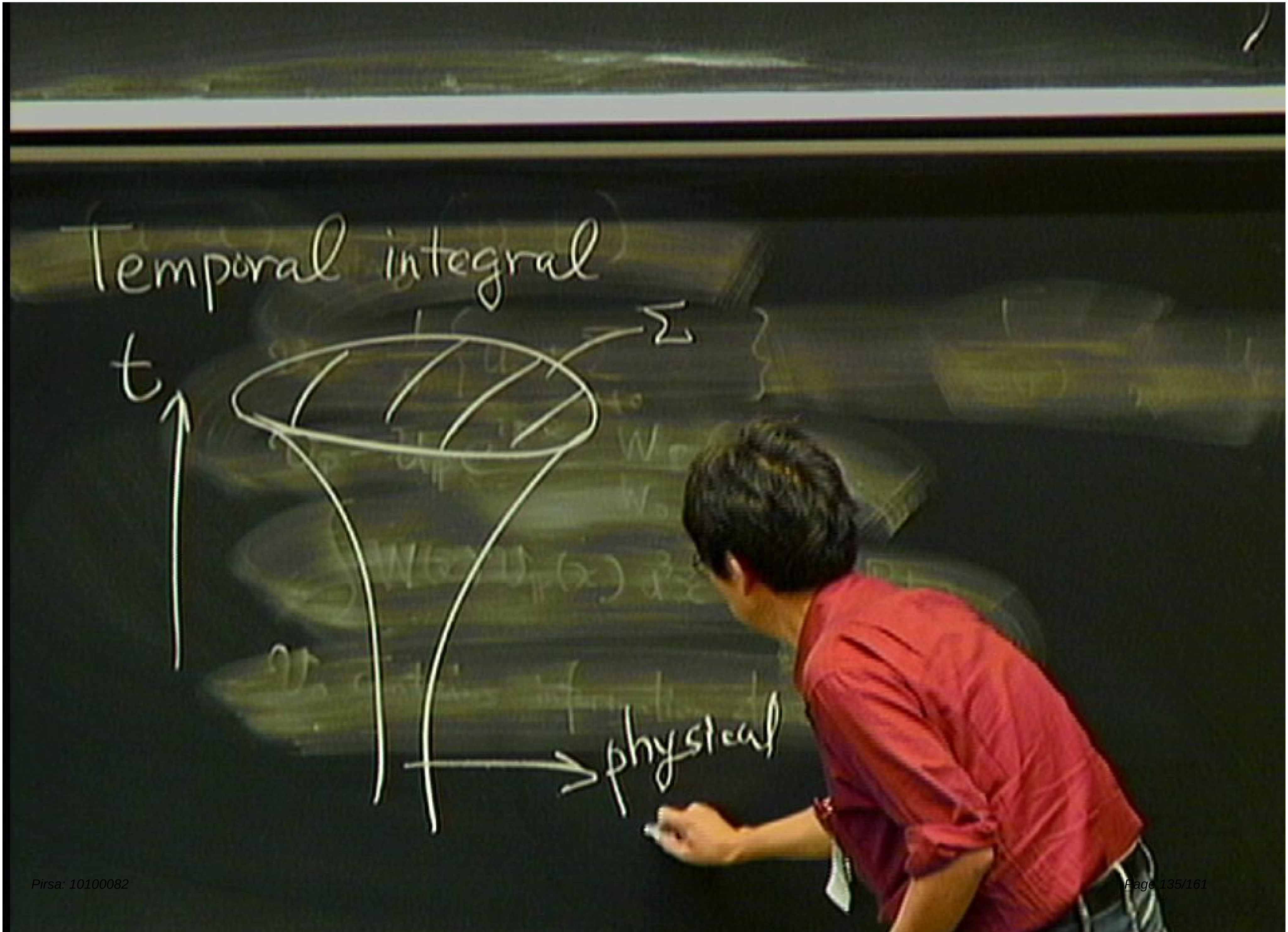
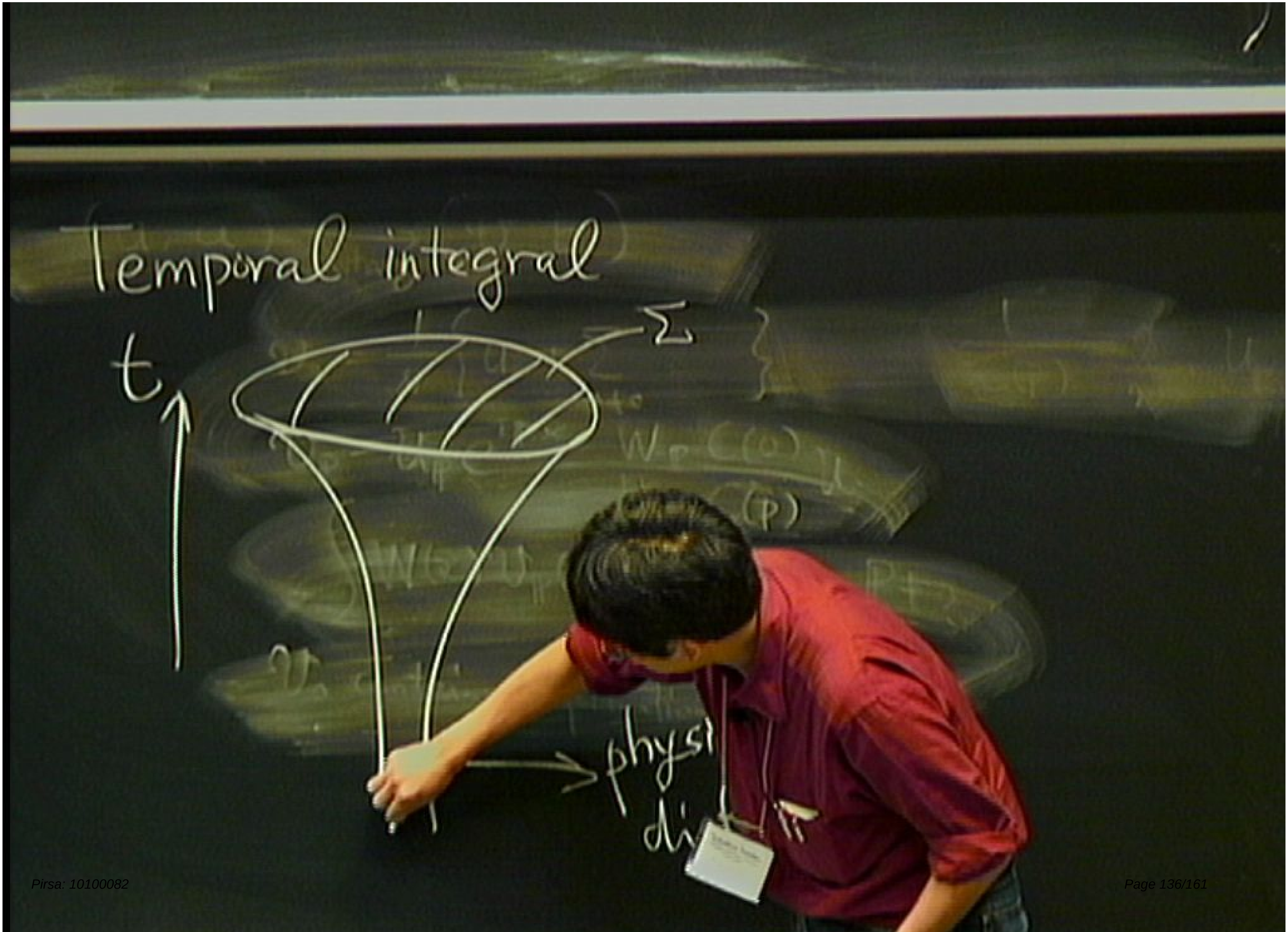

Temporal integral
t
Σ
physical


Temporal integral
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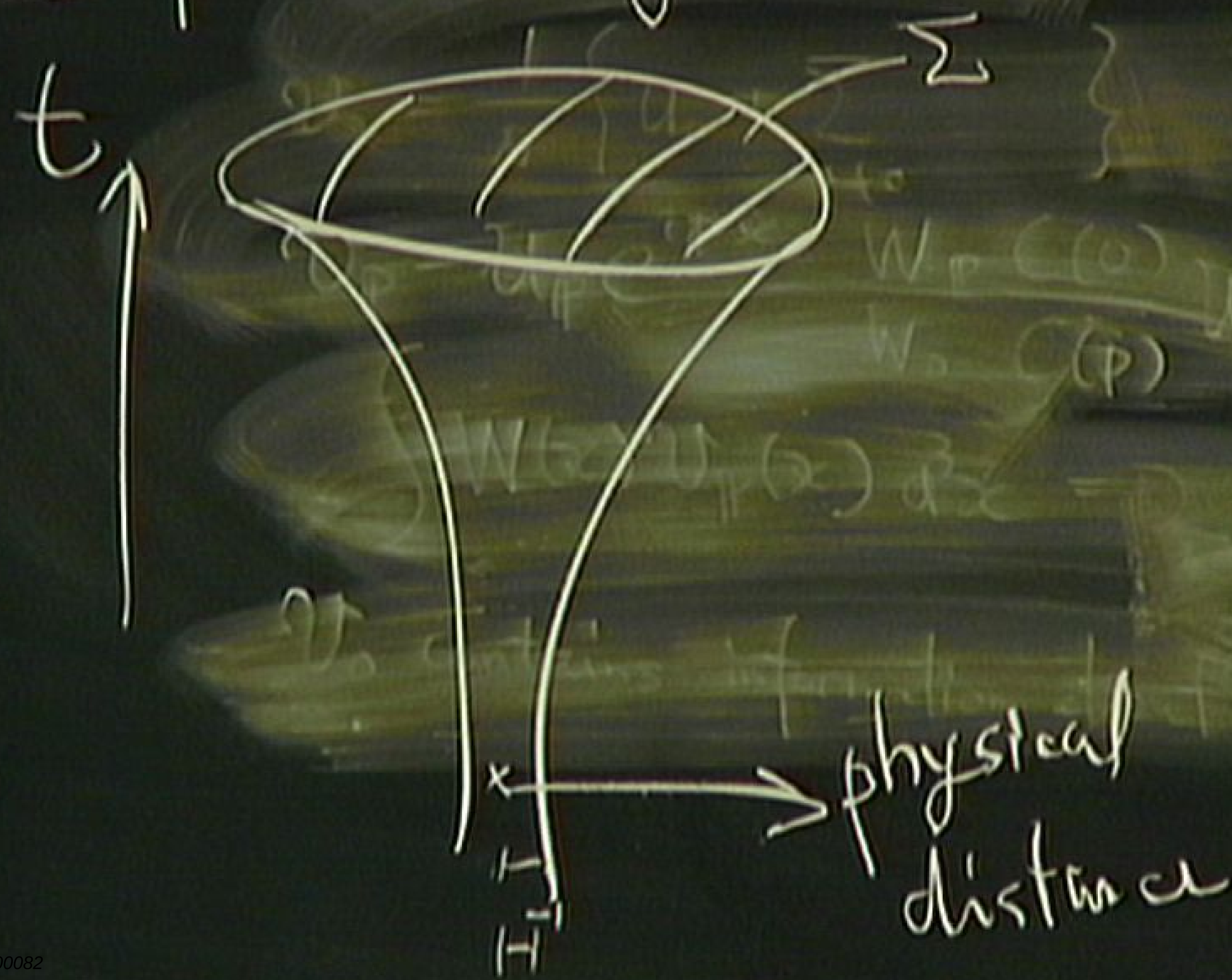
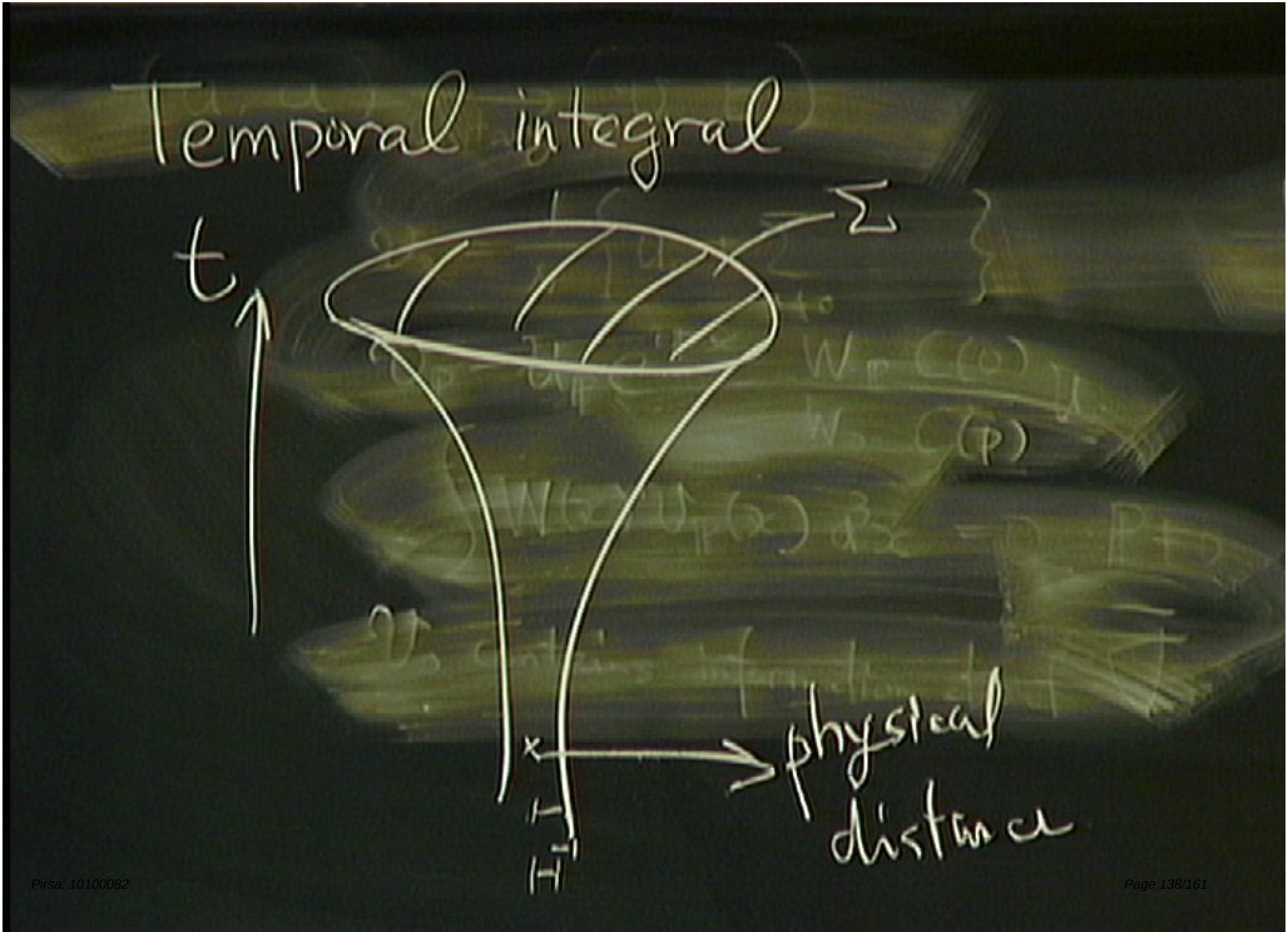
Temporal integral




Temporal integral
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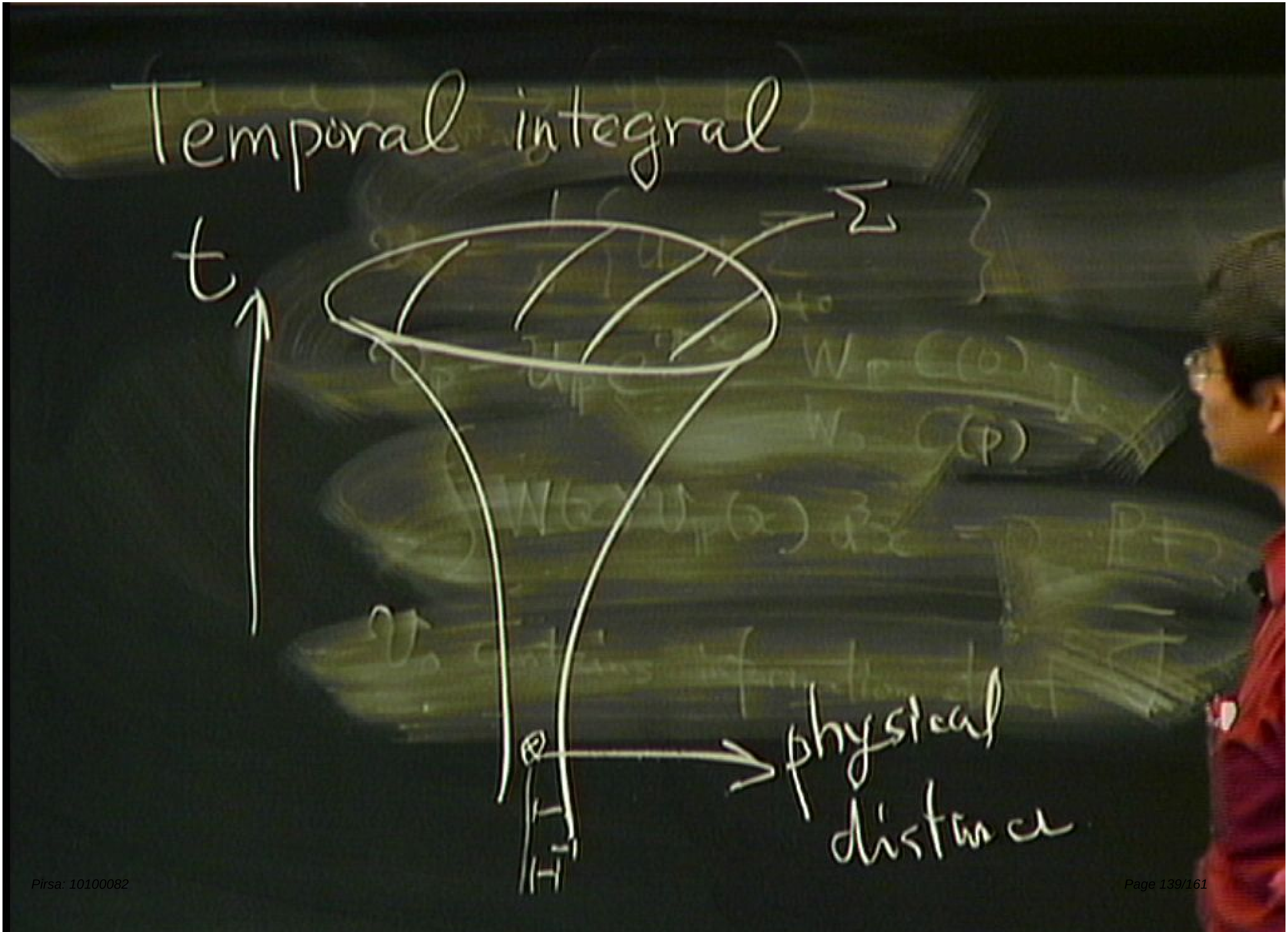
Σ
x
physical distance


Temporal integral
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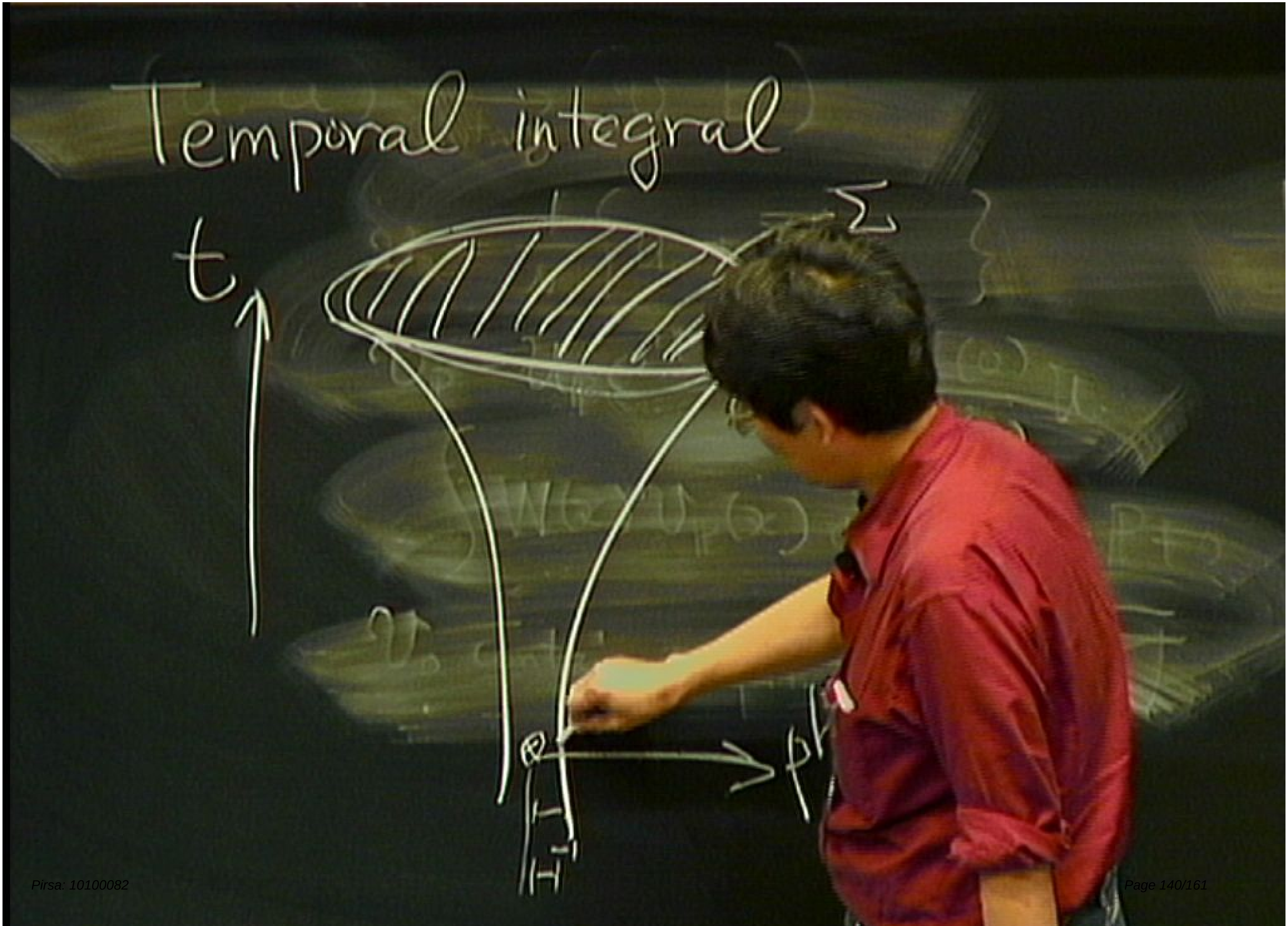
Temporal integral
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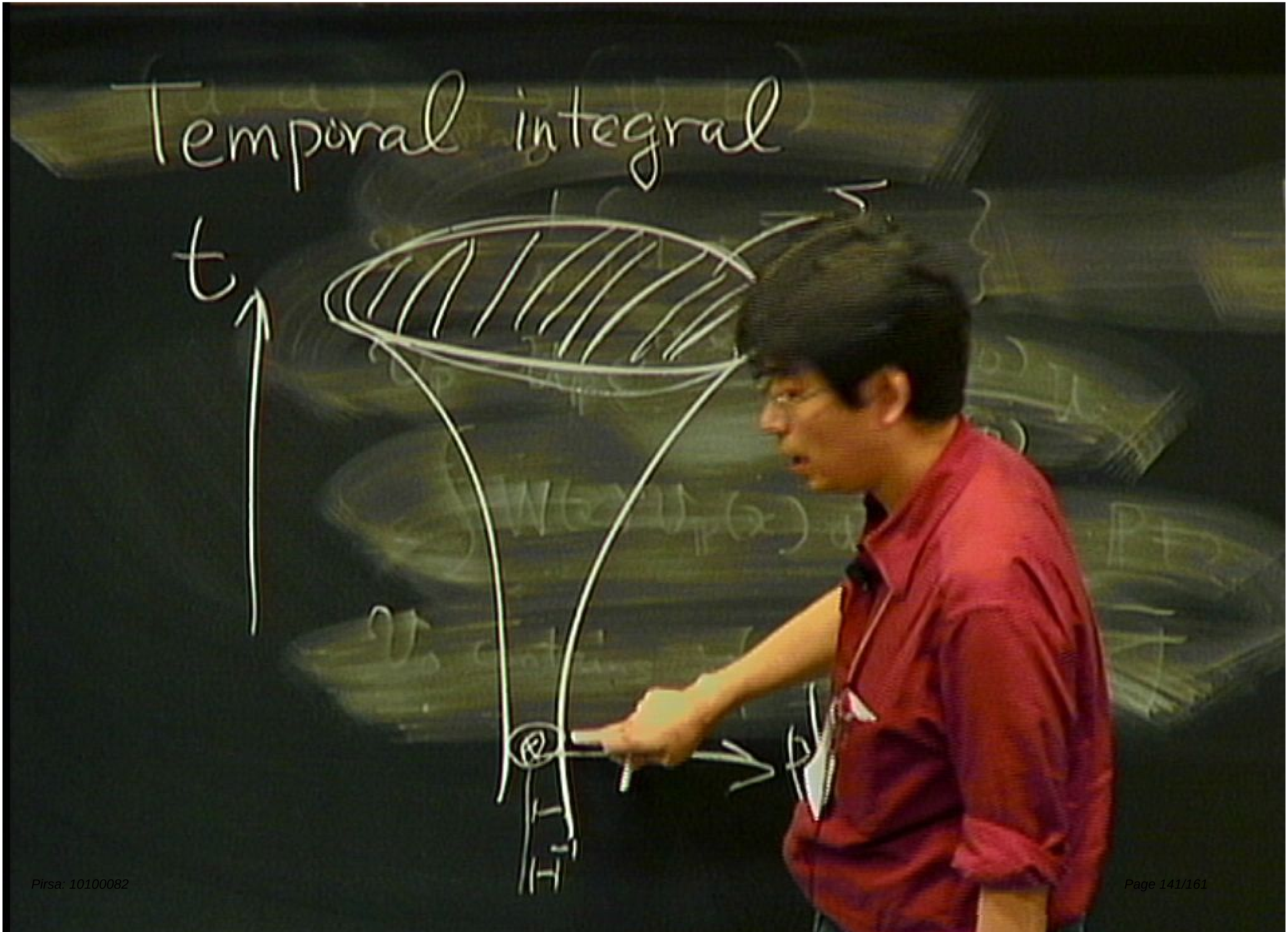
Temporal integral
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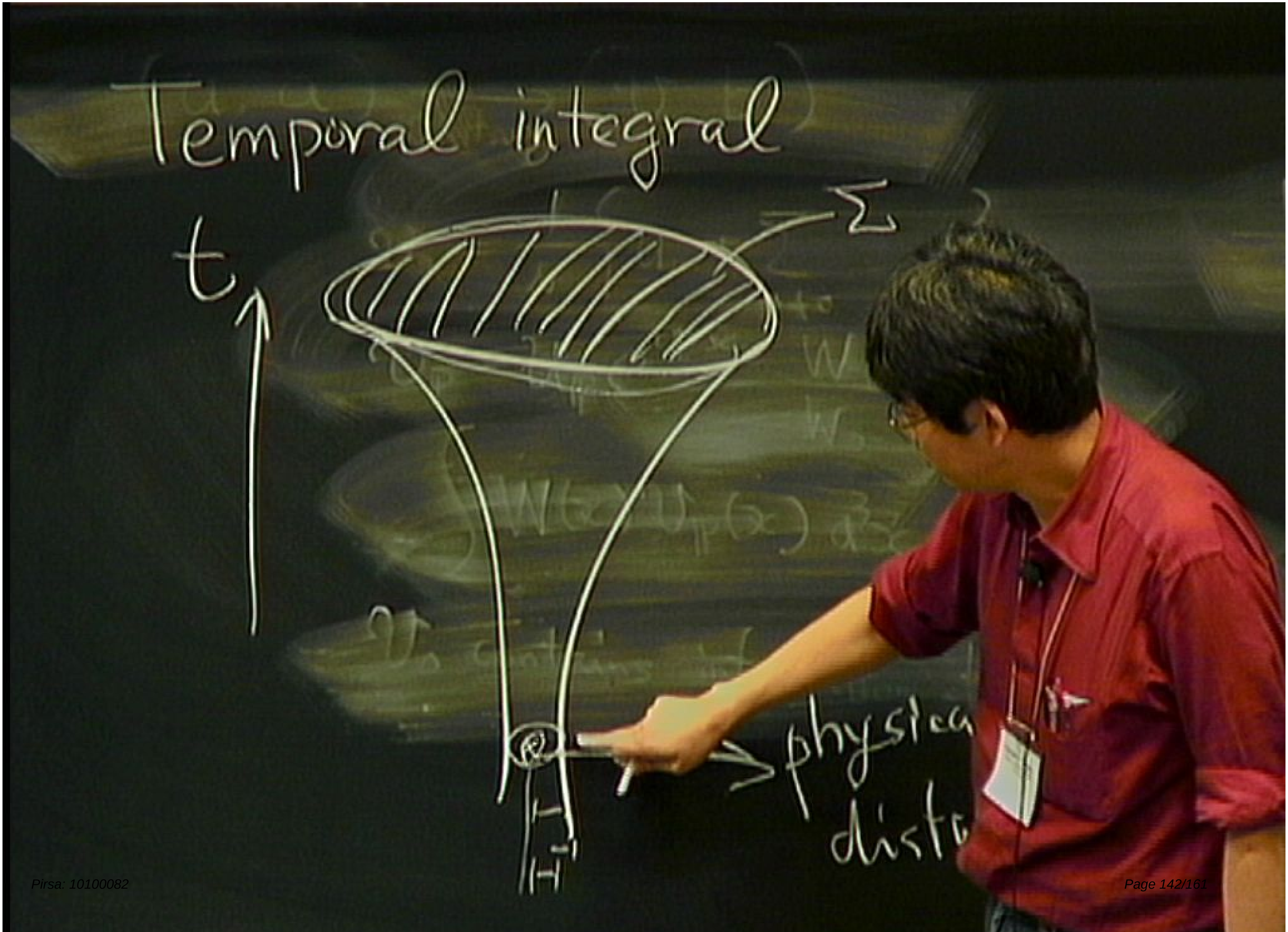
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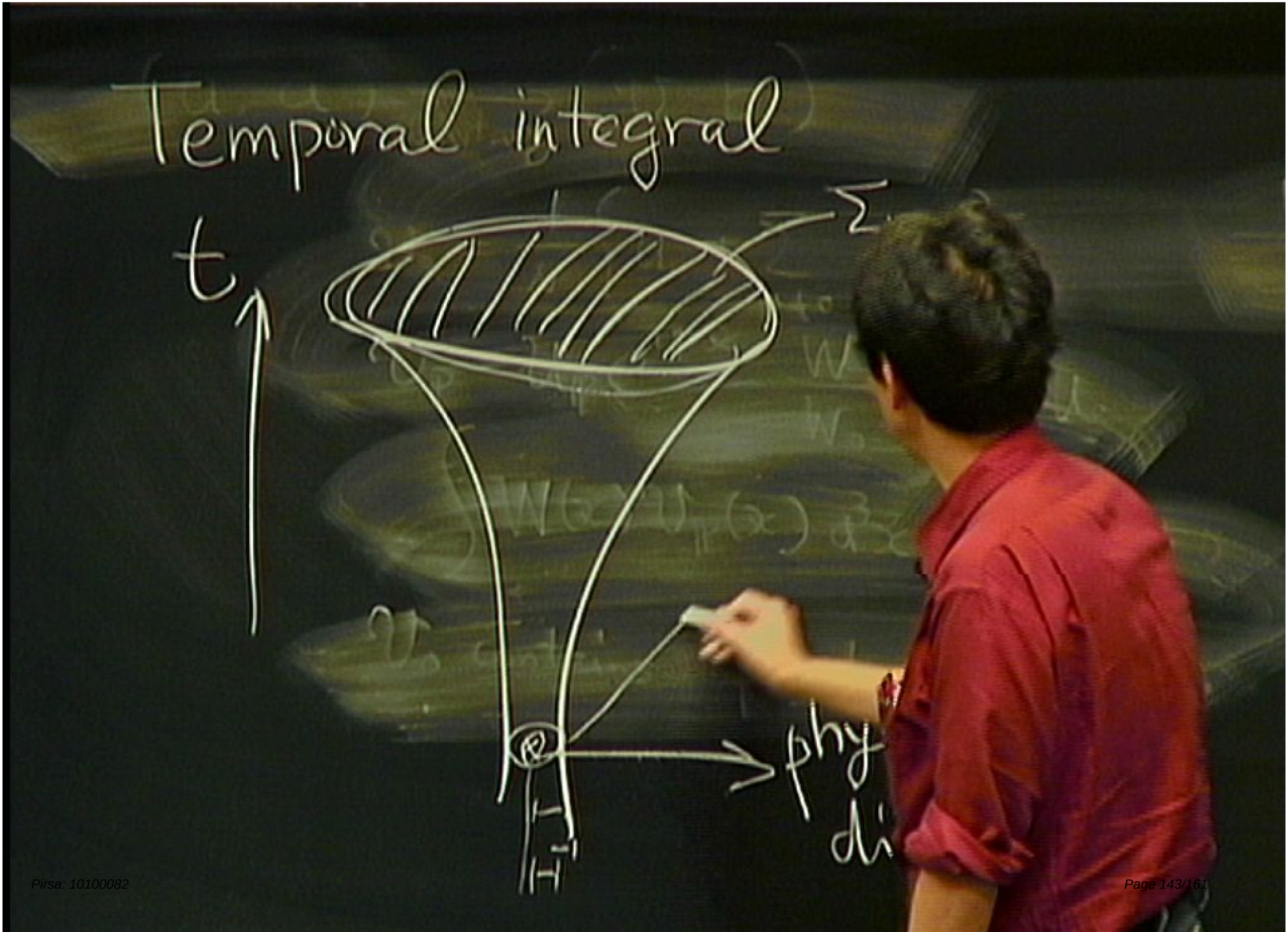
Temporal integral
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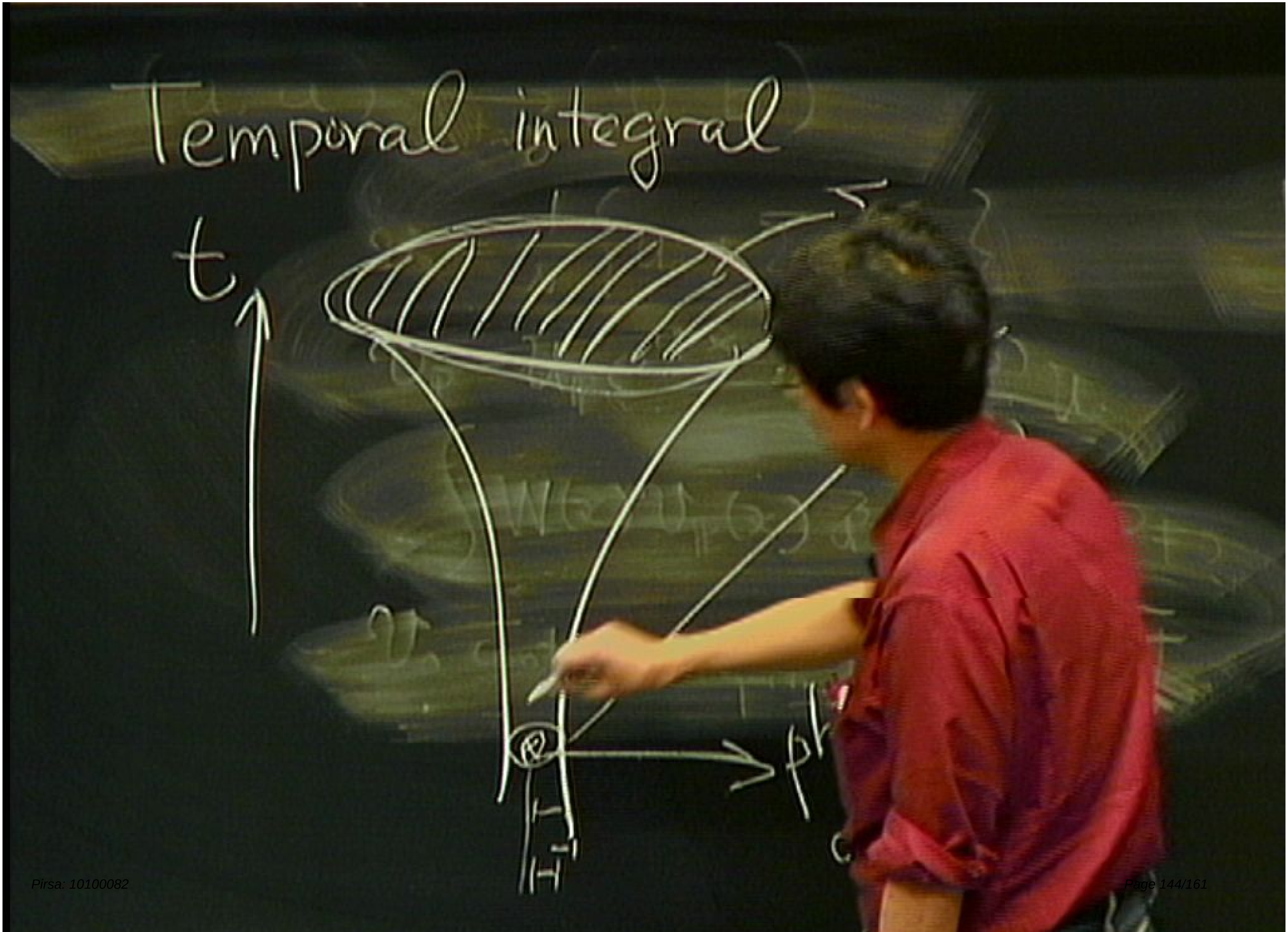
Temporal integral
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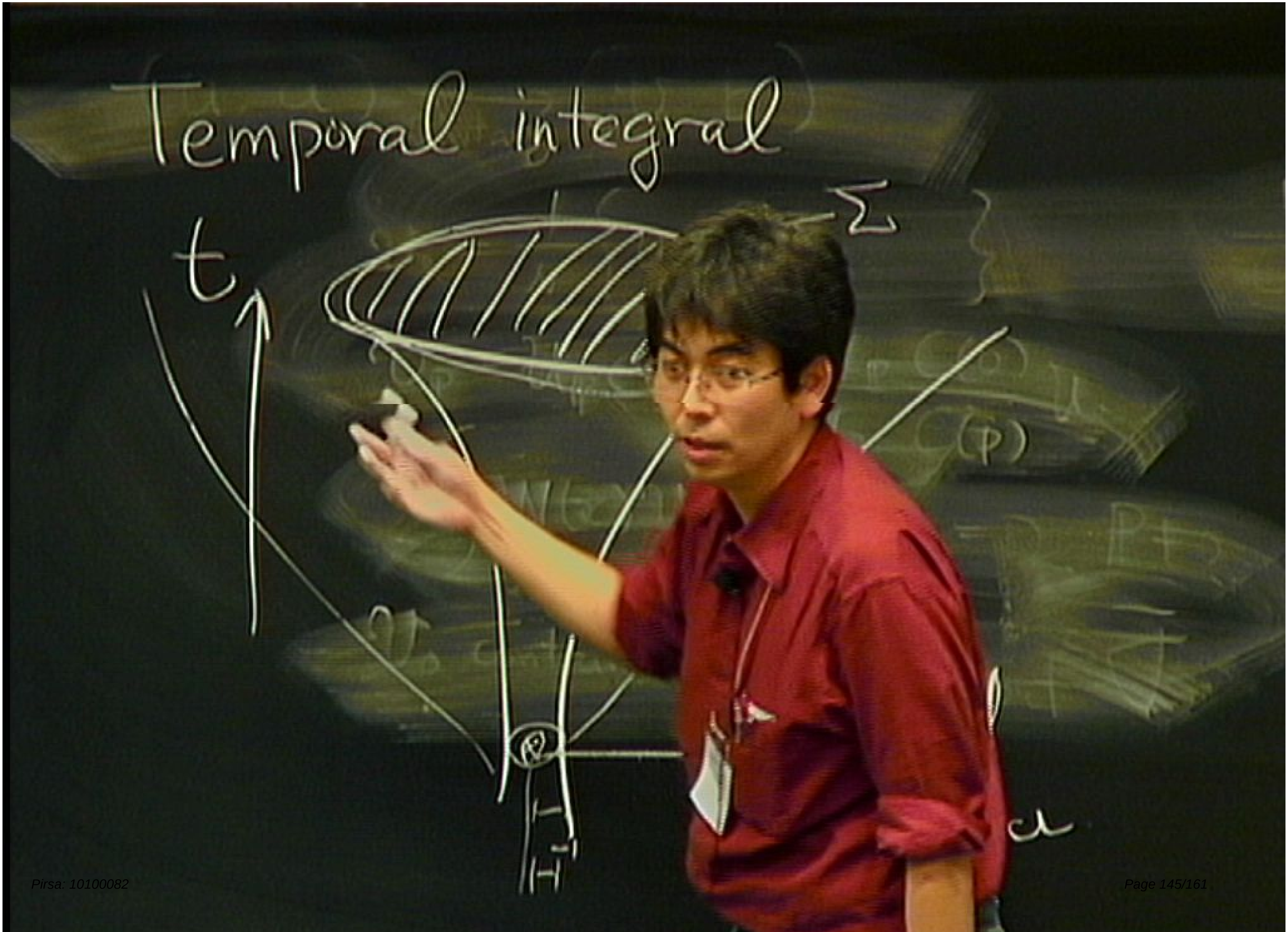
Temporal integral
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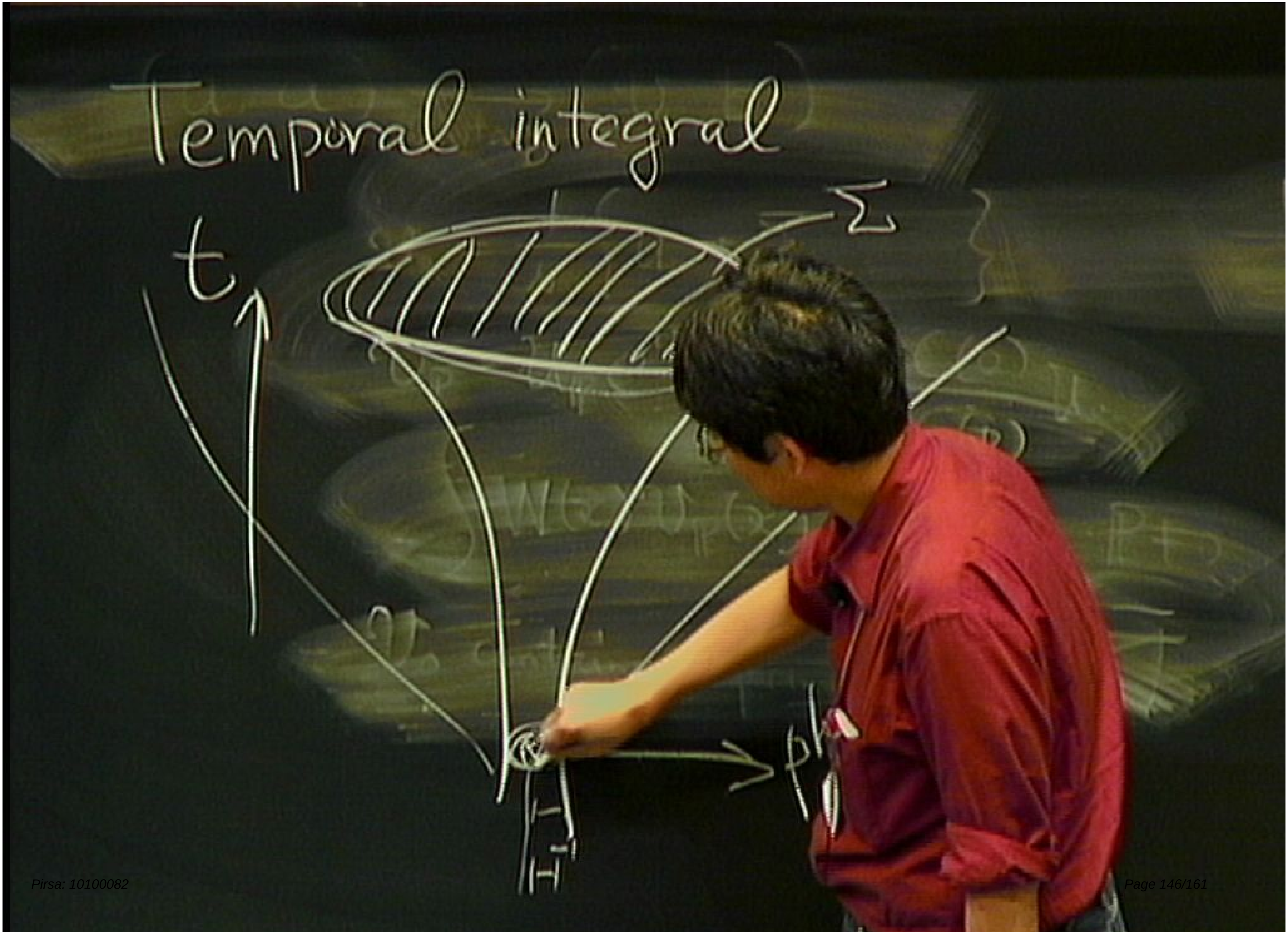
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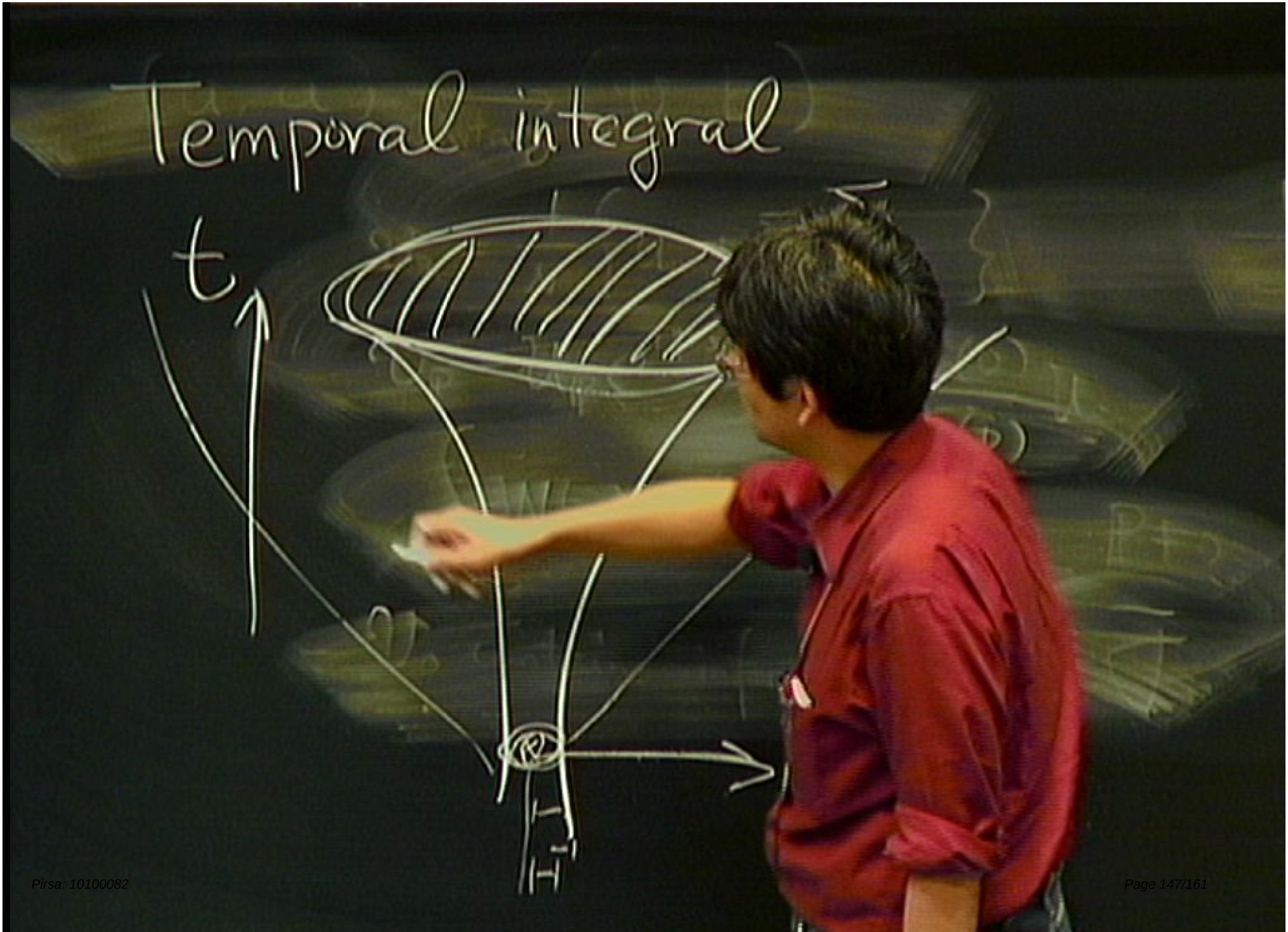
Temporal integral
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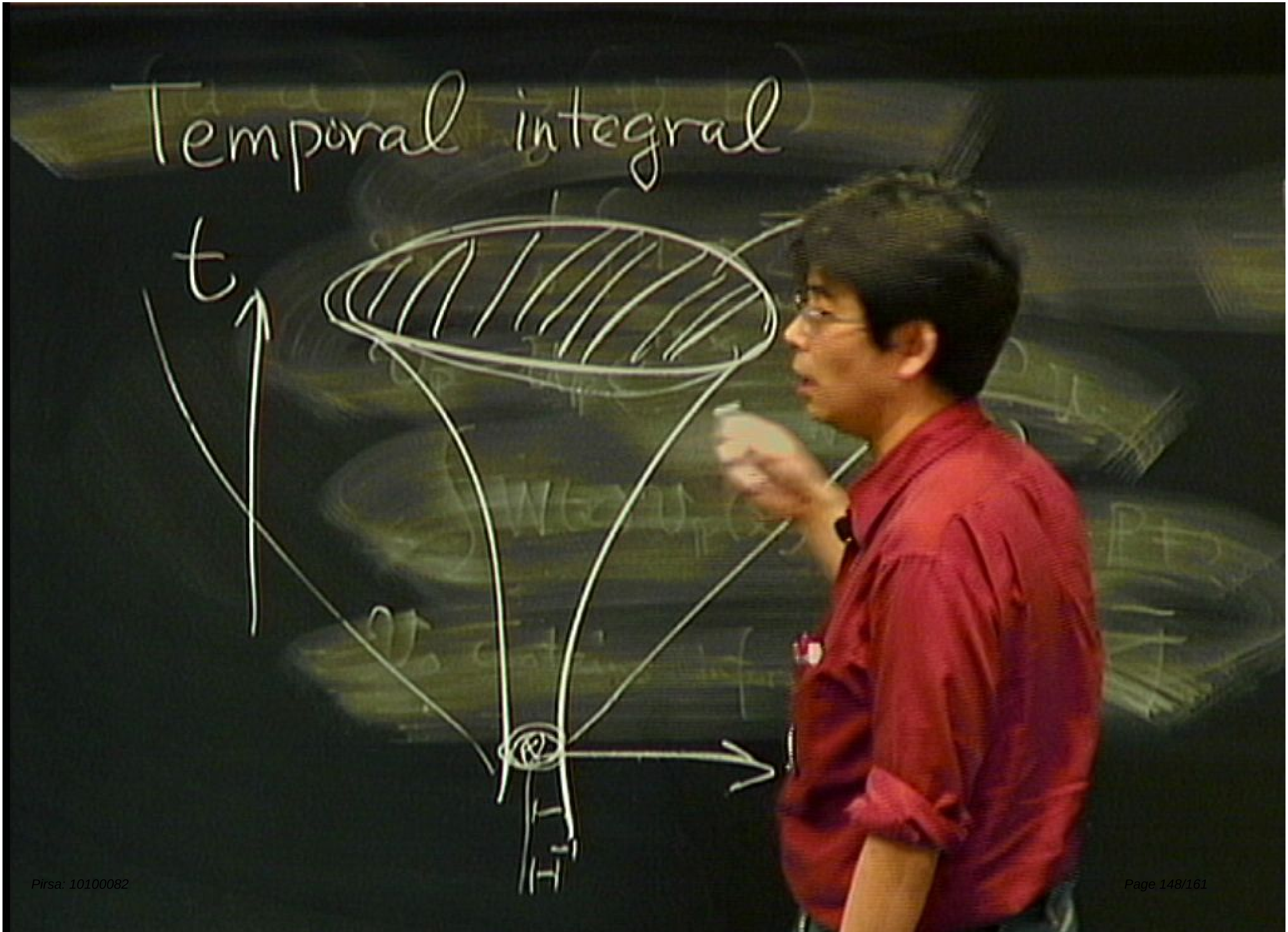
Temporal integral
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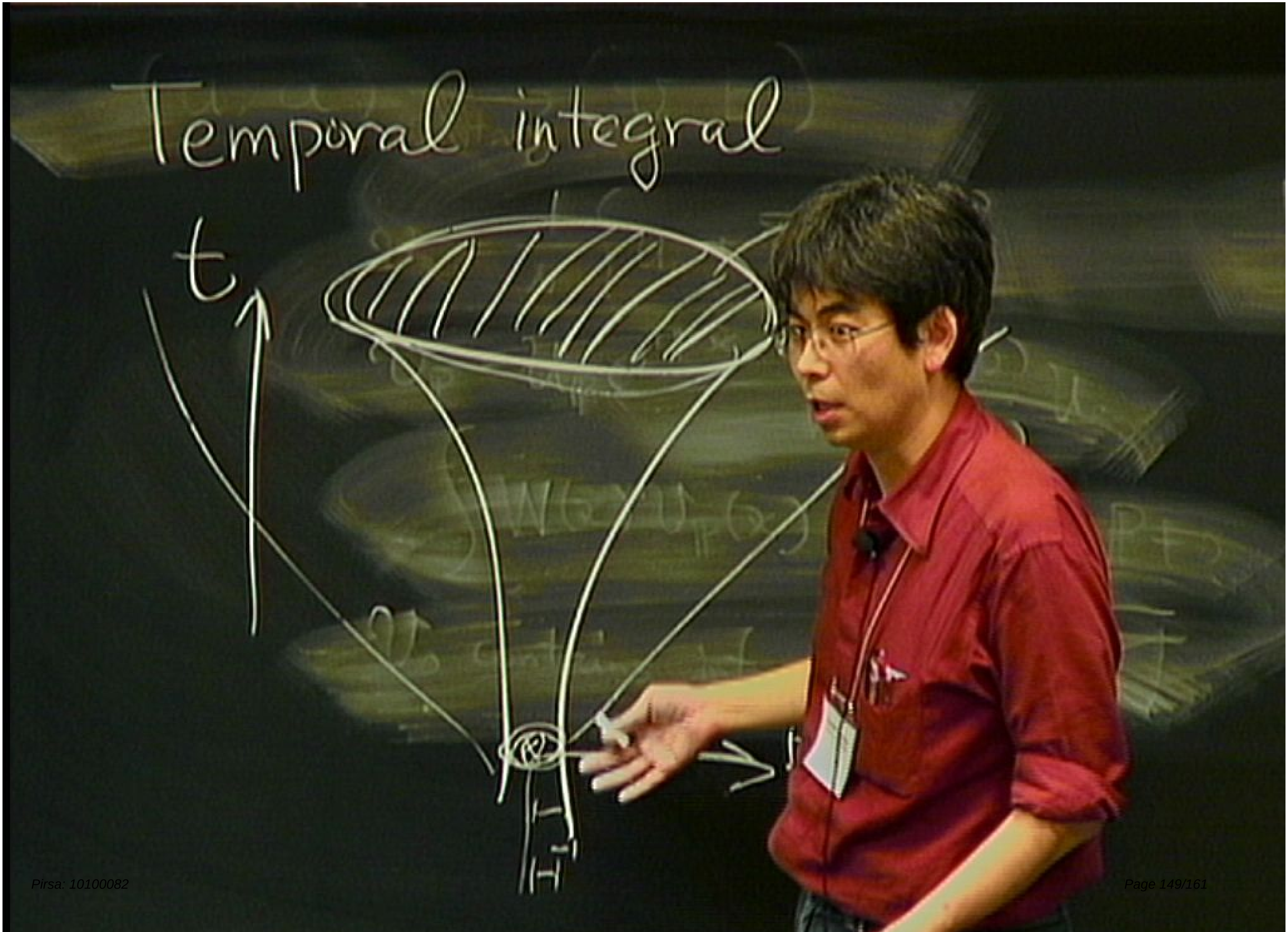
Temporal integral
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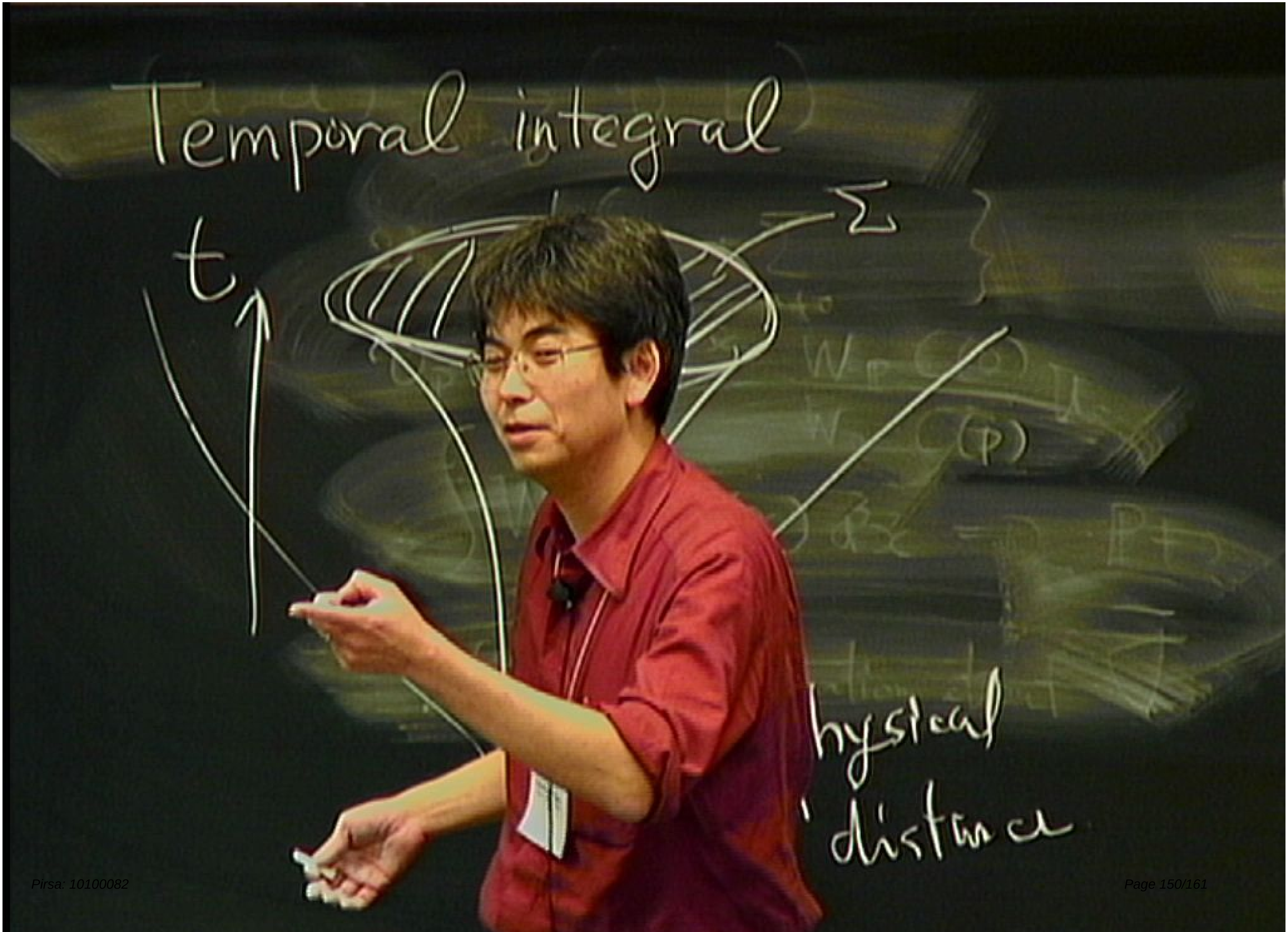
Temporal integral
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Σ
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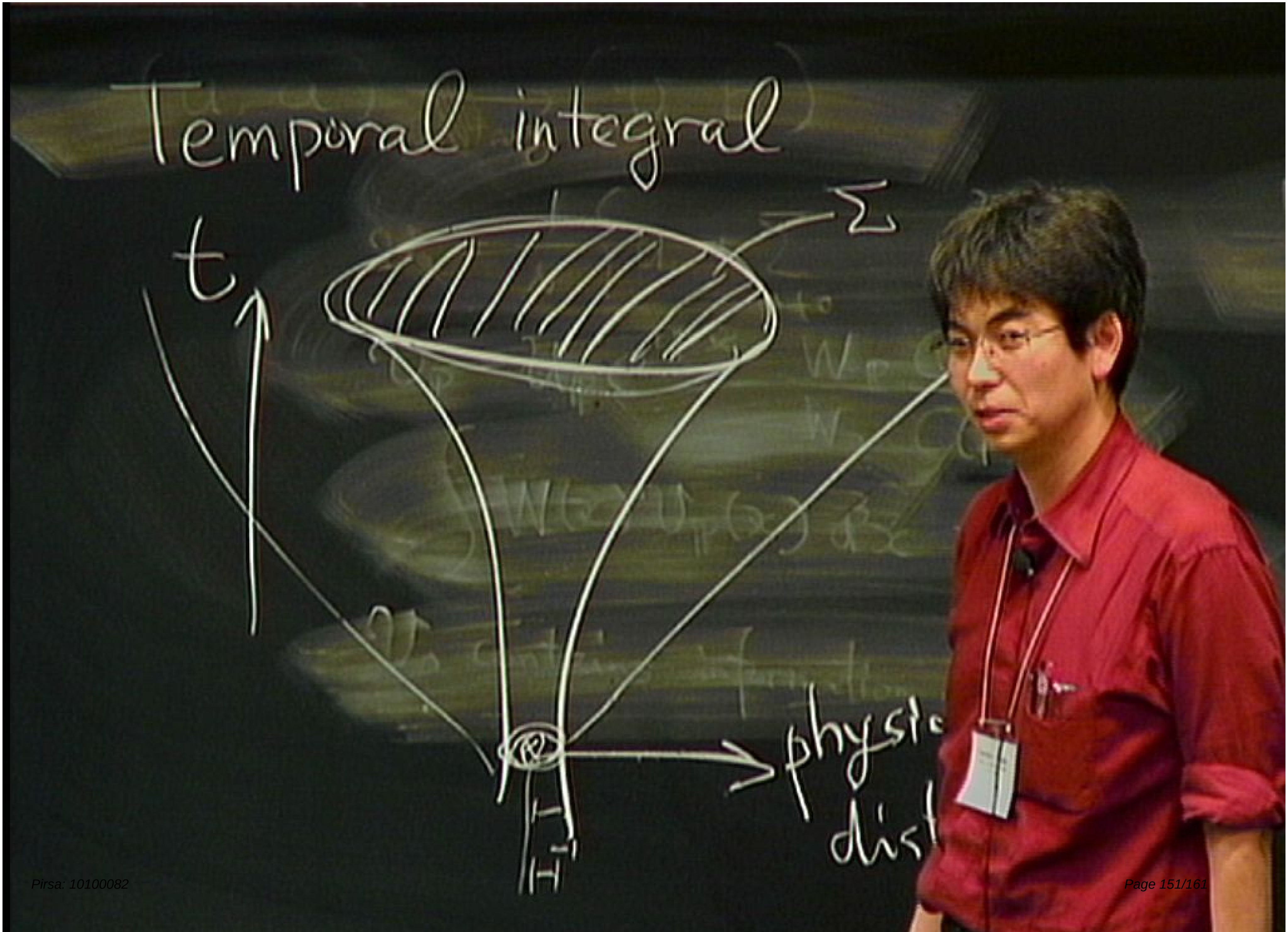
Temporal integral
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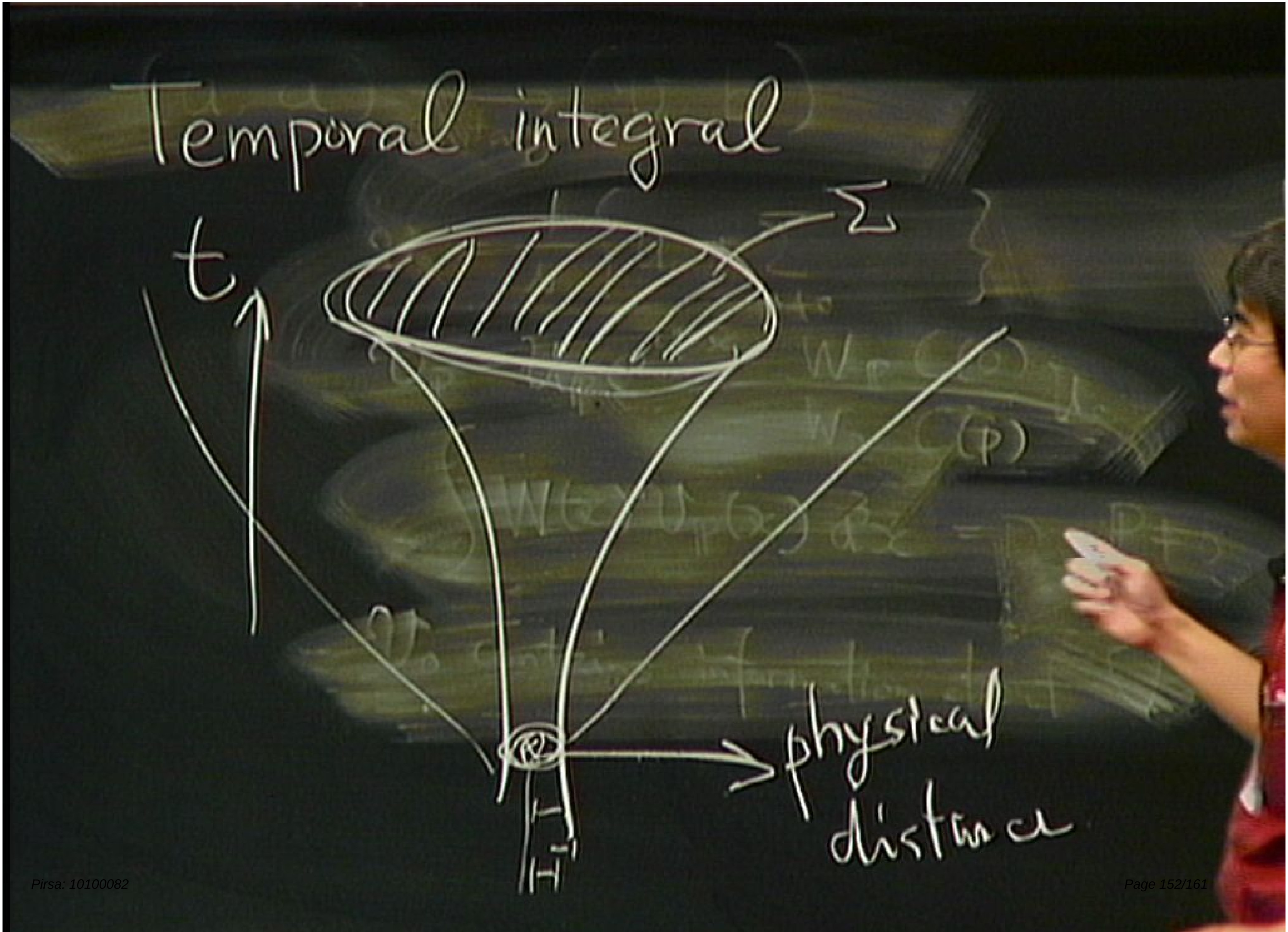
Σ


Temporal integral
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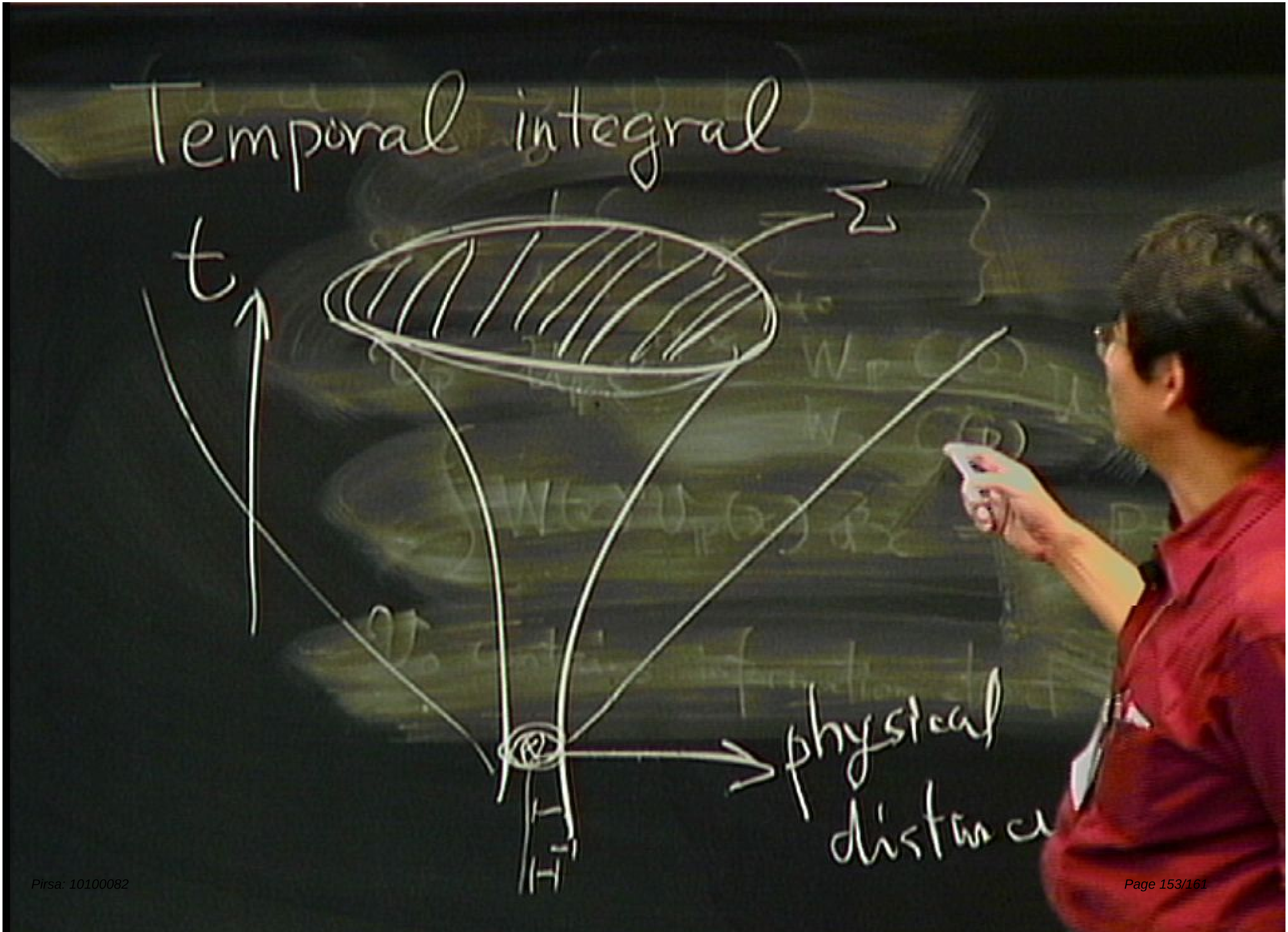
Σ
physical distance


Temporal integral
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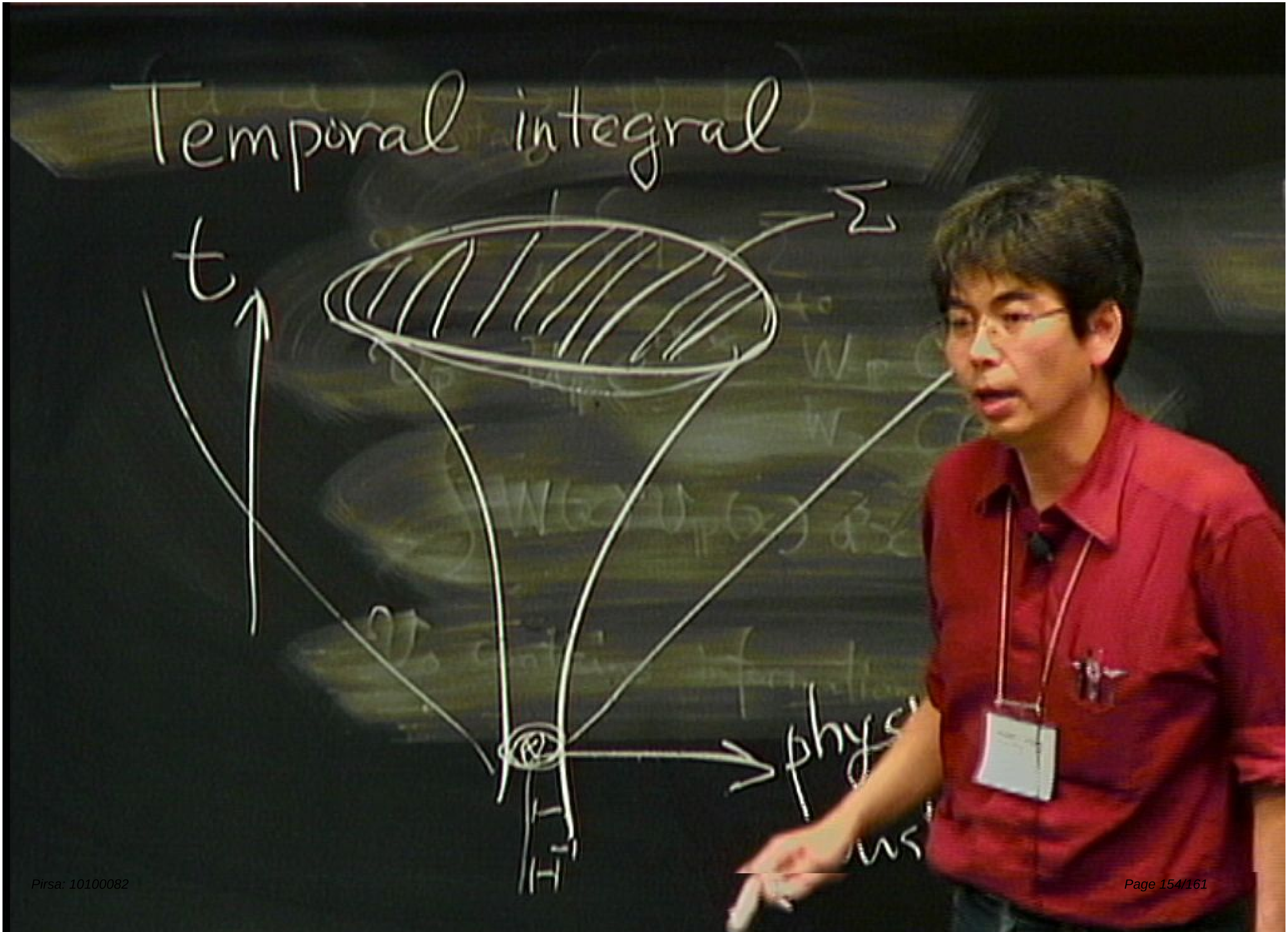
distance



Temporal integral
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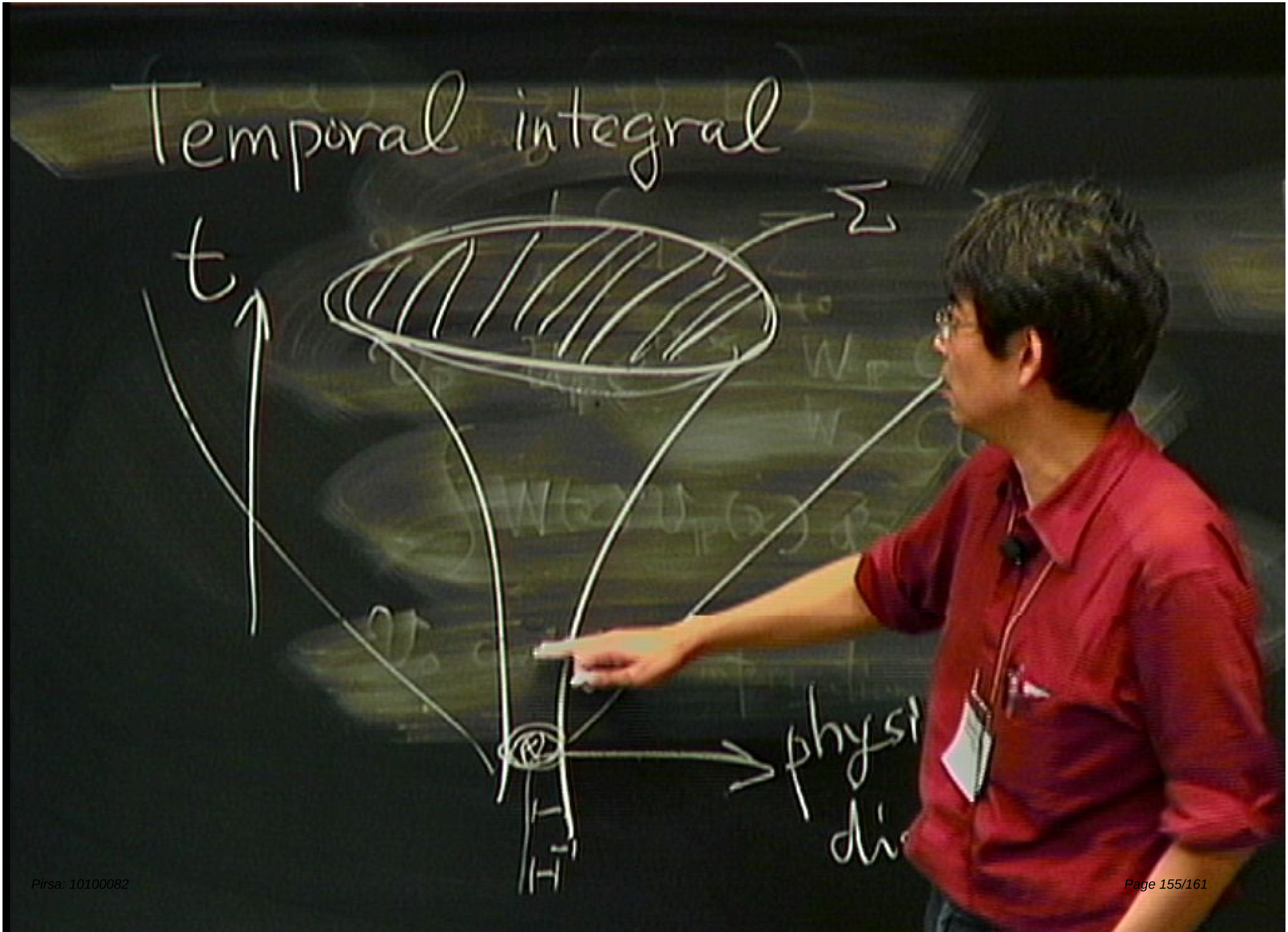
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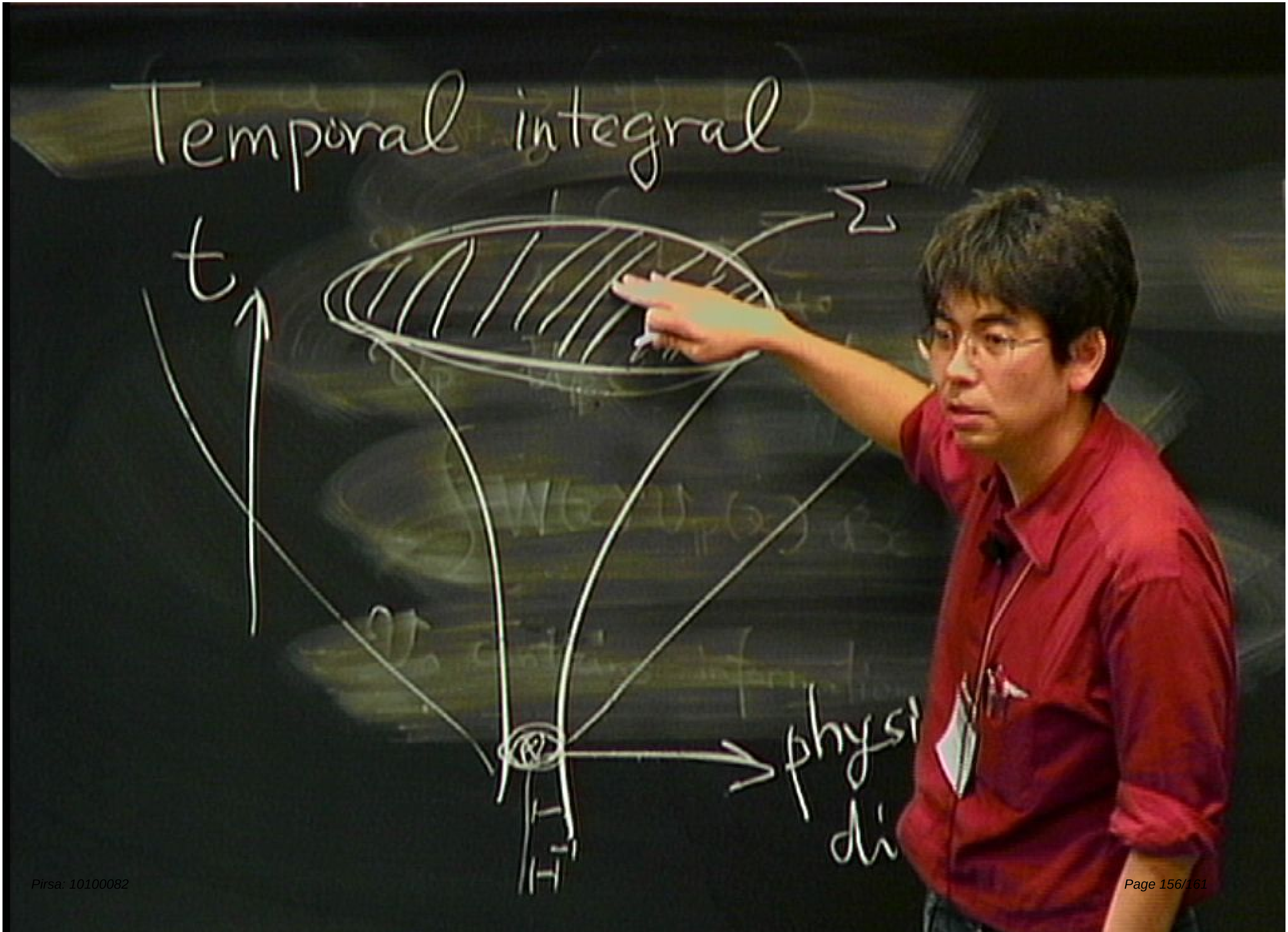
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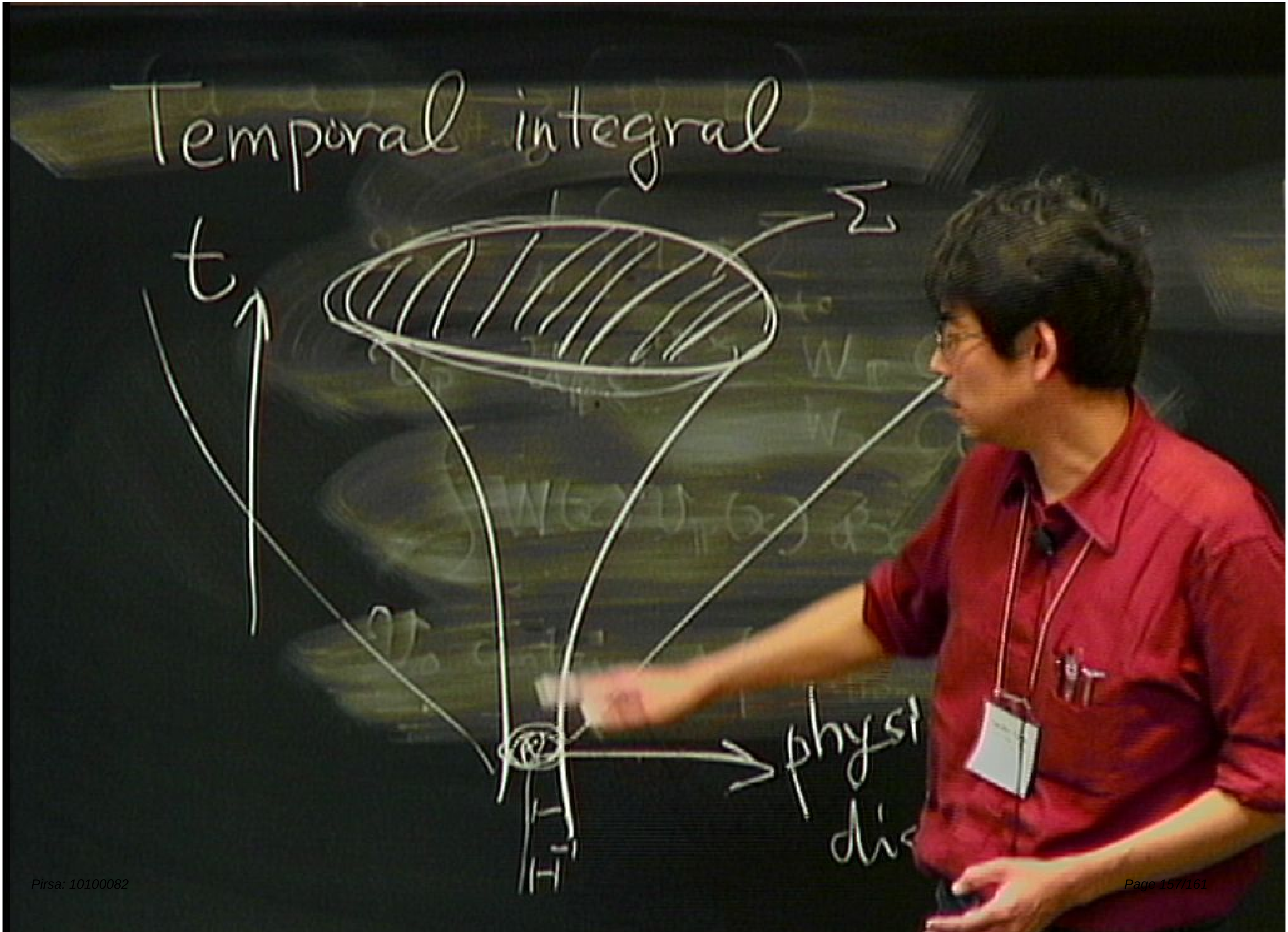
Temporal integral
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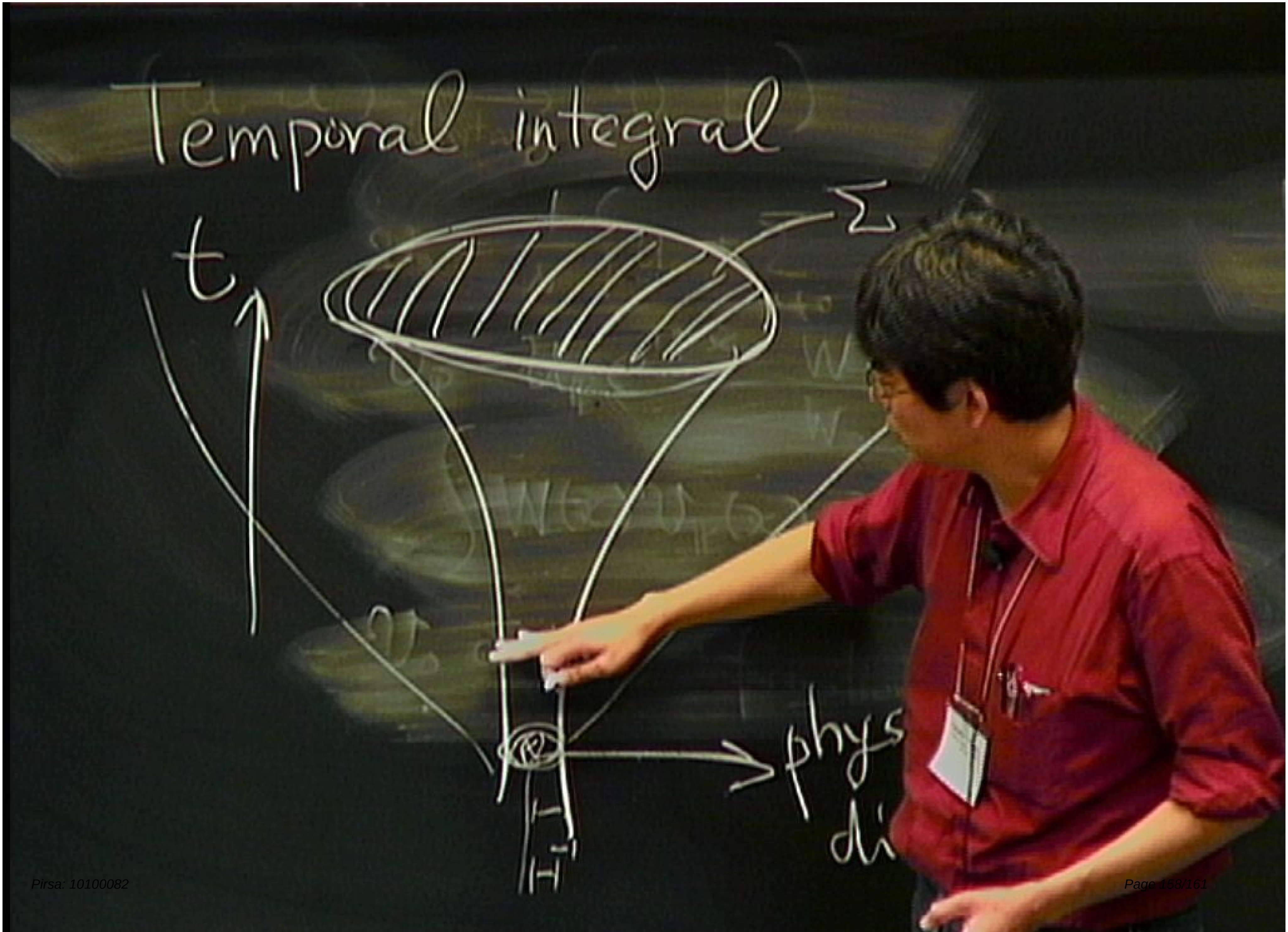
Temporal integral
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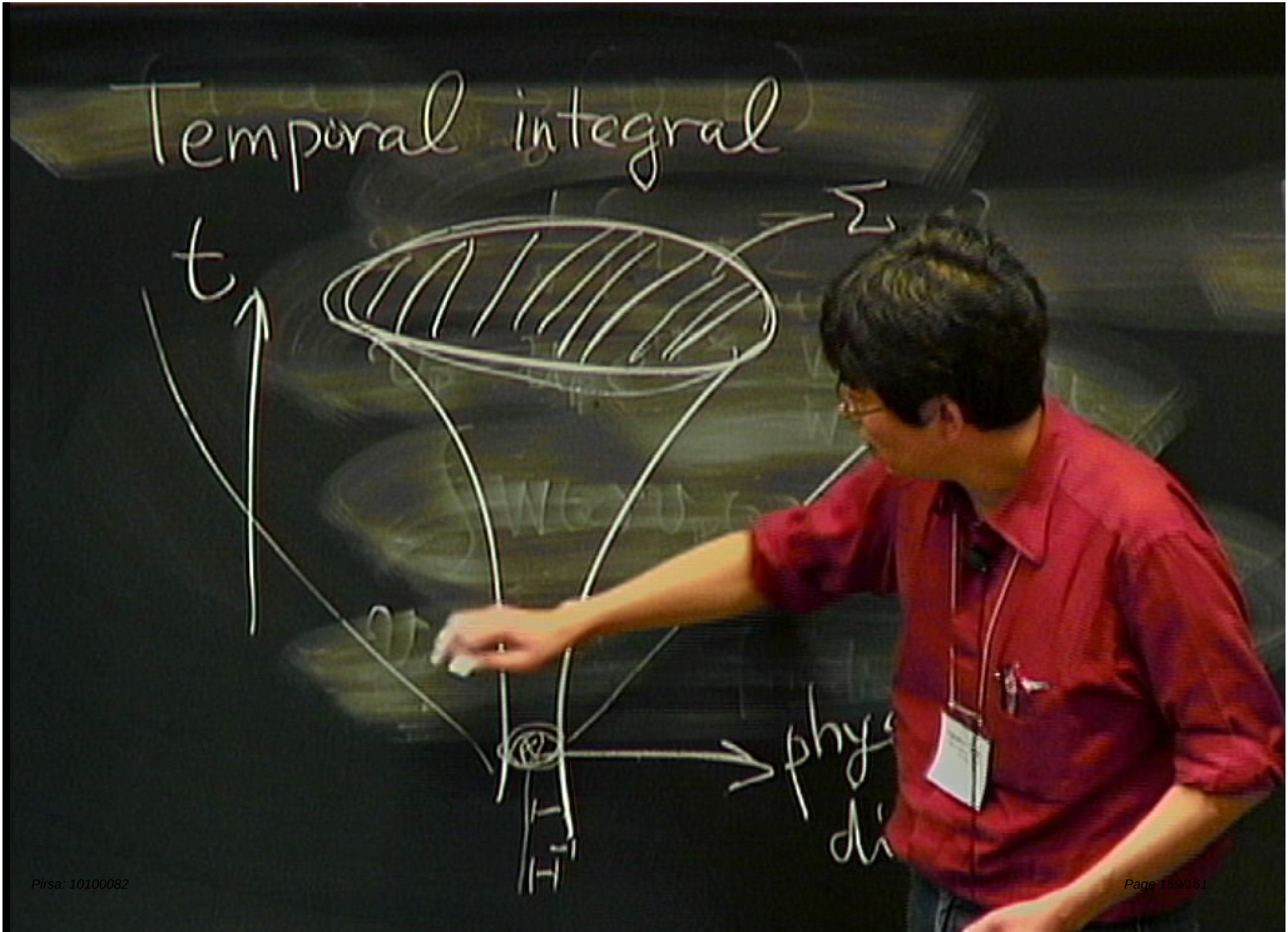
Temporal integral
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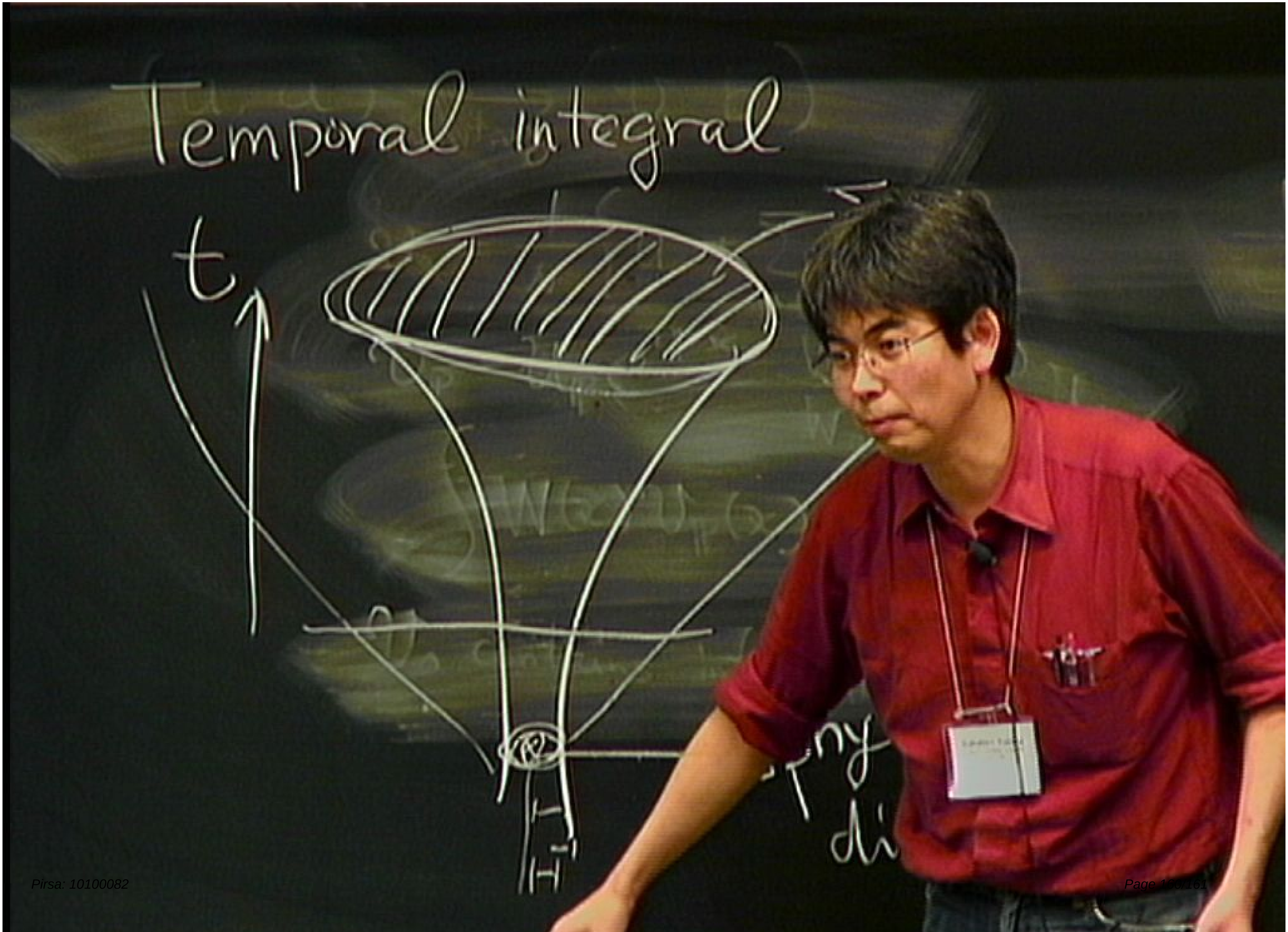
Temporal integral
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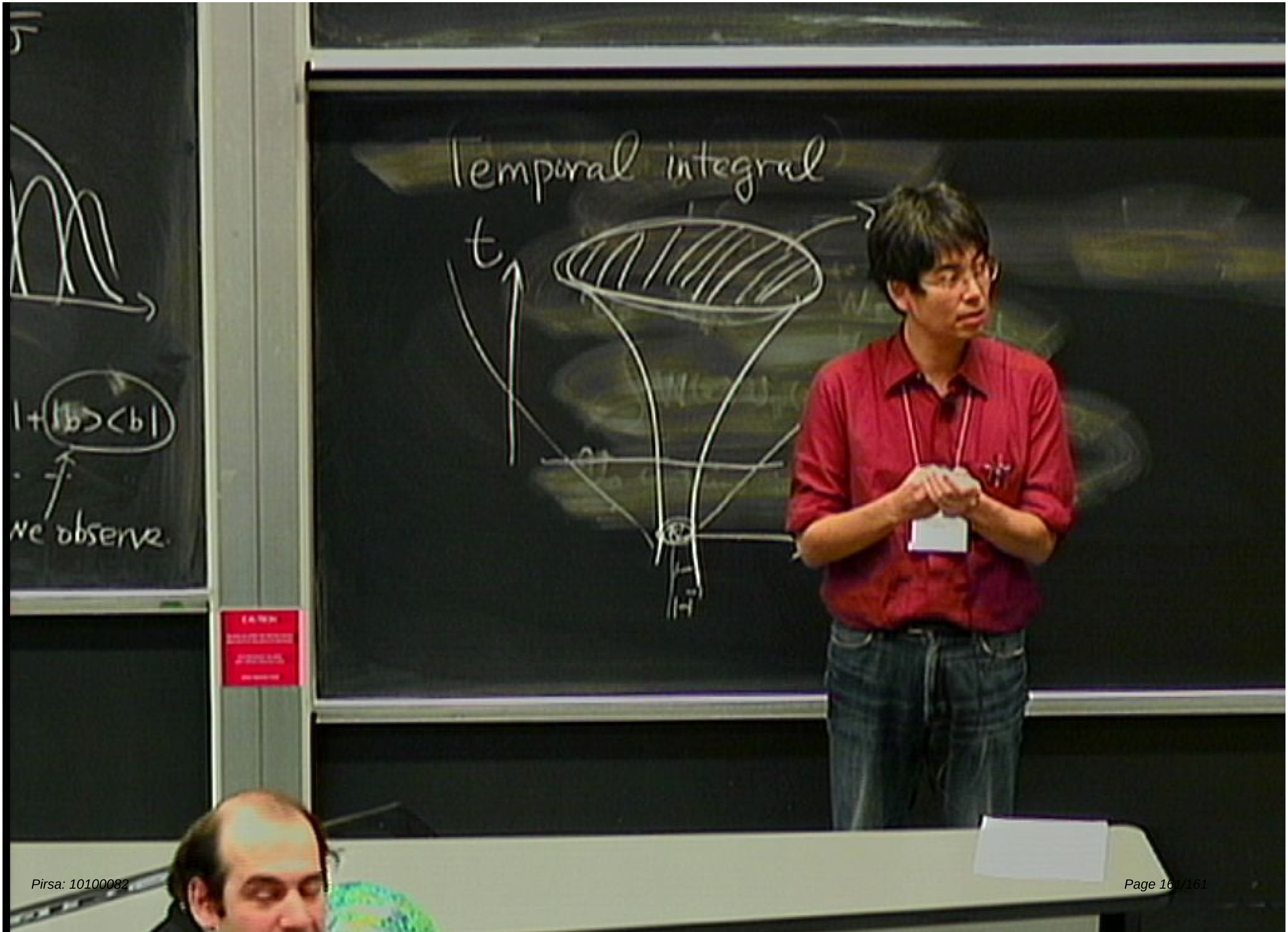

Temporal integral
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we observe