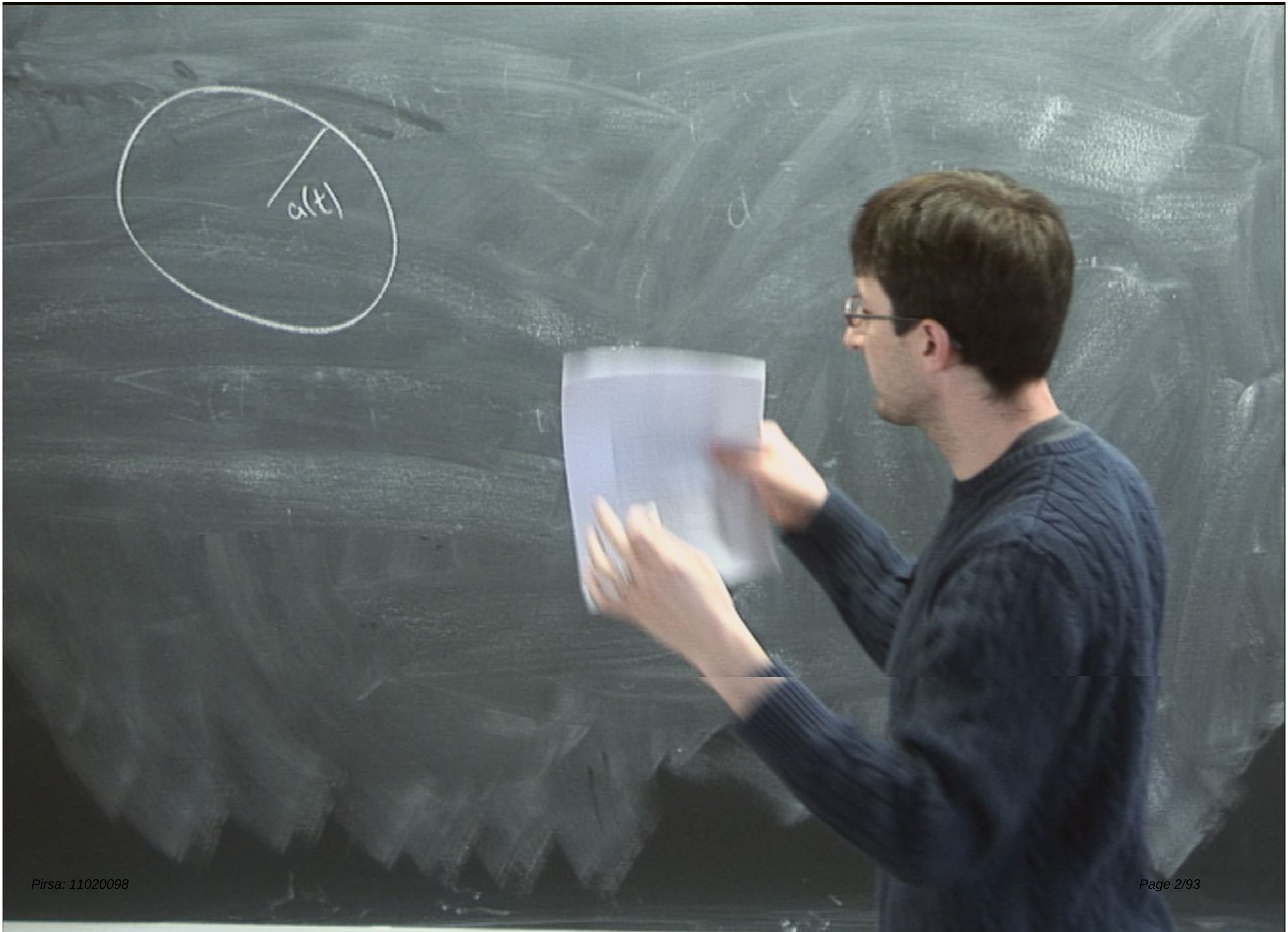
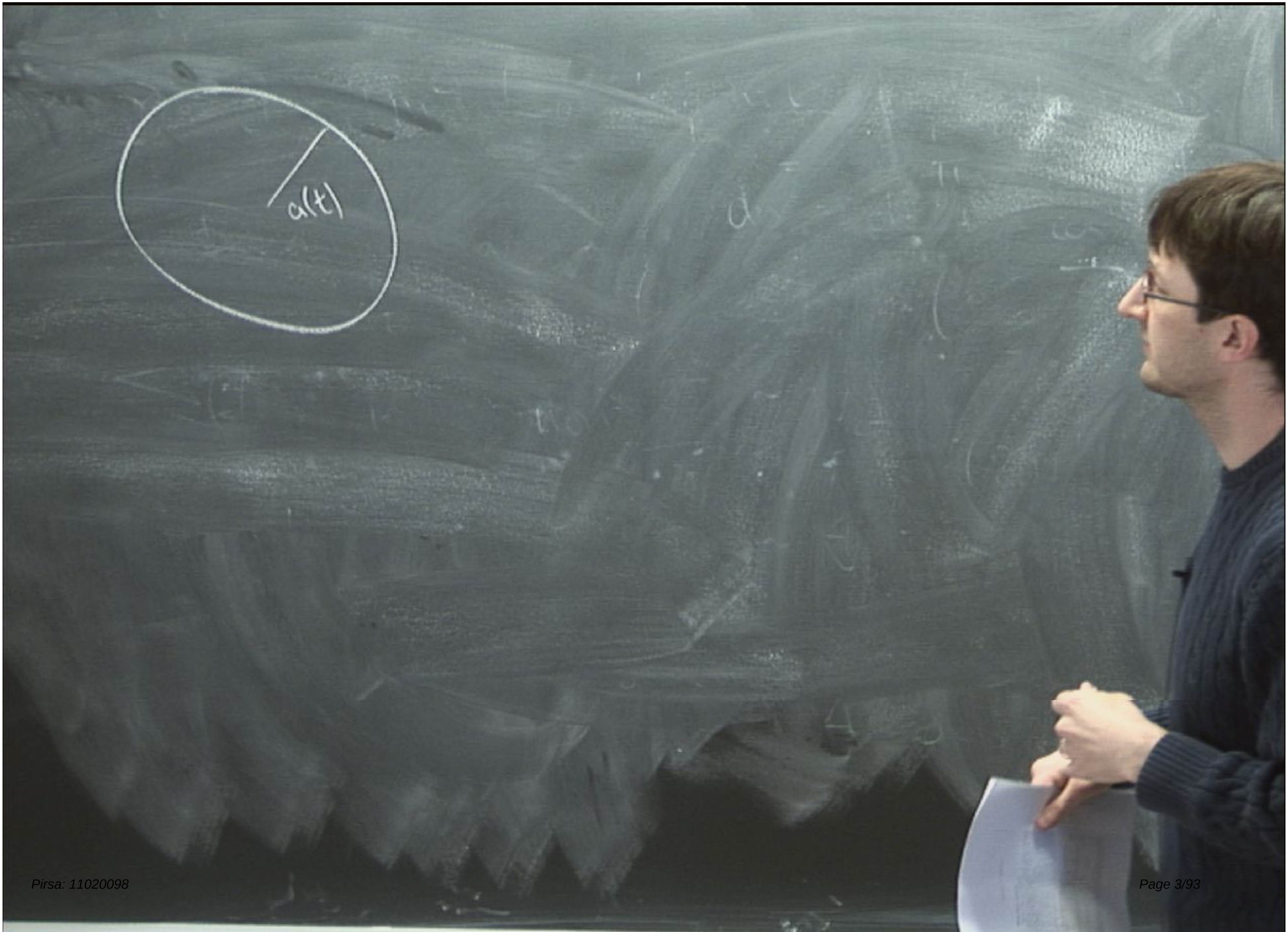
Title: Cosmology Review - Lecture 15

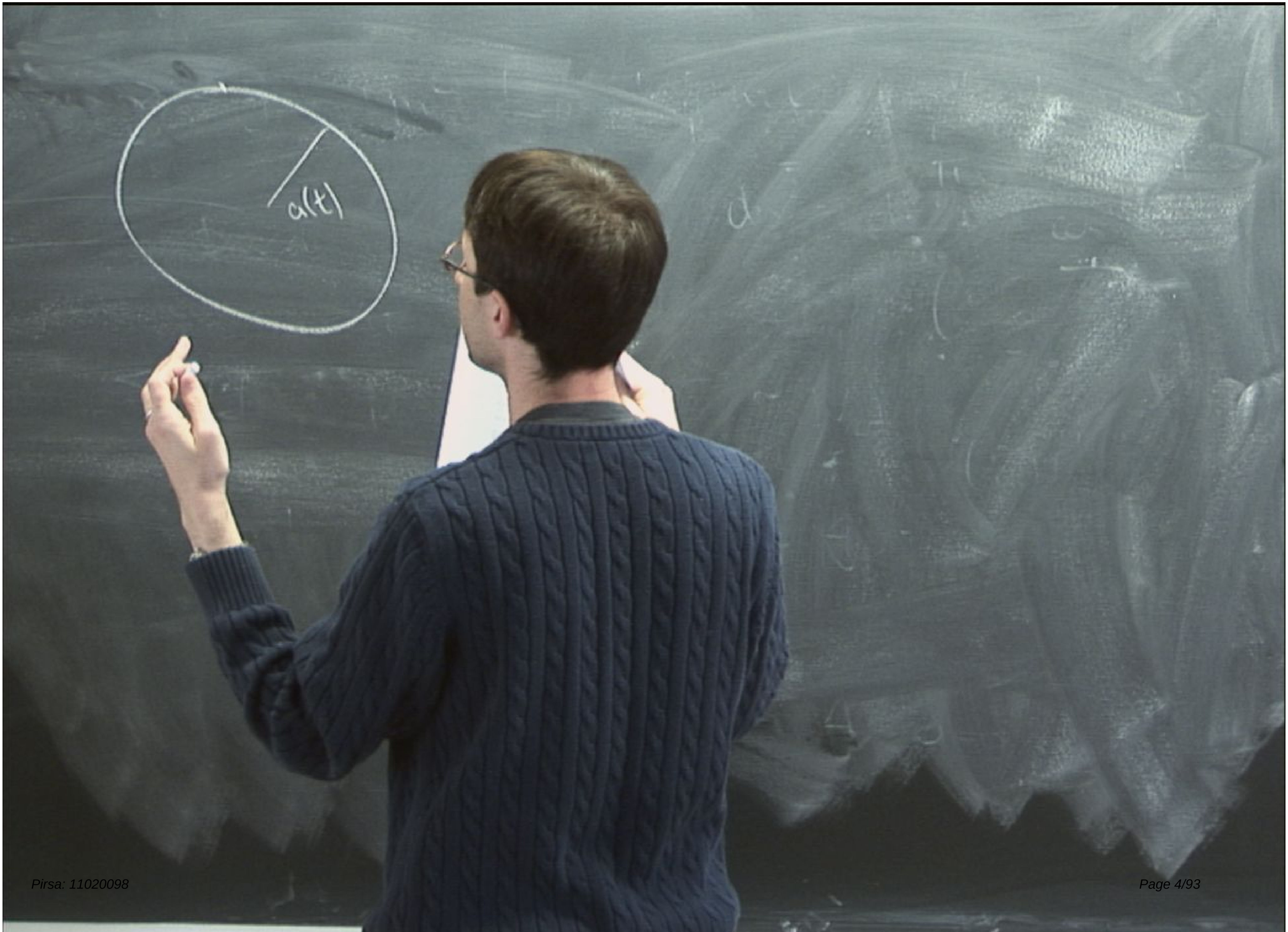
Date: Feb 11, 2011 11:30 AM

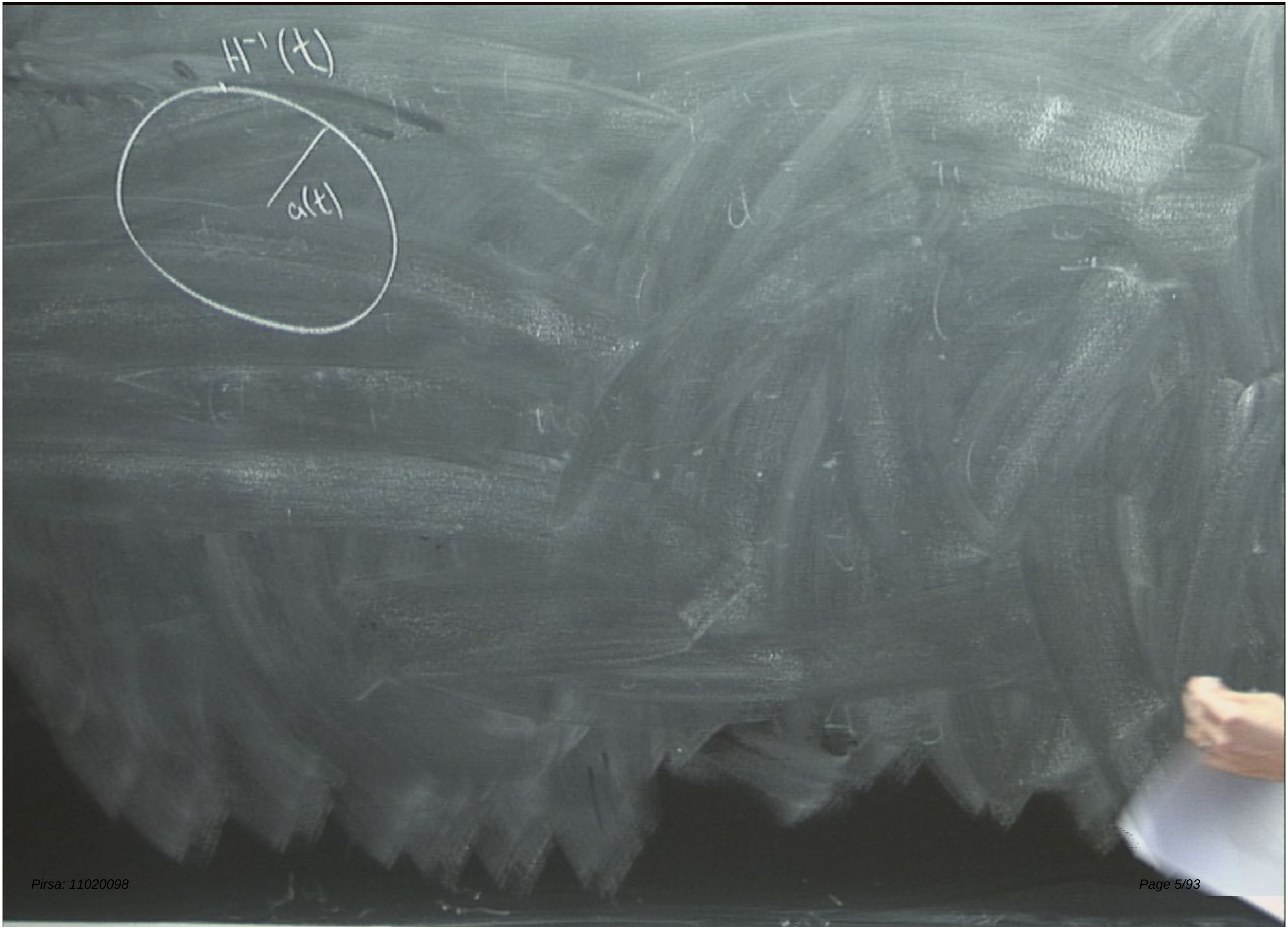
URL: http://pirsa.org/11020098

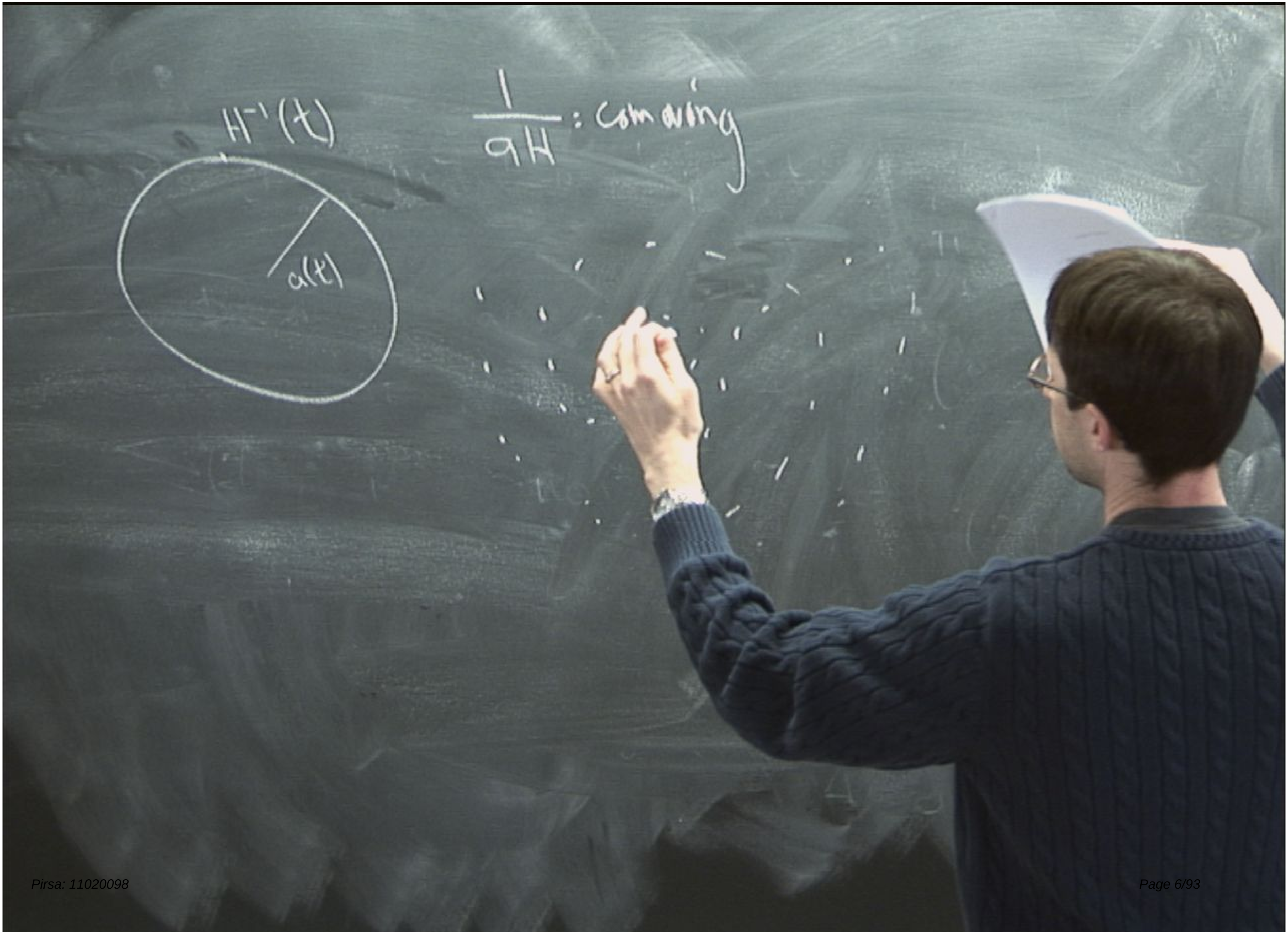
Abstract:

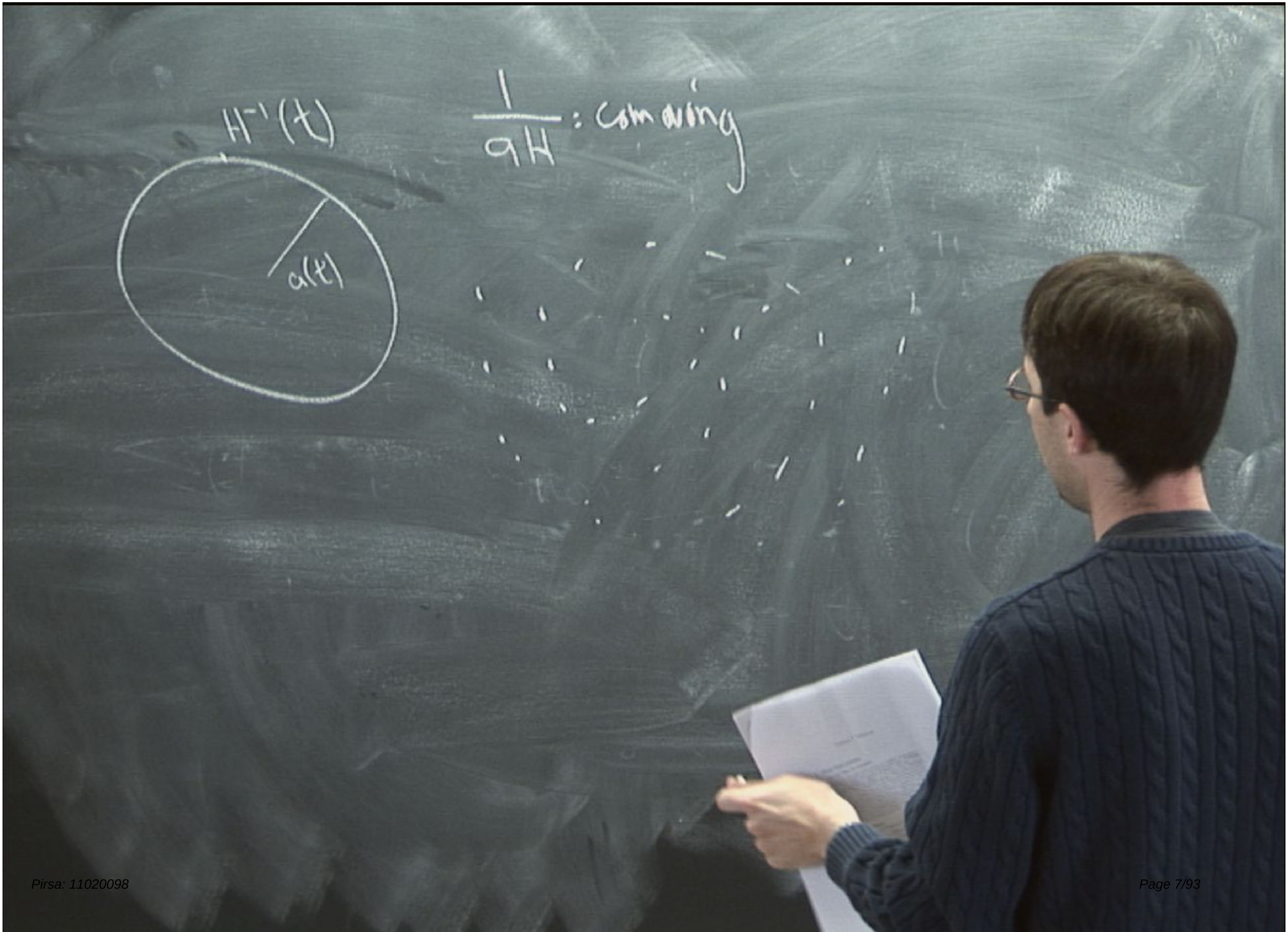

a(t)

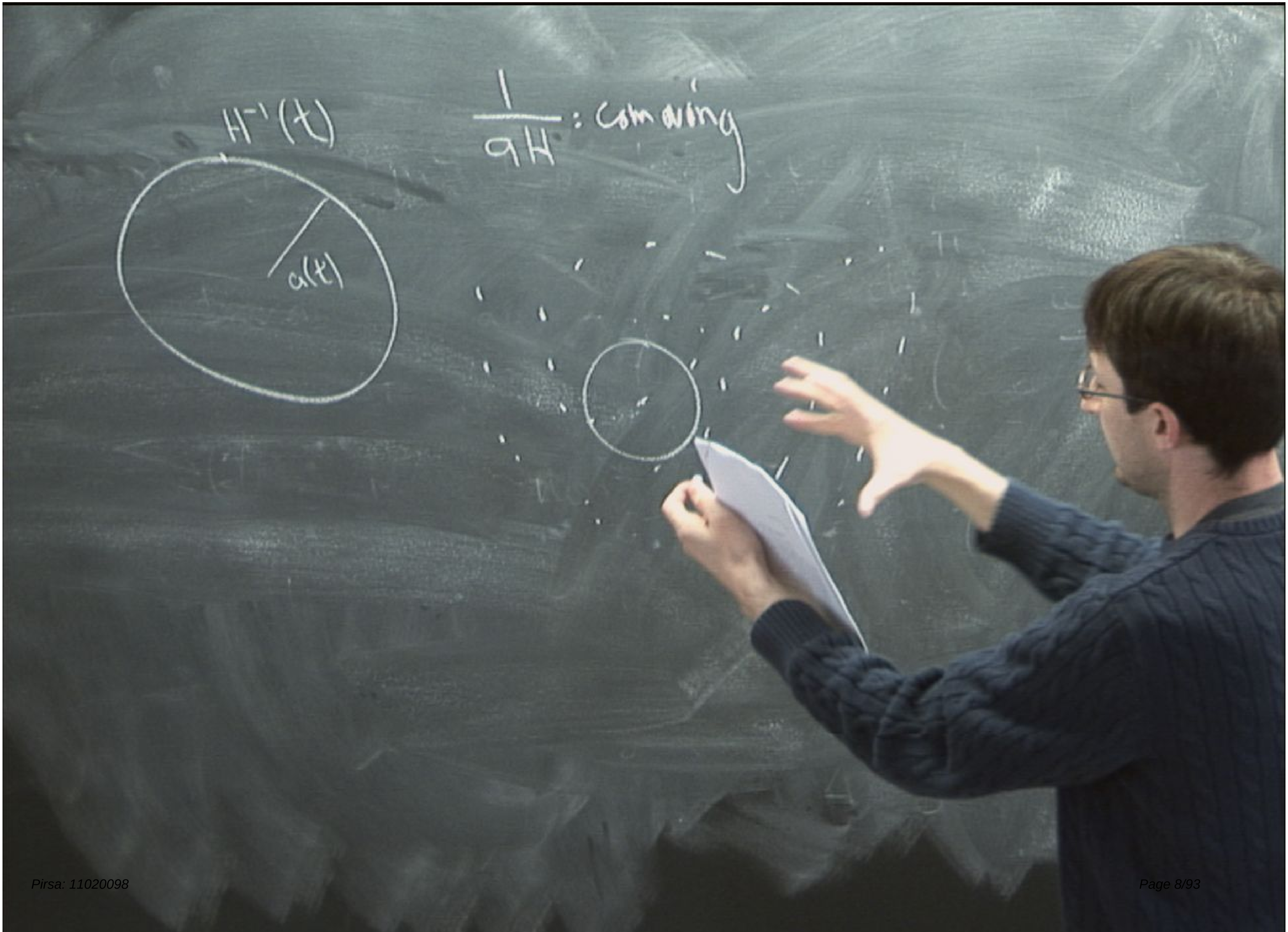

a(t)

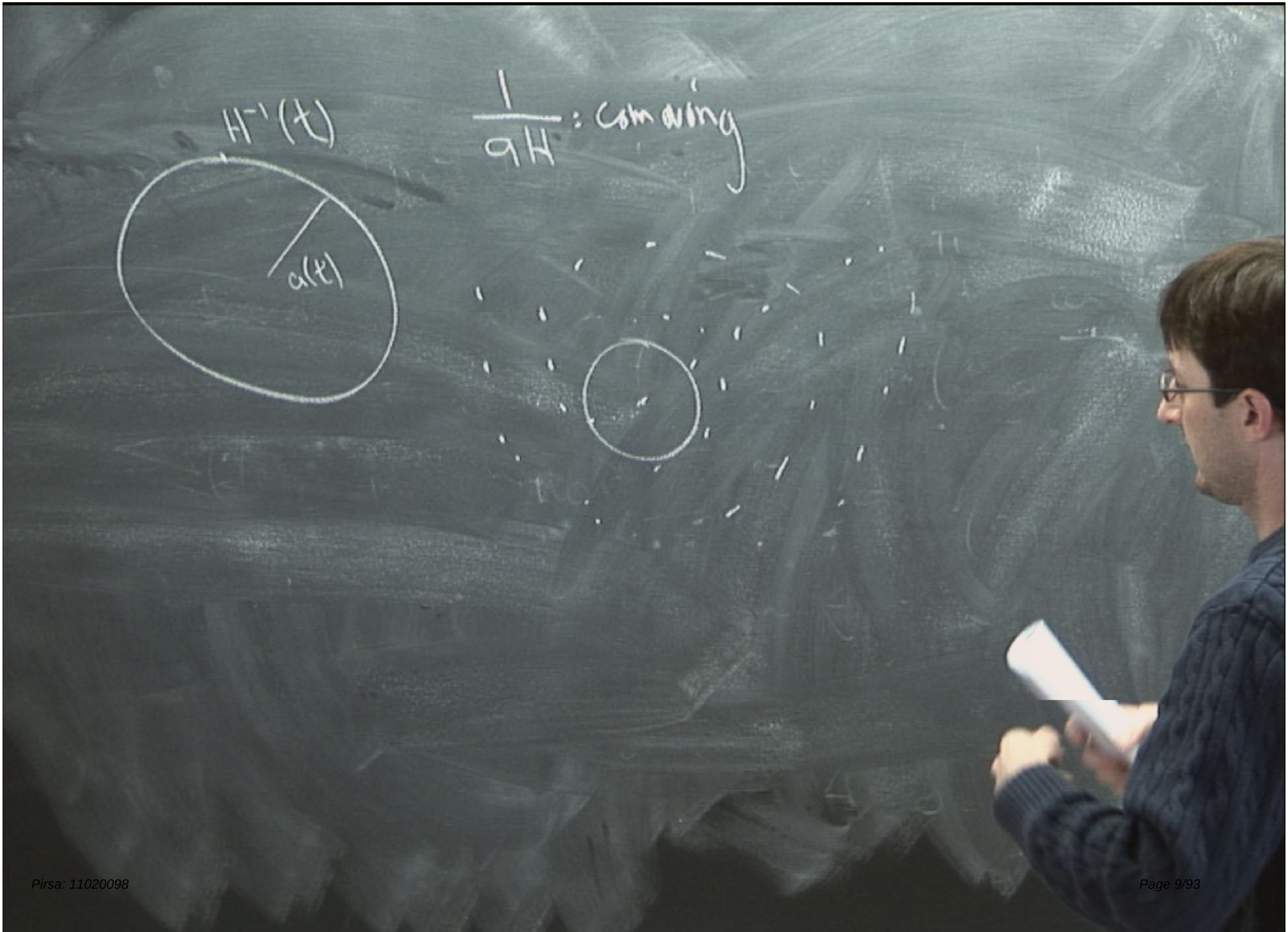

a(t)

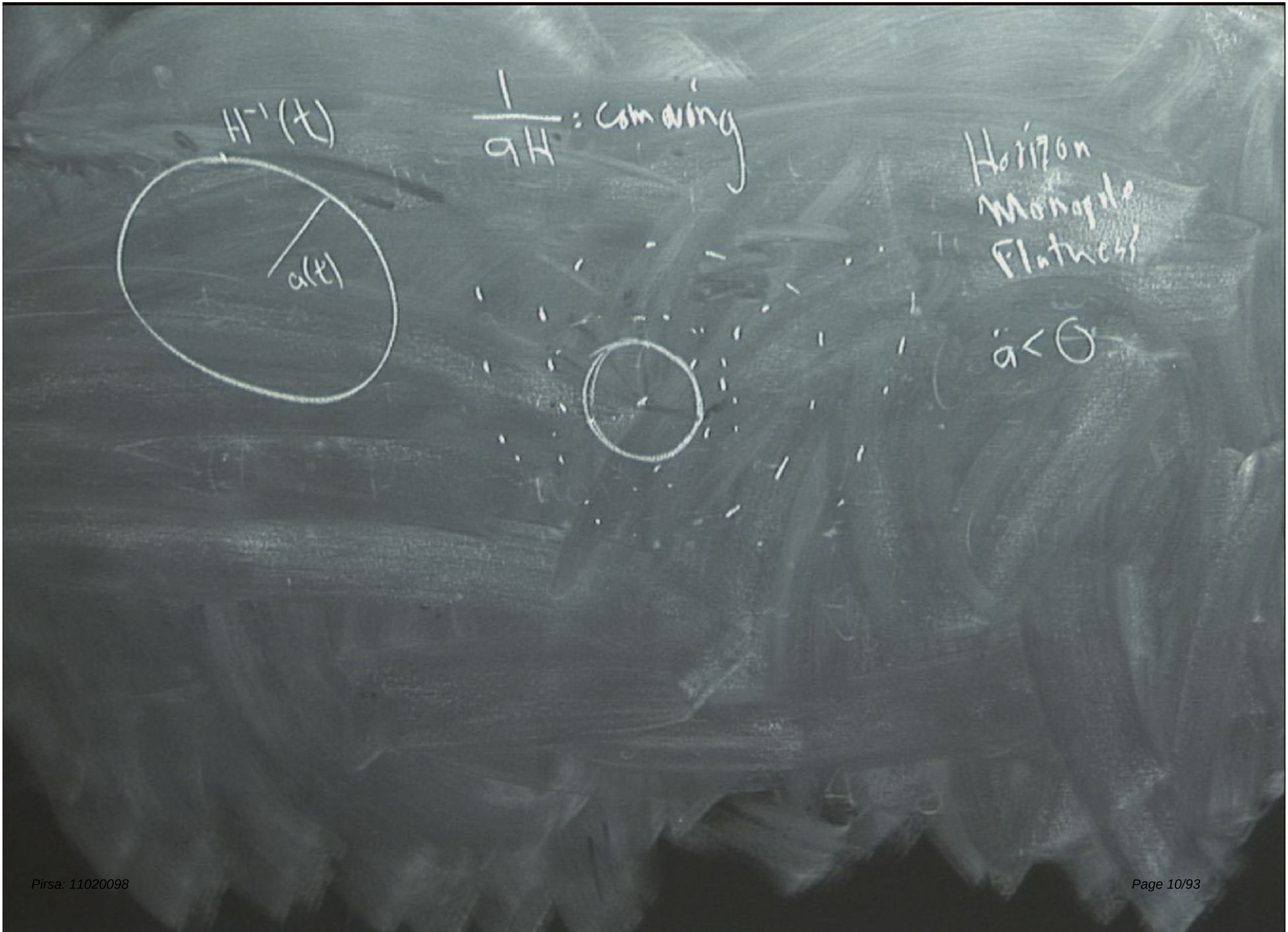

H⁻¹(t)
a(t)


$H^{-1}(t)$
$\frac{1}{aH}$: comoving
$a(t)$

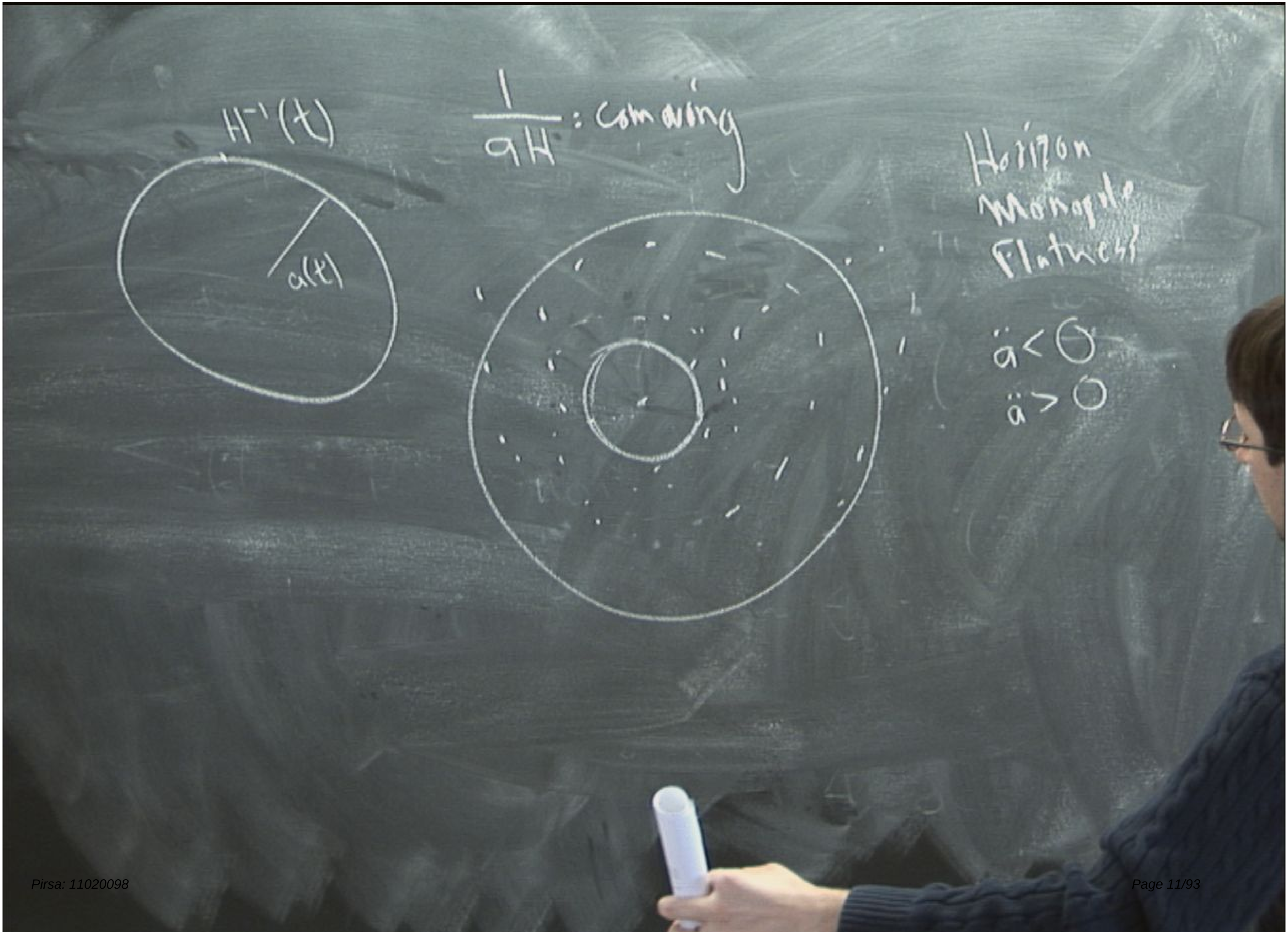

$H^{-1}(t)$
$a(t)$
$\frac{1}{aH}$: comoving

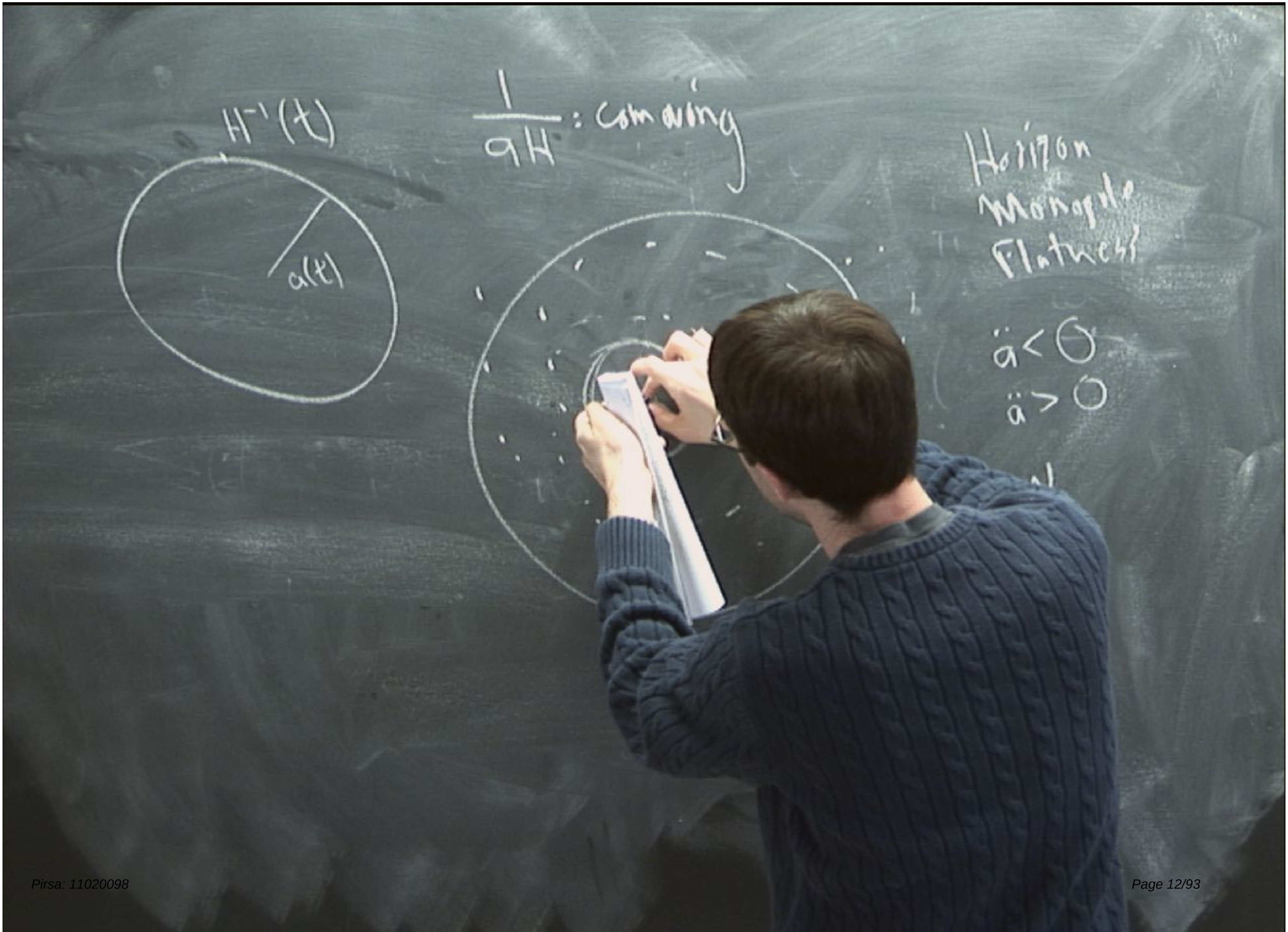

$H^{-1}(t)$
$a(t)$
$\frac{1}{aH}$: comoving

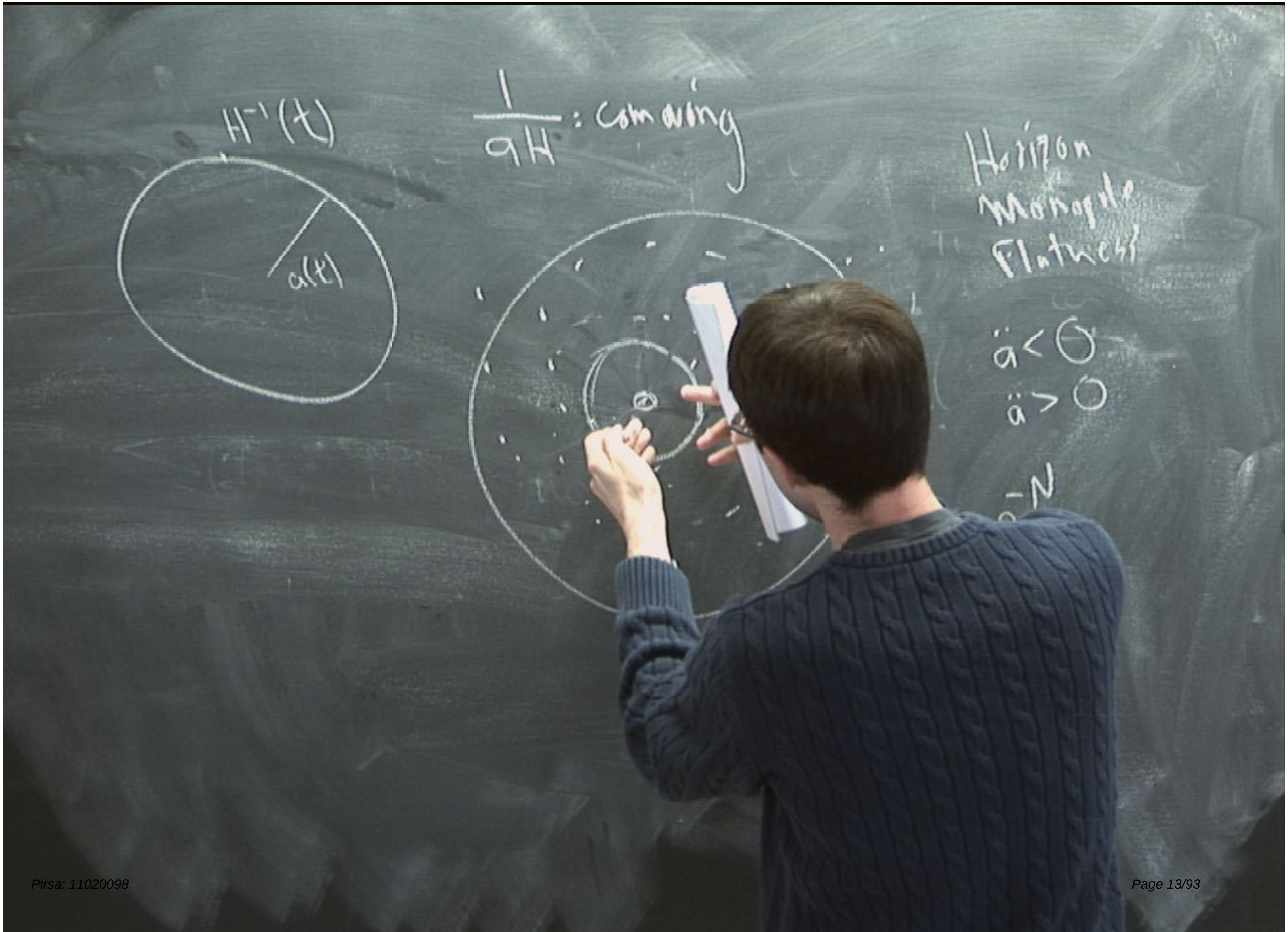

H⁻¹(t)
a(t)
1/aH : comoving



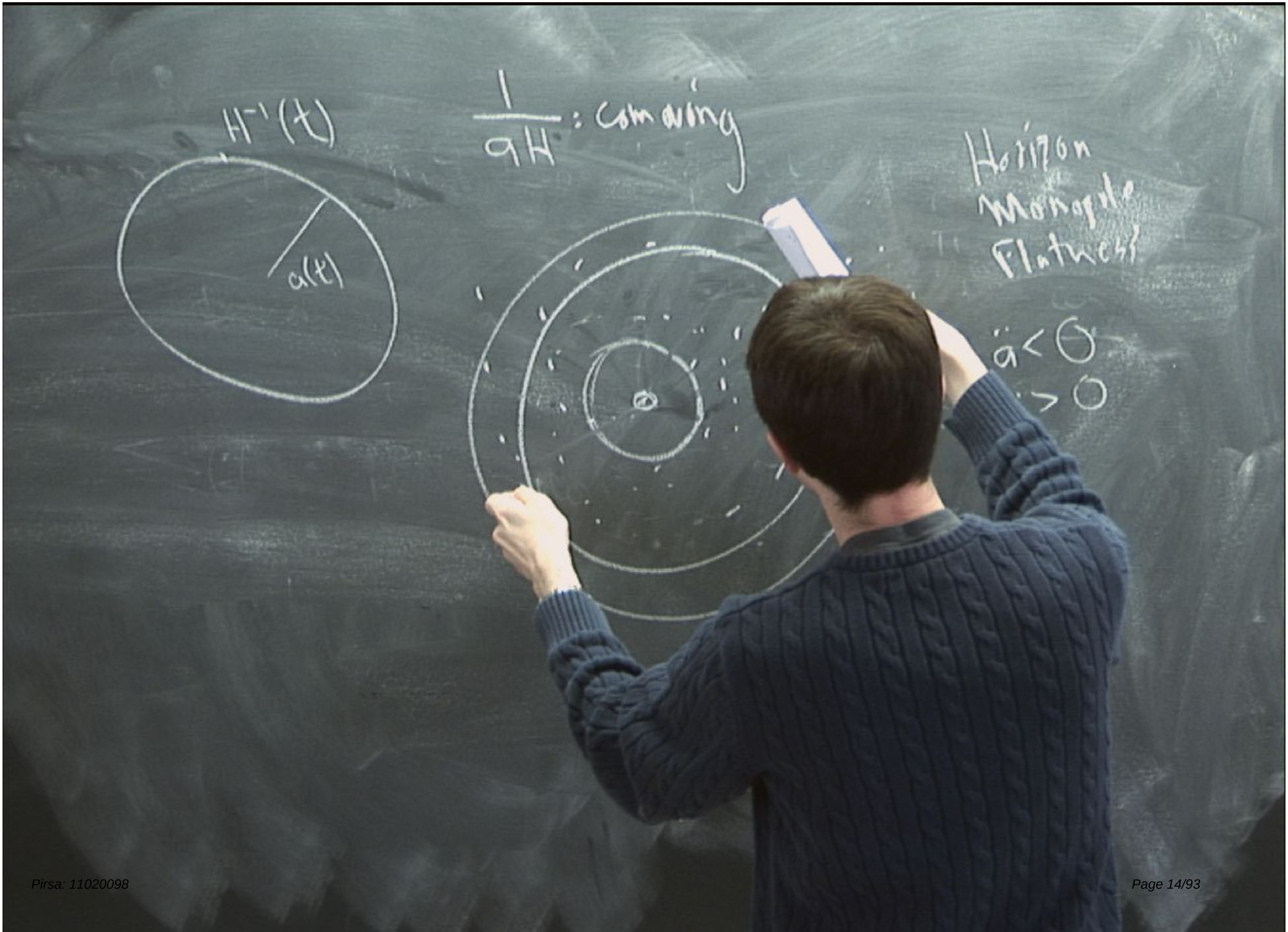
$H^{-1}(t)$
$\frac{1}{aH}$: comoving
$a(t)$
Horizon
Monopole
Flatness
$\ddot{a} < 0$

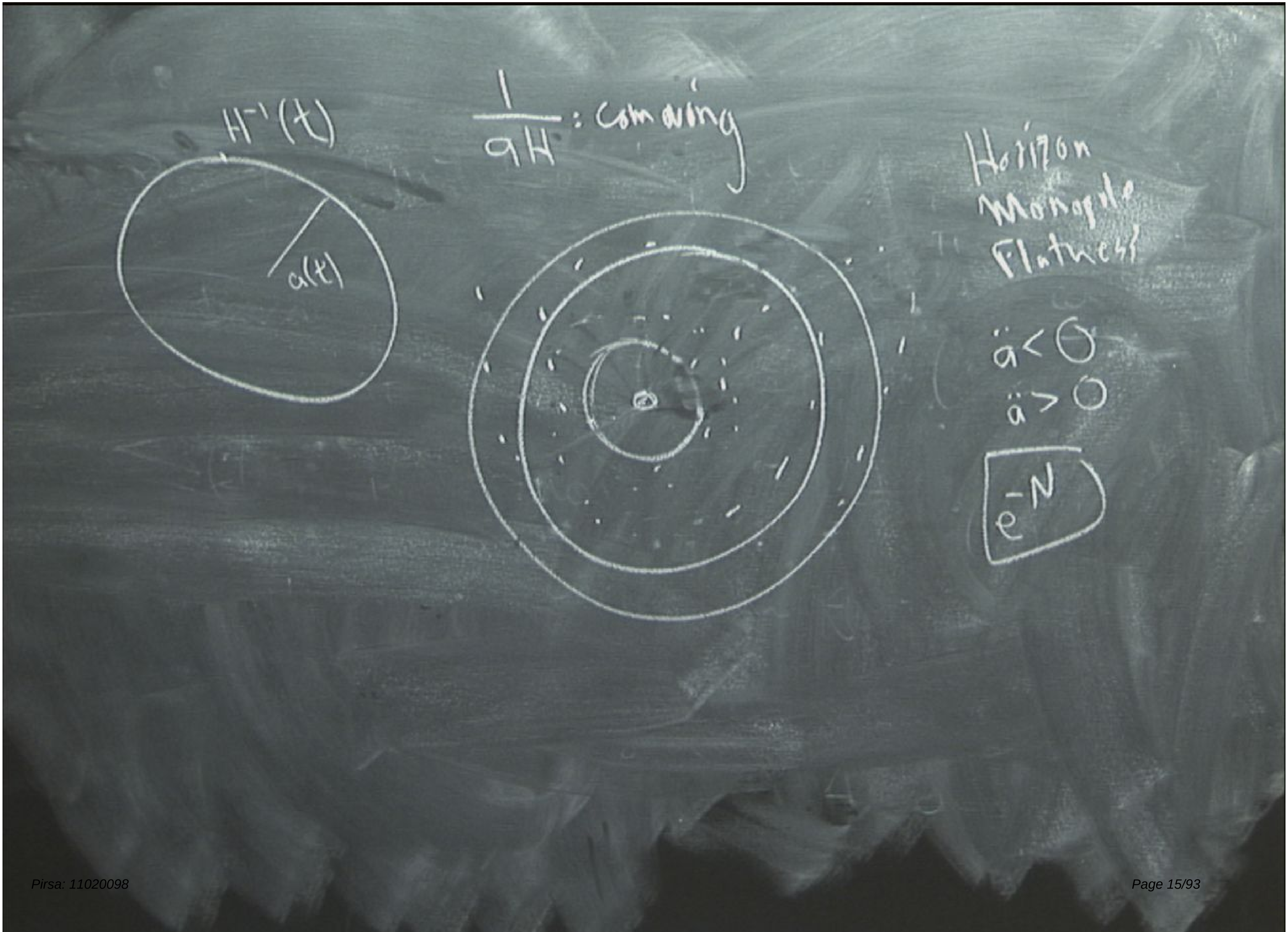

H^-1(t)
a(t)
1/aH : comoving
Horizon
Monopole
Flatness
ä < 0
ä > 0


H⁻¹(t)
a(t)
1/aH : comoving
Horizon
Monopole
Flatness
ä < 0
ä > 0

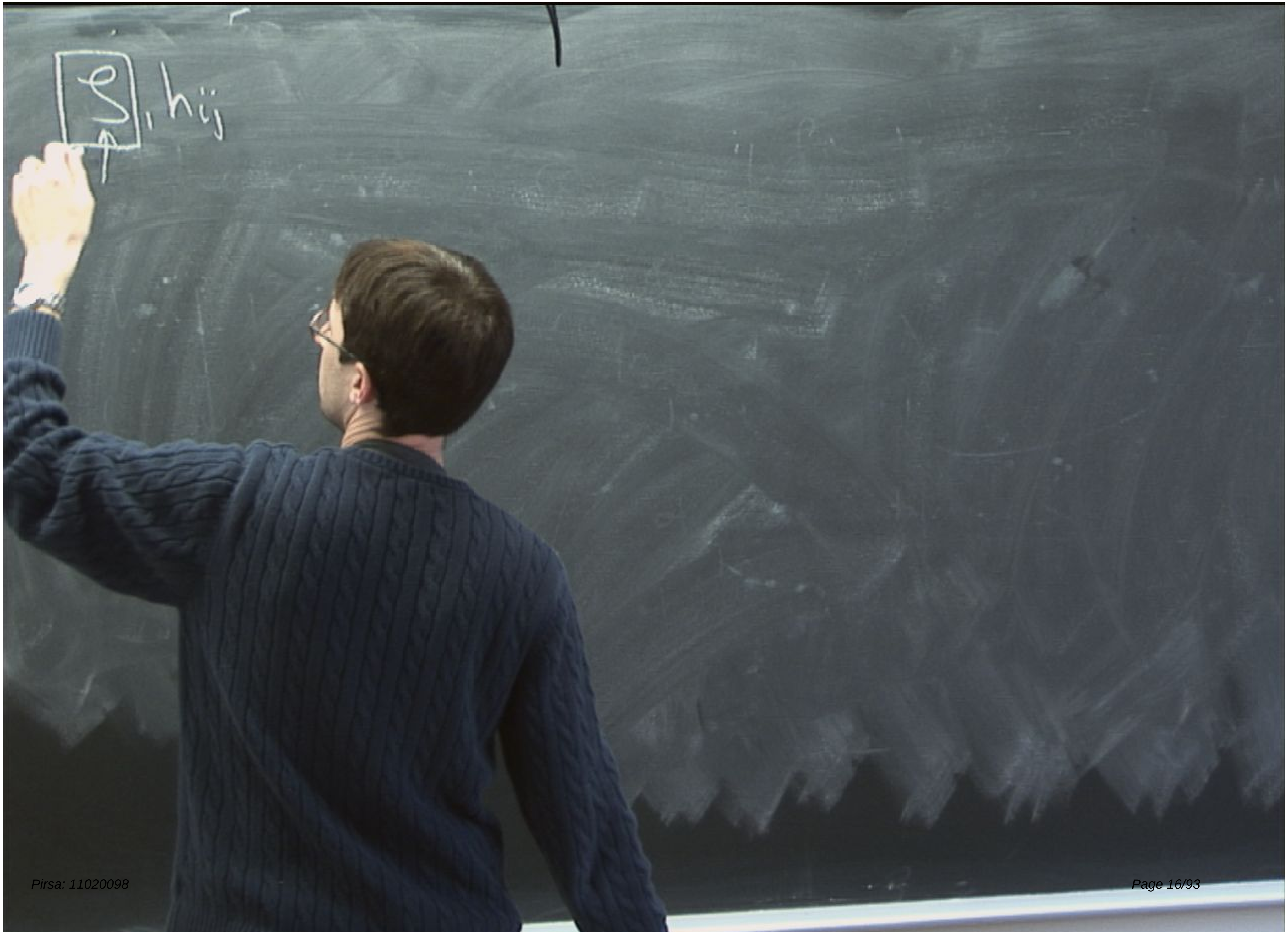


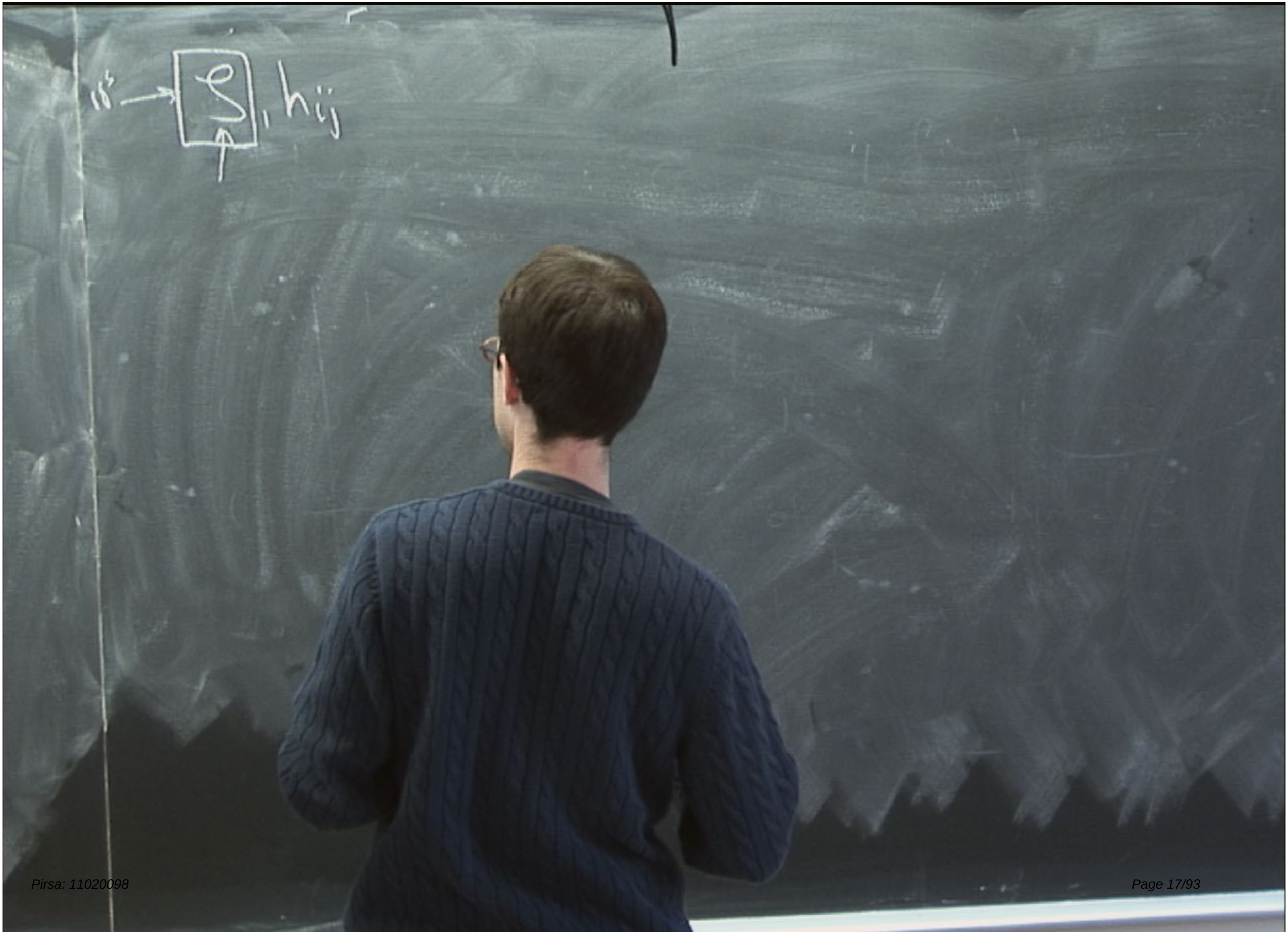
H⁻¹(t)
a(t)
1/aH : comoving
Horizon
Monopole
Flatness
ä < 0
ä > 0
-N


H⁻¹(t)
a(t)
1/aH : comoving
Horizon
Monopole
Flatness
ä < 0
> 0

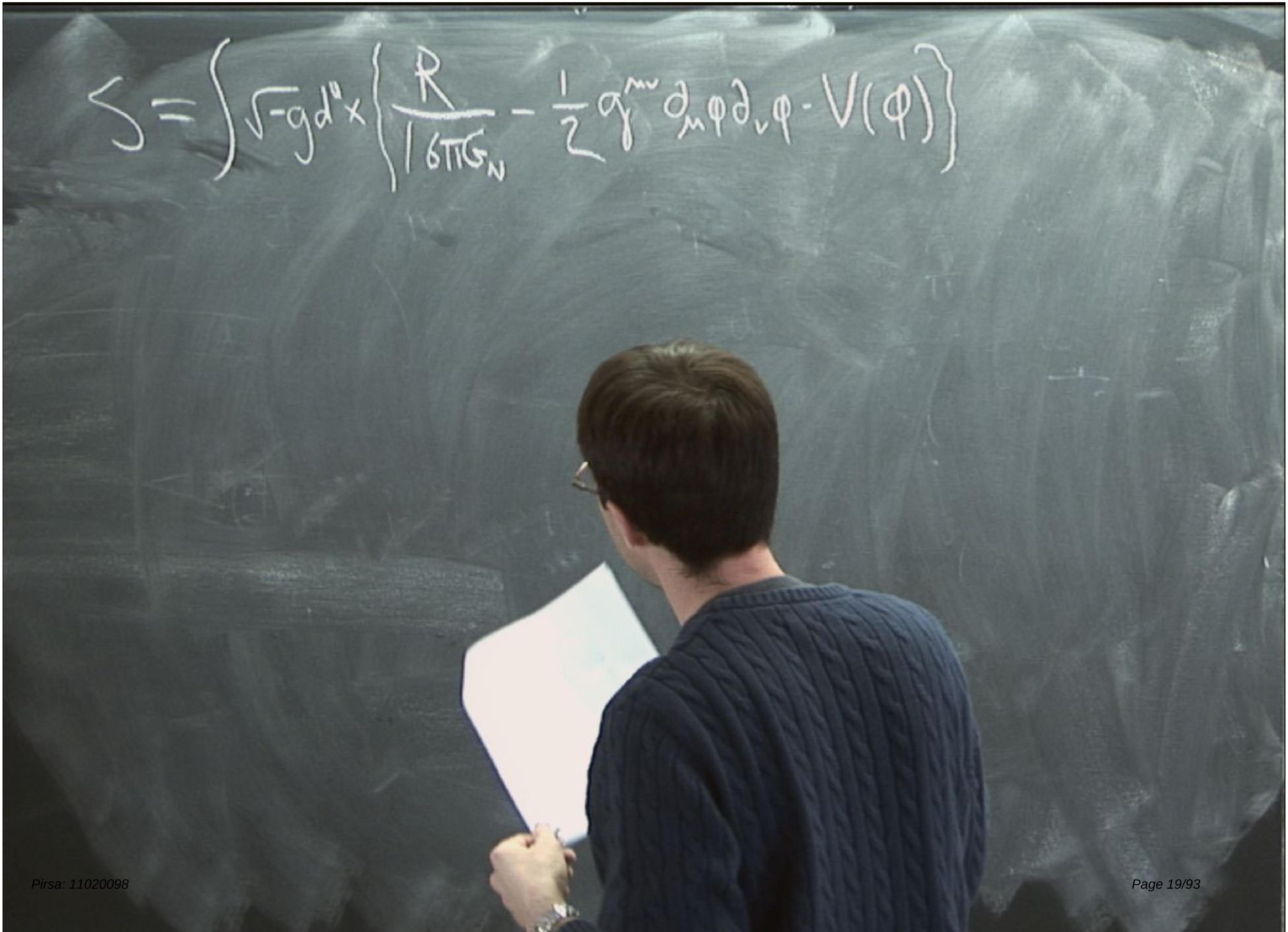


$H^{-1}(t)$
$a(t)$
$\frac{1}{aH}$: comoving
Horizon
Monopole
Flatness
$\ddot{a} < 0$
$\ddot{a} > 0$
e^{-N}


$\boxed{\rho}, h_{ij}$


hij

$10^5 \to \boxed{S}, \boxed{\ddot{h}_{ij}}$


$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V(\varphi) \right\}$

$$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V(\varphi) \right\}$$

$$\varphi = \hat{\varphi}(t) + \delta\varphi(t, \vec{x})$$

$$ds^2 = -N^2 dt^2 + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$$

$$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V(\varphi) \right\}$$

$$\varphi = \hat{\varphi}(t) + \delta \cancel{\hat{\varphi}}\overset{\circ}{\varphi}(t, \vec{x})$$

$$ds^2 = -N^2 dt^2 + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$$

$$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V(\varphi) \right\}$$

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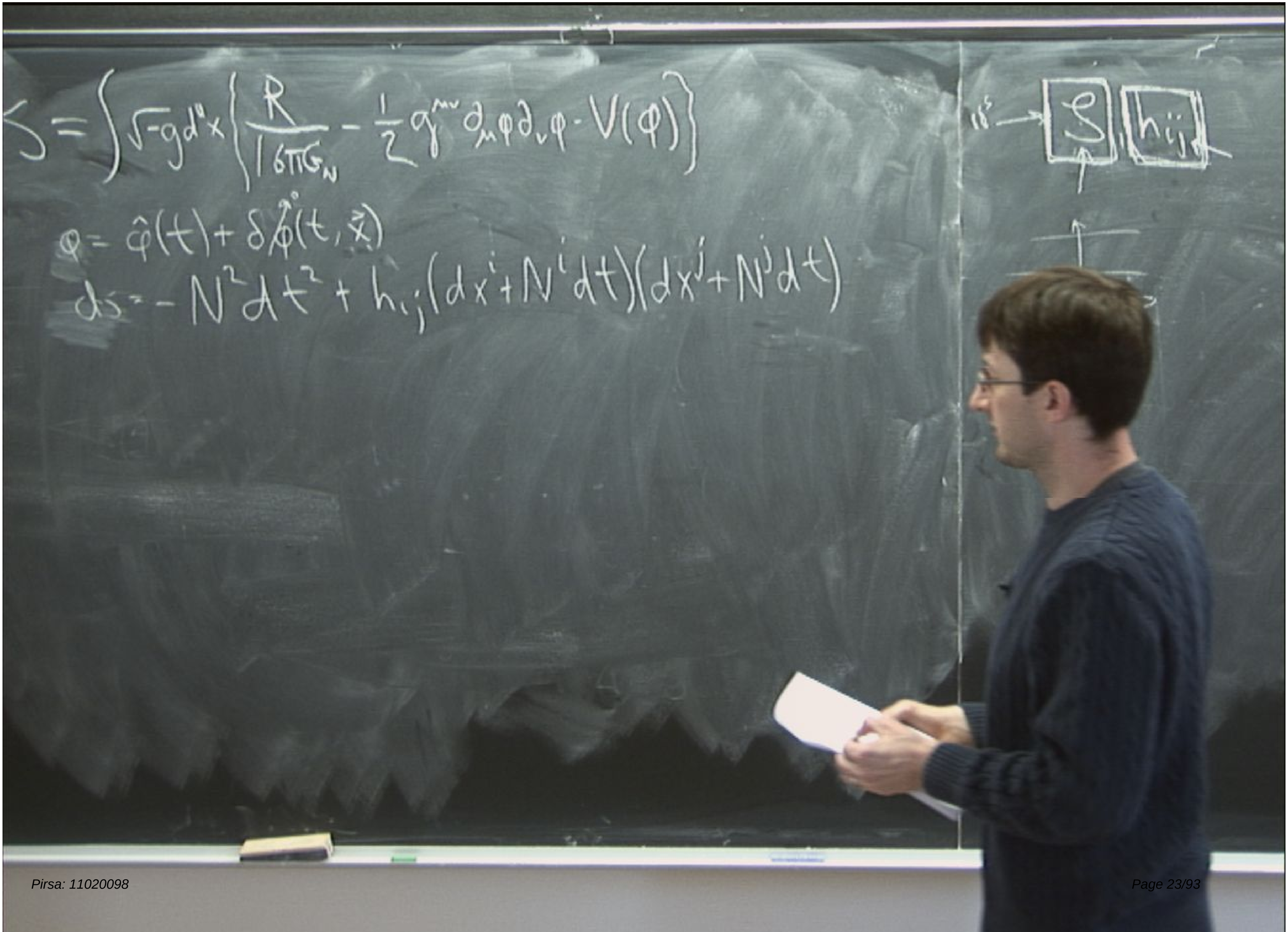
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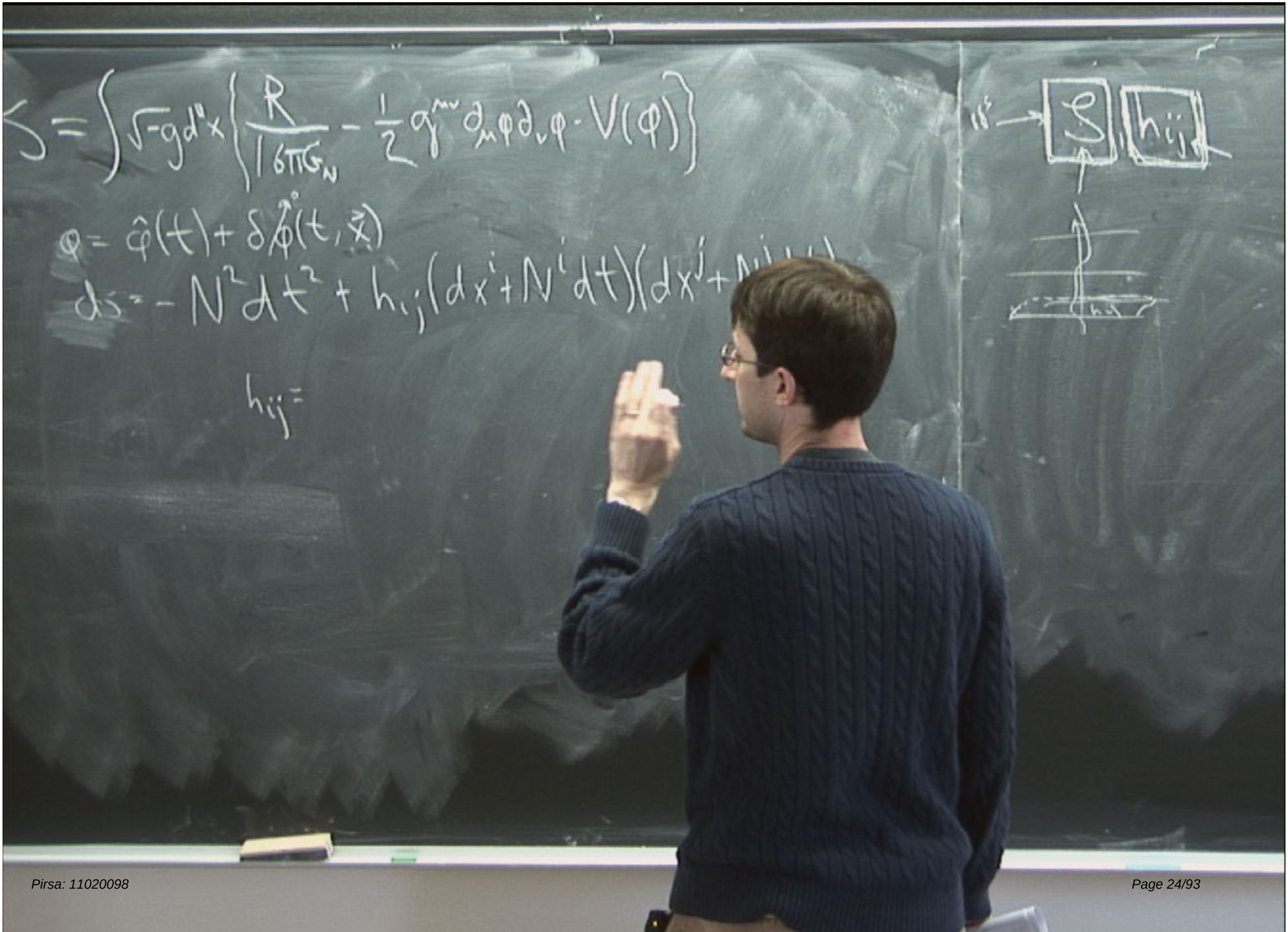
$\varphi = \hat{\varphi}(t) + \delta\varphi(t, \vec{x})$
$ds^2 = -N^2 dt^2 + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$
$\boxed{\zeta}, \boxed{h_{ij}}$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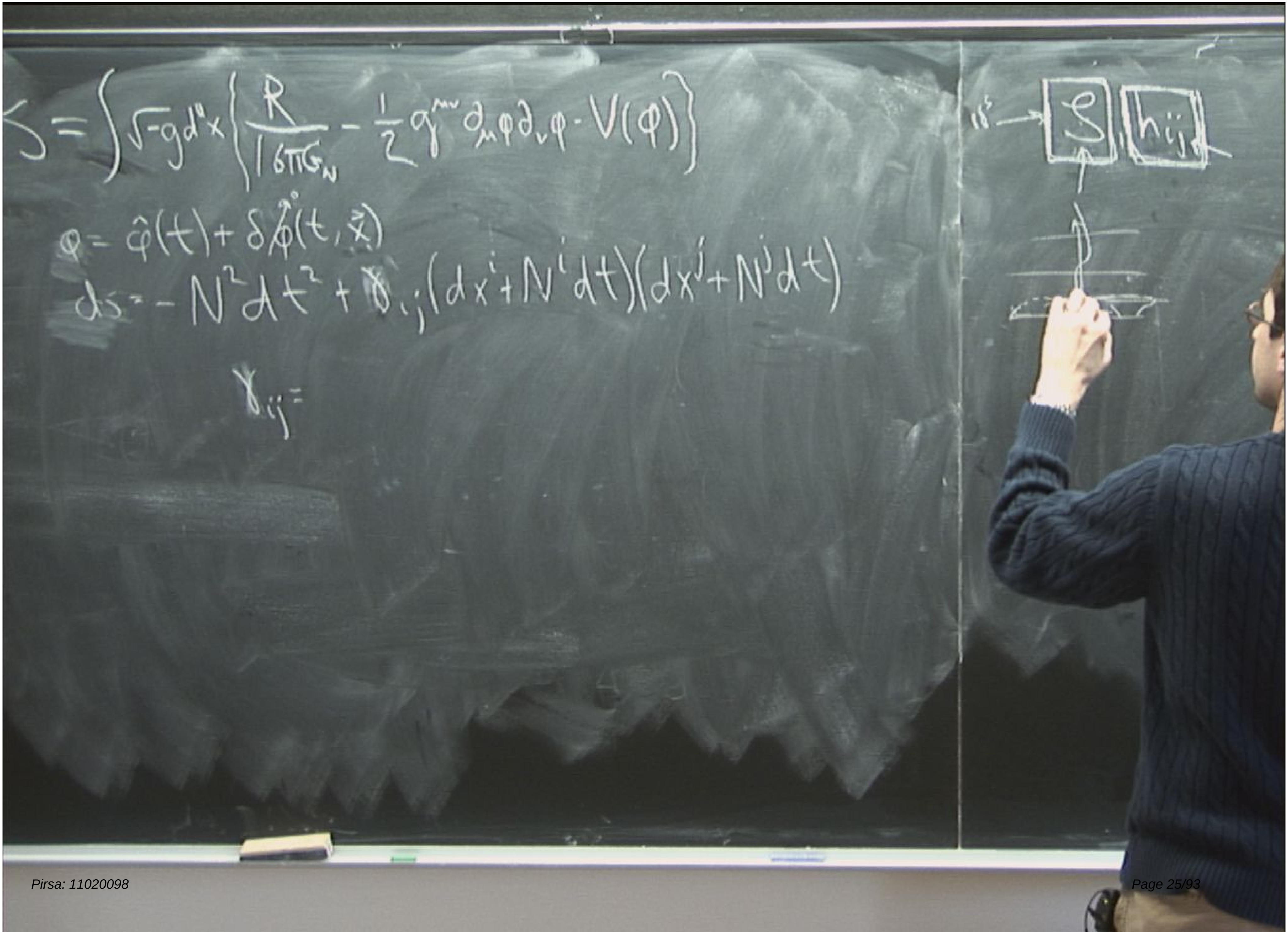
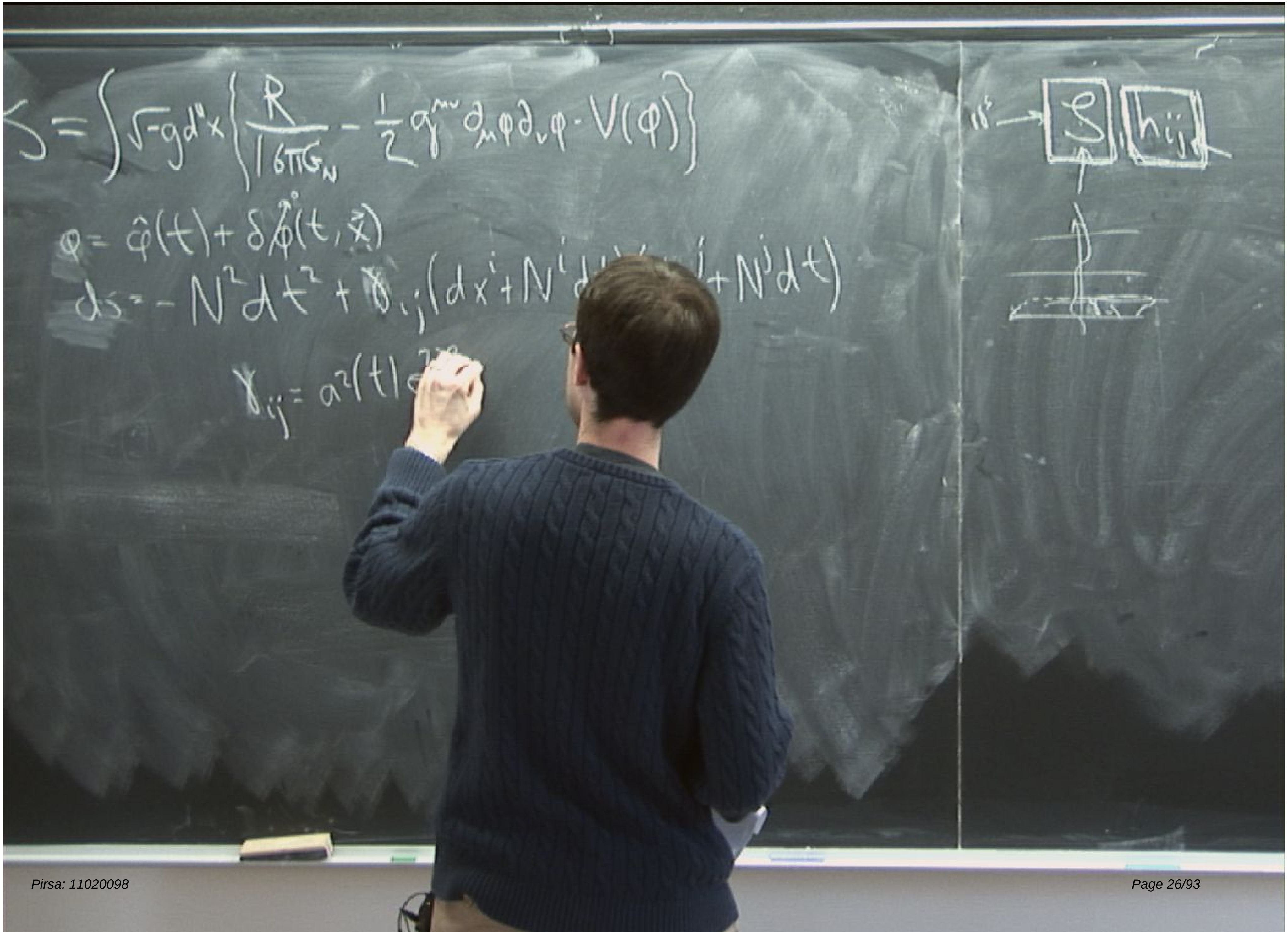
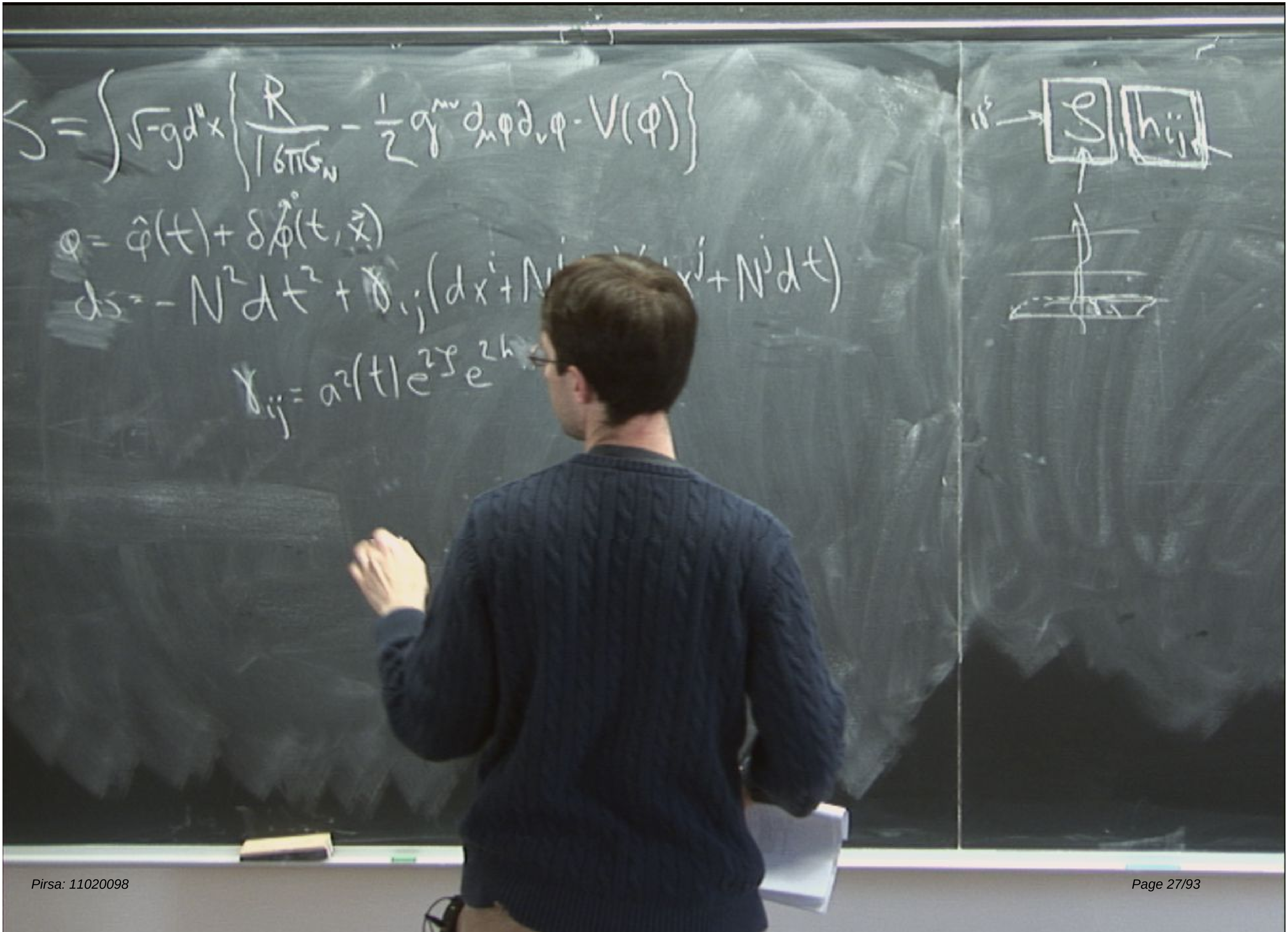
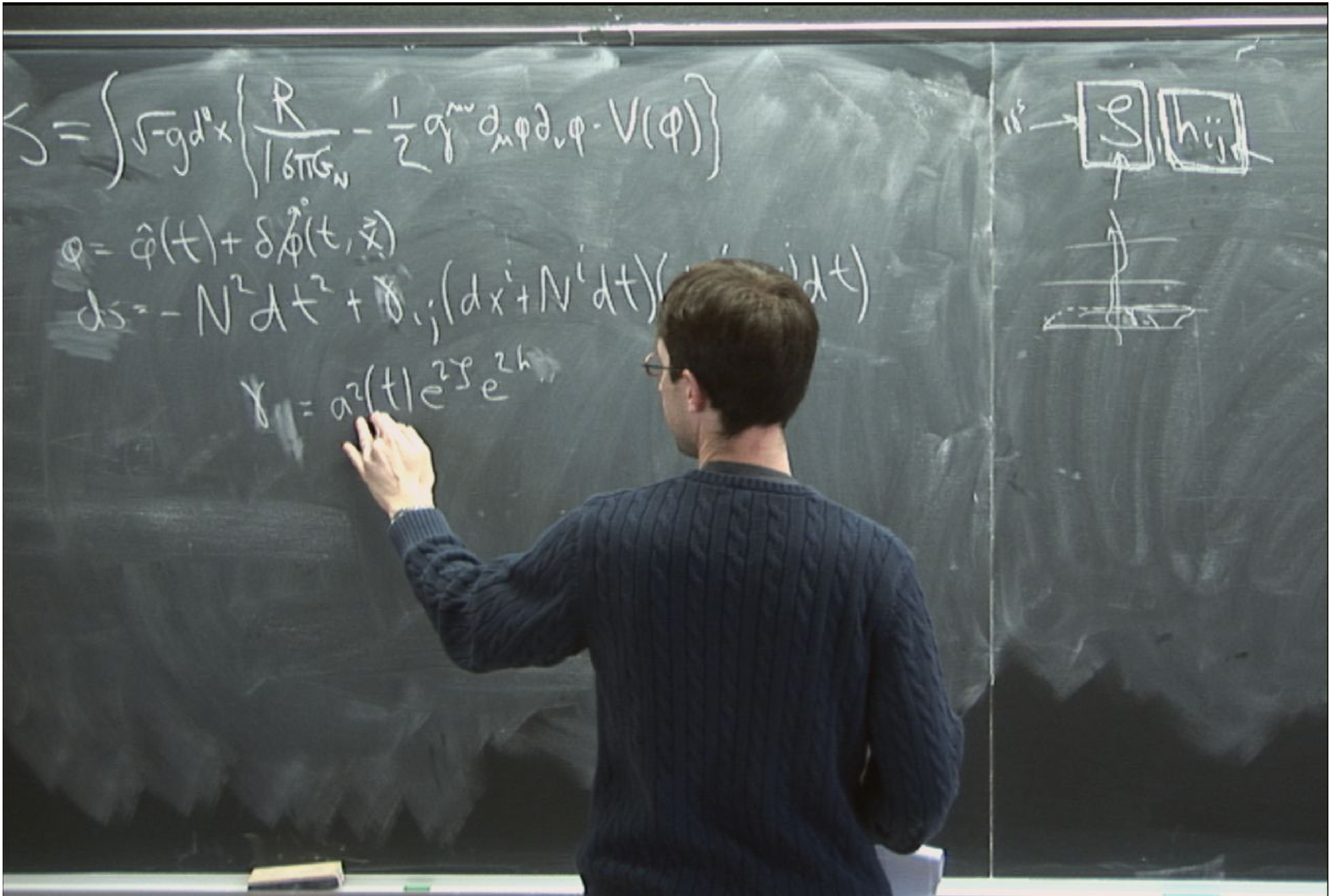
$\varphi = \hat{\varphi}(t) + \delta\varphi(t, \vec{x})$
$ds^2 = -N^2 dt^2 + h_{ij}(dx^i + N^i dt)(dx^j +$
$h_{ij} =$
$\boxed{\zeta}, \boxed{h_{ij}}$

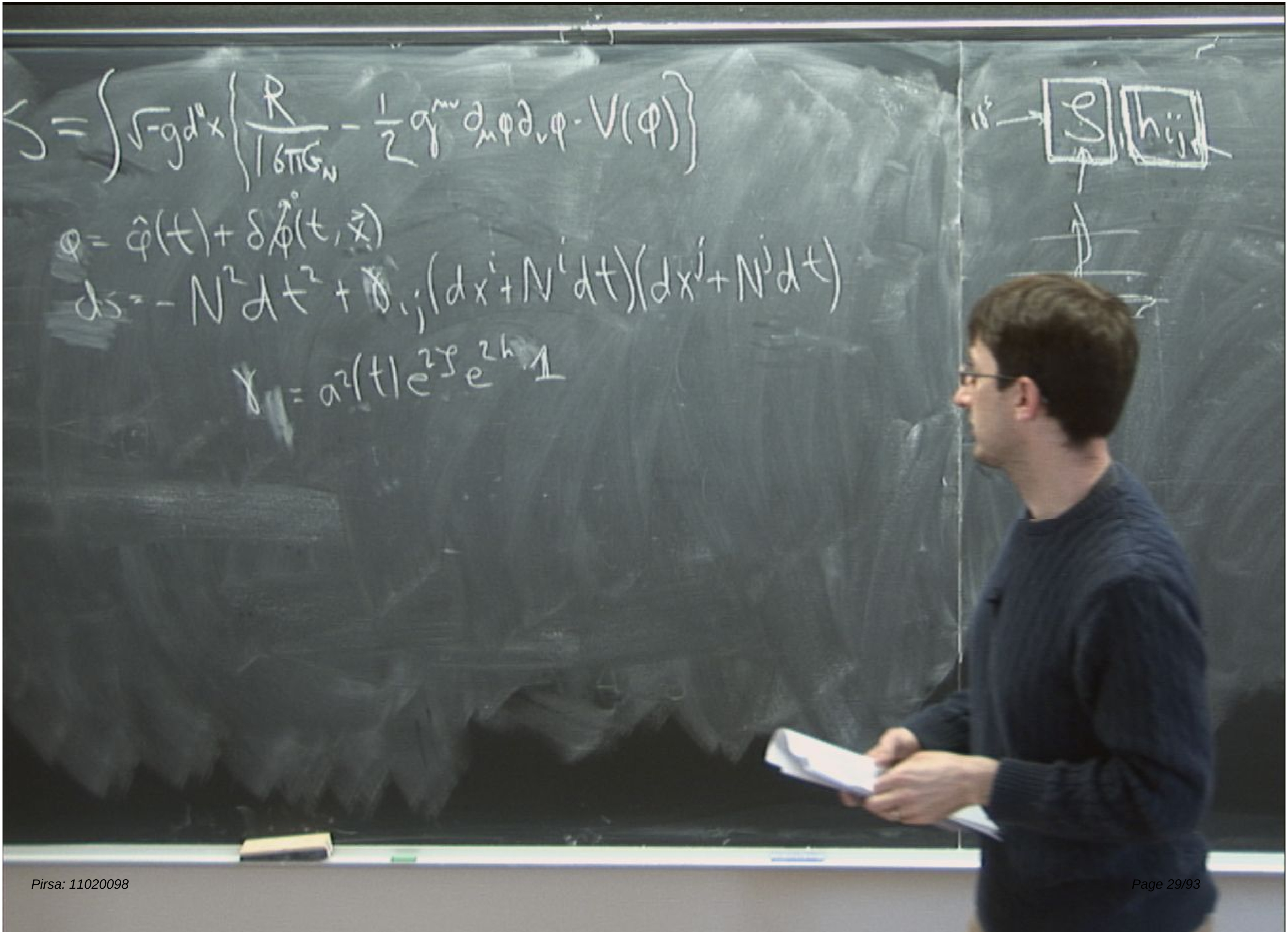

$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V(\varphi) \right\}$
$\varphi = \hat{\varphi}(t) + \delta\varphi(t, \vec{x})$
$ds^2 = -N^2 dt^2 + \gamma_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$
$\gamma_{ij} =$
$\boxed{\zeta}, \boxed{h_{ij}}$



$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V(\varphi) \right\}$
$\varphi = \hat{\varphi}(t) + \delta\varphi(t, \vec{x})$
$ds^2 = -N^2 dt^2 + \gamma_{ij}(dx^i + N^i d$
$+ N^j dt)$
$\gamma_{ij} = a^2(t)$
ζ
h_{ij}


$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu\phi \partial_\nu\phi - V(\phi) \right\}$
$\phi = \hat{\phi}(t) + \delta\phi(t, \vec{x})$
$ds^2 = -N^2 dt^2 + \gamma_{ij}(dx^i + N^i$
$x^j + N^j dt)$
$\gamma_{ij} = a^2(t) e^{2\zeta} e^{2h}$
$\boxed{\zeta}, \boxed{h_{ij}}$


S = ∫ √-g d⁴x { R/16πG_N − ½ g^{μν} ∂_μφ ∂_νφ − V(φ) }
φ = φ̂(t) + δφ(t, x⃗)
ds² = − N² dt² + γ_ij (dx^i + N^i dt)(dx^j + N^j dt)
γ_ij = a²(t) e^{2ζ} e^{2h}
ζ, h_ij



$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$
$\phi = \hat{\phi}(t) + \delta\phi(t, \vec{x})$
$ds^2 = -N^2 dt^2 + \gamma_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$
$\gamma_{ij} = a^2(t) e^{2\zeta} e^{2h} \mathbb{1}$
$\boxed{\zeta}, \boxed{h_{ij}}$

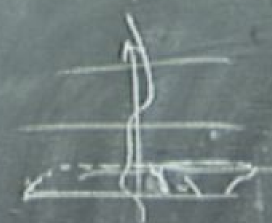
$$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V(\varphi) \right\}$$

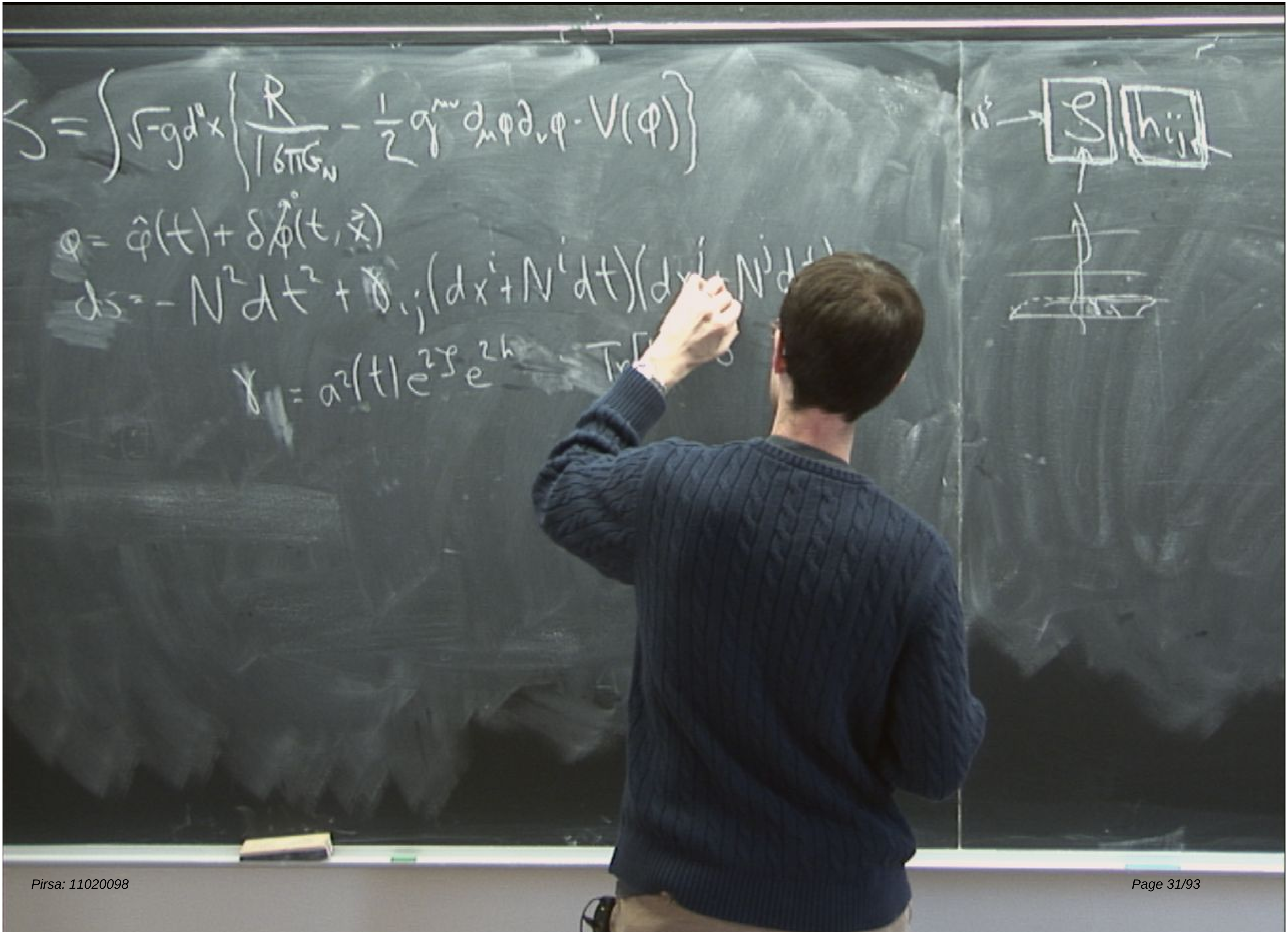
$$\varphi = \hat{\varphi}(t) + \delta\varphi(t, \vec{x})$$

$$ds^2 = -N^2 dt^2 + \gamma_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$$

$$\gamma_{ij} = a^2(t) e^{2\zeta} e^{2h}$$

$$\rightarrow \boxed{\zeta},\ \boxed{h_{ij}}$$





$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V(\varphi) \right\}$
$\varphi = \hat{\varphi}(t) + \delta\varphi(t, \vec{x})$
$ds^2 = -N^2 dt^2 + \gamma_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$
$\gamma_{ij} = a^2(t) e^{2\zeta} e^{2h}$
ζ
h_{ij}

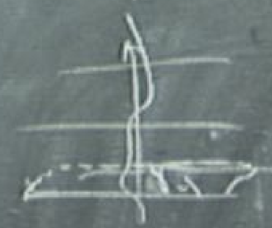
$$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu}\partial_\mu\phi\,\partial_\nu\phi - V(\phi) \right\}$$

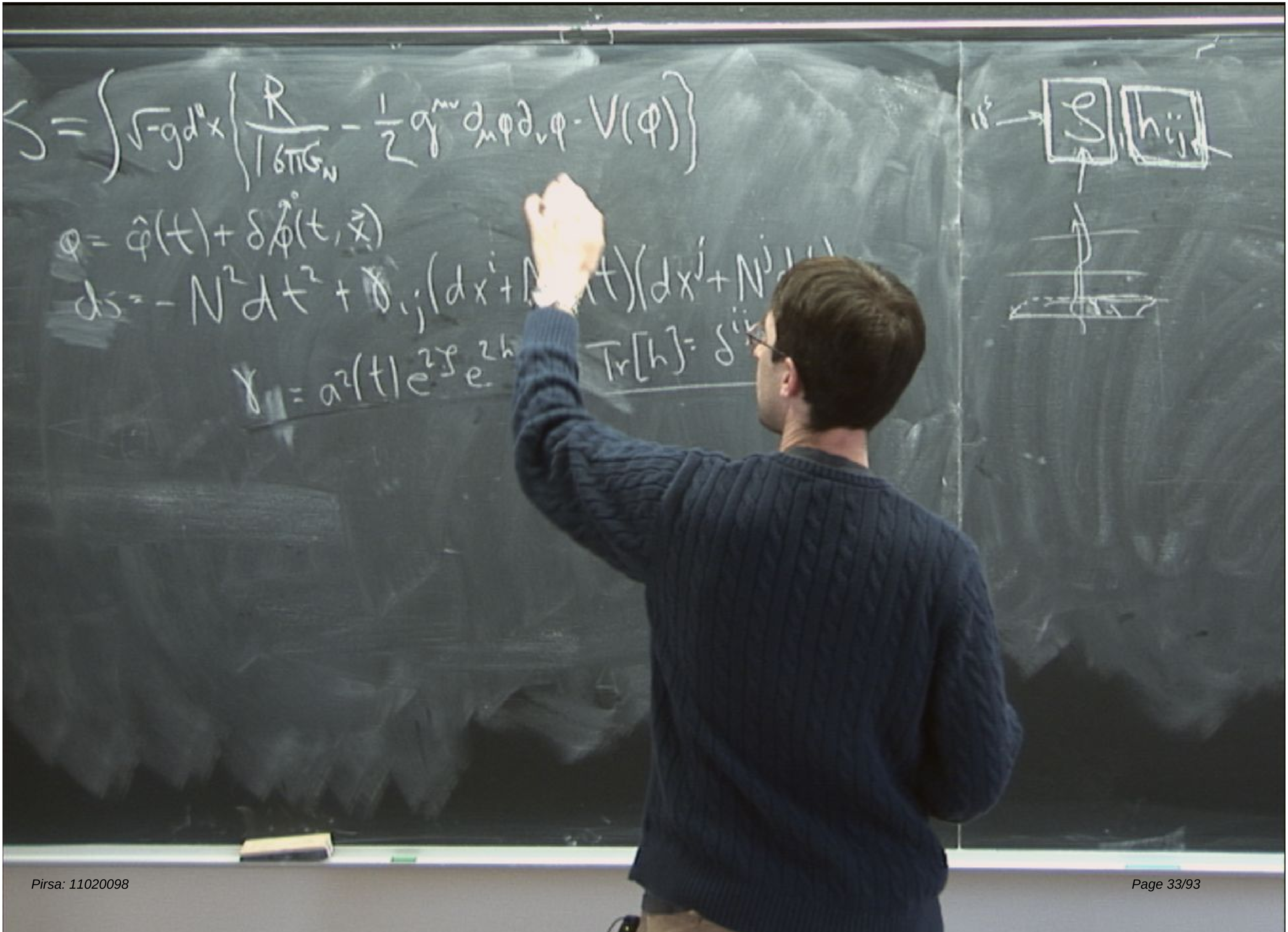
$$\phi = \hat{\phi}(t) + \cancelto{0}{\delta\phi}(t,\vec{x})$$

$$ds^2 = -N^2 dt^2 + \gamma_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$$

$$\gamma_{ij} = a^2(t)\, e^{2\zeta} e^{2h} \qquad \mathrm{Tr}[h] = \delta^{ij}\partial_i h_{jk} = 0$$

11's $\rightarrow$ $\boxed{\zeta}$, $\boxed{h_{ij}}$




$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V(\varphi) \right\}$
$\varphi = \hat{\varphi}(t) + \delta\varphi(t, \vec{x})$
$ds^2 = -N^2 dt^2 + \gamma_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$
$\gamma_{ij} = a^2(t) e^{2\zeta} e^{2h}$
$Tr[h] = \delta^{ij}$
$\boxed{\zeta}, \boxed{h_{ij}}$

$$S=\int\sqrt{-g}\,d^4x\left\{\frac{R}{16\pi G_N}-\frac{1}{2}g^{\mu\nu}\partial_\mu\phi\,\partial_\nu\phi-V(\phi)\right\}$$

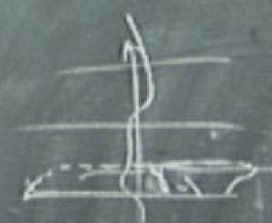
$$\phi=\hat{\phi}(t)+\delta\phi(t,\vec{x})$$

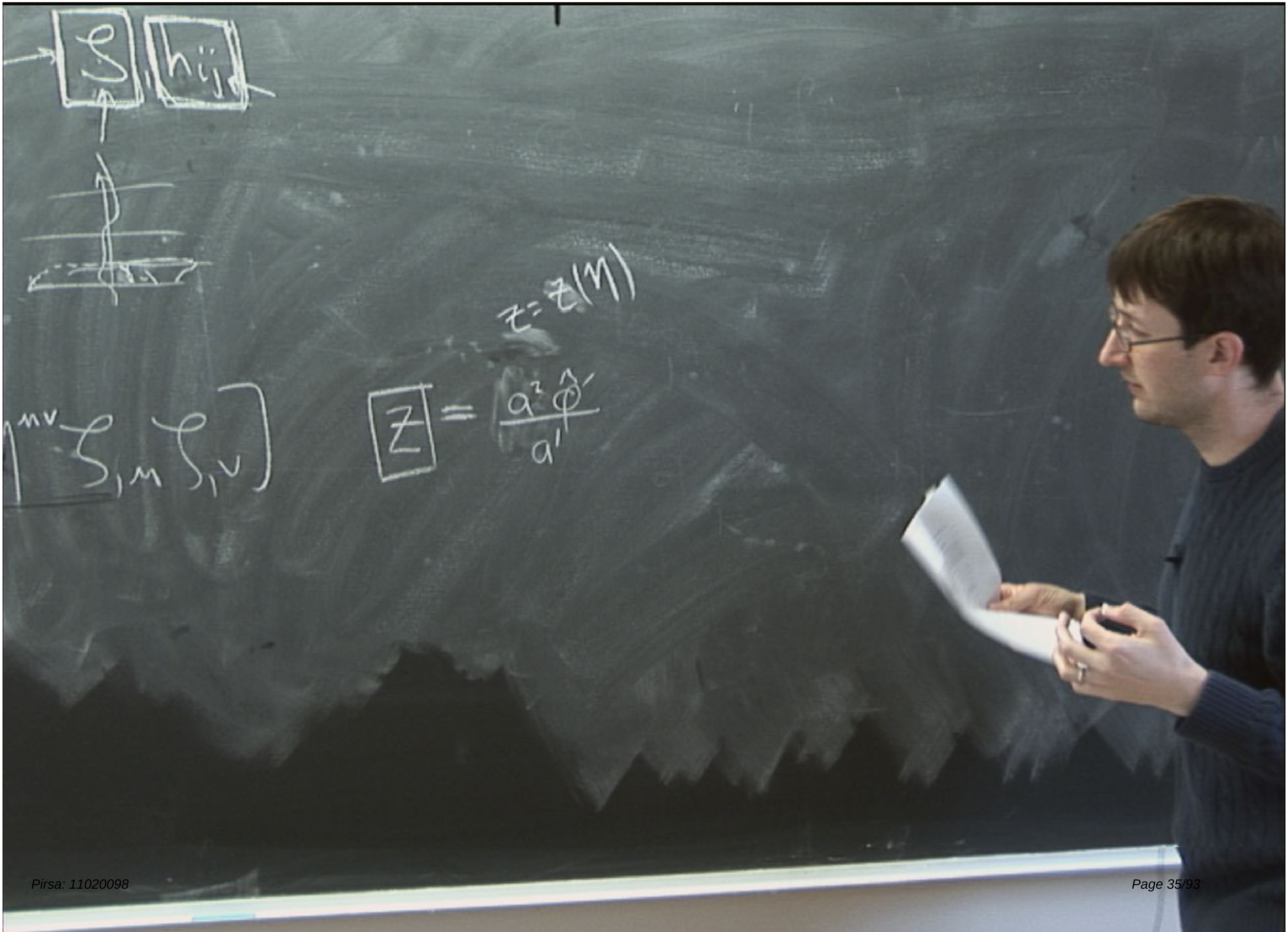
$$ds^2=-N^2dt^2+\gamma_{ij}(dx^i+N^i dt)(dx^j+N^j dt)$$

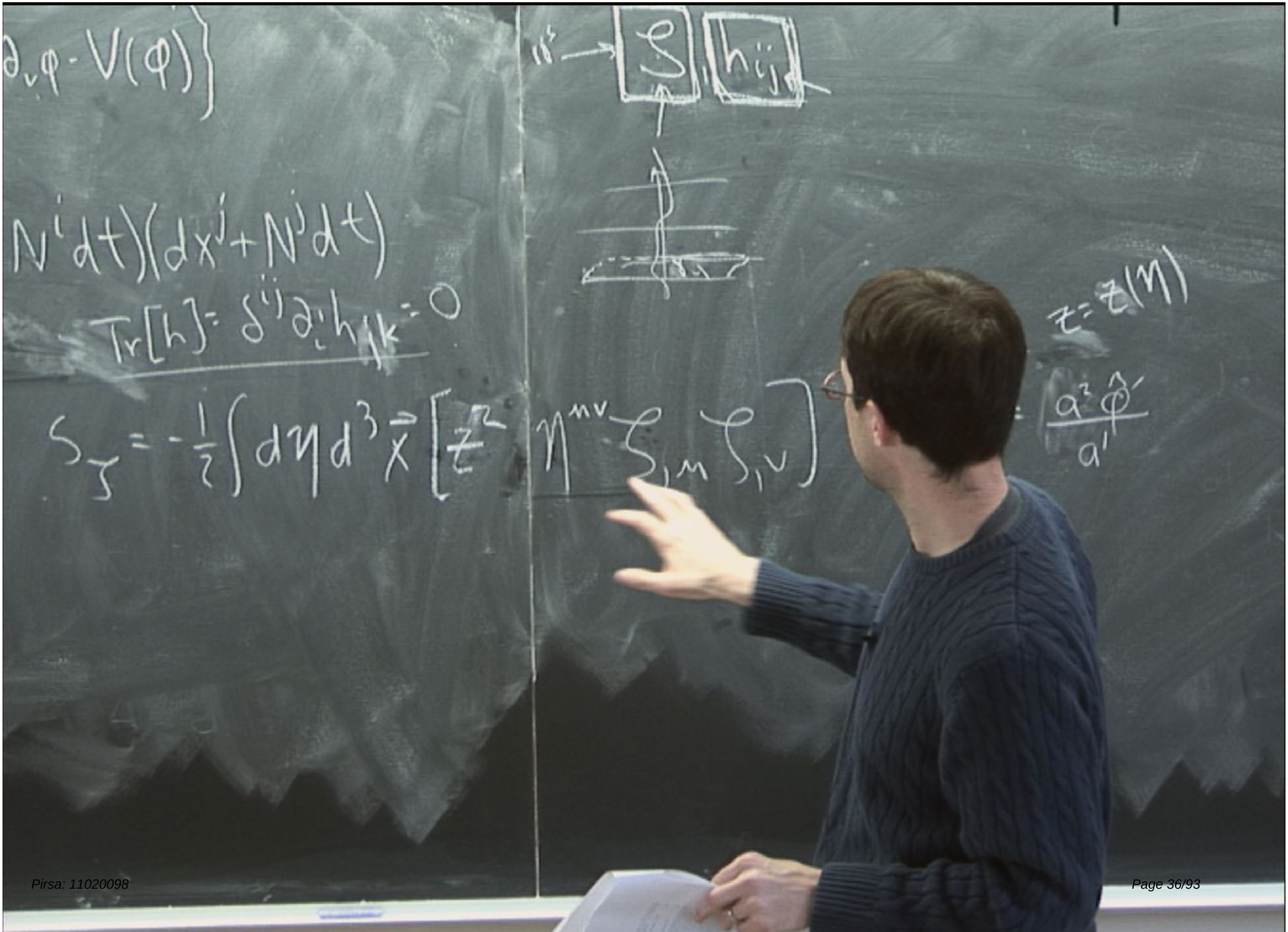
$$\gamma_{ij}=a^2(t)e^{2\zeta}e^{2h} \qquad Tr[h]=\delta^{ij}\partial_i h_{jk}=0$$

$$S=\underbrace{\;+S_\zeta+S_h\;}+\ldots \qquad S_\zeta=-\frac{1}{2}\int d\eta\, d^3\vec{x}\left[z^2\,\eta^{\mu\nu}\zeta_{,\mu}\zeta_{,\nu}\right]$$

$\rightarrow \boxed{\zeta},\ \boxed{h_{ij}}$




z = z(η)
Z = a² φ' / a'


$\partial_\nu\varphi - V(\varphi)\}$
ζ, h_{ij}
$N^i dt)(dx^j + N^j dt)$
$\mathrm{Tr}[h] = \delta^{ij}\partial_i h_{jk} = 0$
$S_\zeta = -\frac{1}{2}\int d\eta\, d^3\vec{x}\, [z^2\, \eta^{\mu\nu}\zeta_{,\mu}\zeta_{,\nu}]$
$z = z(\eta)$
$\frac{a^2\hat{\varphi}'}{a'}$

$\partial_\nu\varphi - V(\varphi)\Big\}$

$N^i dt)(dx^j + N^j dt)$

$\mathrm{Tr}[h] = \delta^{ij}\partial_i h_{jk} = 0$

$$S_\zeta = -\frac{1}{2}\int d\eta\, d^3\vec{x}\left[z^2\, \eta^{\mu\nu}\zeta_{,\mu}\zeta_{,\nu}\right]$$

$\to \boxed{\zeta}, \boxed{h_{ij}}$

$z = z(\eta)$

$$\boxed{z} = \frac{a^3\hat{\varphi}'}{a'}$$

$$S = \int dt\, L(q_i, \dot{q}_i)$$

$$p_i = \frac{\partial L}{\partial \dot{q}_i}$$

$$[\hat{q}_i, \hat{q}_j] = [\hat{p}_i, \hat{p}_j] = 0$$

$$[\hat{q}_i, \hat{p}_j] = i\hbar\delta_{ij}$$

$$S = \int dt\, L(q_i, \dot{q}_i)$$

$$p_i = \frac{\partial L}{\partial \dot{q}_i}$$

$$[\hat{q}_i, \hat{q}_j] = [\hat{p}_i, \hat{p}_j] = 0$$

$$[\hat{q}_i, \hat{p}_j] = i\hbar\delta_{ij}$$

$$\phi(\vec{x}, t) \qquad \Pi(\vec{x}, t) = \frac{\partial \phi(\vec{x}, t)}{\partial t}$$

$$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

$$\phi = \hat{\phi}(t) + \delta\phi(t, \vec{x})$$

$$ds^2 = -N^2 dt^2 + \gamma_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$$

$$\gamma_{ij} = a^2(t) e^{2\zeta} e^{2h} \qquad \partial_i h_{ik} = 0$$

$$S = \underbrace{\quad + S_\zeta + \quad}\ + \ldots$$

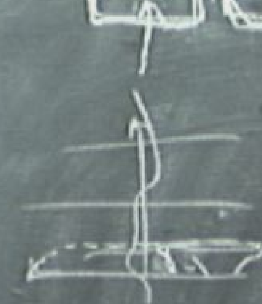
$$S_\zeta = \int d\eta\, d^3\vec{x} \left[z^2\, \eta^{\mu\nu} \zeta_{,\mu} \zeta_{,\nu} \right.$$

$$\pi(\vec{x}, \eta) = z^2(\eta)\, \zeta'(\vec{x}, \eta)$$

$$\boxed{\zeta}, \boxed{h_{ij}}$$

$$S=\int\sqrt{-g}\,d^4x\left\{\frac{R}{16\pi G_N}-\frac{1}{2}g^{\mu\nu}\partial_\mu\phi\,\partial_\nu\phi-V(\phi)\right\}$$

$$\text{"}\rightarrow\boxed{\zeta},\ \boxed{h_{ij}}$$



$$\phi=\hat{\phi}(t)+\delta\phi(t,\vec{x})$$

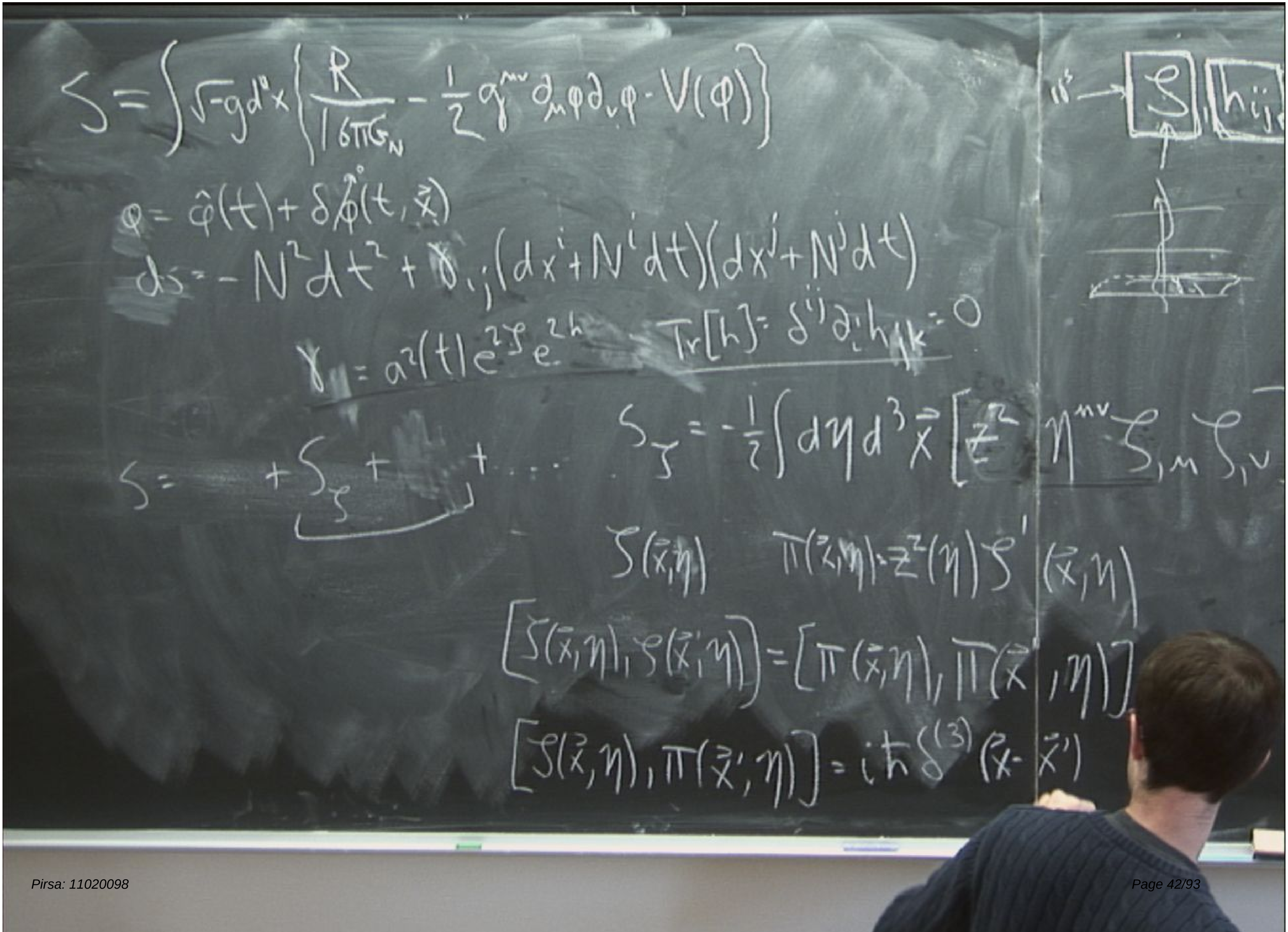
$$ds^2=-N^2dt^2+\gamma_{ij}(dx^i+N^idt)(dx^j+N^jdt)$$

$$\gamma_{ij}=a^2(t)e^{2\zeta}e^{2h}\qquad Tr[h]=\delta^{ij}\partial_i h_{jk}=0$$

$$S=\quad+\underbrace{S_\zeta+\quad}+\ldots$$

$$S_\zeta=-\frac{1}{2}\int d\eta\, d^3\vec{x}\left[z^2\ \eta^{\mu\nu}\zeta_{,\mu}\zeta_{,\nu}\right.$$

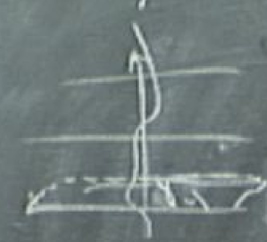
$$\zeta(\vec{x},\eta)\qquad \pi(\vec{x},\eta)=z^2(\eta)\,\zeta'(\vec{x},\eta)$$



$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V(\varphi) \right\}$
$\boxed{\zeta}, \boxed{h_{ij}}$
$\varphi = \hat{\varphi}(t) + \delta\varphi(t, \vec{x})$
$ds^2 = -N^2 dt^2 + \gamma_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$
$\gamma_{ij} = a^2(t) e^{2\zeta} e^{2h}$
$\mathrm{Tr}[h] = \delta^{ij} \partial_i h_{jk} = 0$
$S = + S_\zeta + \quad + \ldots$
$S_\zeta = -\frac{1}{2} \int d\eta\, d^3\vec{x} \left[z^2 \eta^{\mu\nu} \zeta_{,\mu} \zeta_{,\nu} \right.$
$\zeta(\vec{x}, \eta) \quad \pi(\vec{x}, \eta) = z^2(\eta) \zeta'(\vec{x}, \eta)$
$[\zeta(\vec{x}, \eta), \zeta(\vec{x}', \eta)] = [\pi(\vec{x}, \eta), \pi(\vec{x}', \eta)]$
$[\zeta(\vec{x}, \eta), \pi(\vec{x}', \eta)] = i\hbar\, \delta^{(3)}(\vec{x} - \vec{x}')$

$$S=\int\sqrt{-g}\,d^4x\left\{\frac{R}{16\pi G_N}-\frac{1}{2}g^{\mu\nu}\partial_\mu\varphi\,\partial_\nu\varphi-V(\varphi)\right\}$$

$10^5 \longrightarrow \boxed{\zeta},\ \boxed{h_{ij}}$



$$\varphi=\hat{\varphi}(t)+\delta\varphi(t,\vec{x})$$

$$ds^2=-N^2dt^2+\gamma_{ij}(dx^i+N^i dt)(dx^j+N^j dt)$$

$$\gamma_{ij}=a^2(t)\,e^{2\zeta}e^{2h} \qquad \mathrm{Tr}[h]=\delta^{ij}\partial_i h_{jk}=0$$

$$S=\underbrace{\ \ +S_\zeta+\ \ }\ +\ldots$$

$$S_\zeta=-\frac{1}{2}\int d\eta\, d^3\vec{x}\left[z^2\,\eta^{\mu\nu}\zeta_{,\mu}\zeta_{,\nu}\right.$$

$$\zeta(\vec{x},\eta) \qquad \Pi(\vec{x},\eta)=z^2(\eta)\,\zeta'(\vec{x},\eta)$$

$$[\zeta(\vec{x},\eta),\zeta(\vec{x}',\eta)]=[\Pi(\vec{x},\eta),\Pi(\vec{x}',\eta)]=0$$

$$[\zeta(\vec{x},\eta),\Pi(\vec{x}',\eta)]=i\hbar\,\delta^{(3)}(\vec{x}-\vec{x}')$$

$$S = \int \sqrt{-g}\, d^4x \left\{ \frac{R}{16\pi G_N} - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right\}$$

$$\phi = \hat{\phi}(t) + \delta\phi(t, \vec{x})$$

$$ds^2 = -N^2 dt^2 + \gamma_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$$

$$\gamma_{ij} = a^2(t) e^{2\zeta} e^{2h} \qquad Tr[h] = \delta^{ij}\partial_i h_{jk} = 0$$

$$S_\zeta = -\frac{1}{2}\int d\eta\, d^3\vec{x} \left[z^2 \eta^{\mu\nu} \zeta_{,\mu} \zeta_{,\nu} \right.$$

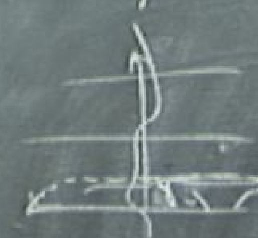
$$S = \underbrace{+ S_\zeta + \quad}_{} + \ldots$$

$$\zeta(\vec{x},\eta) \qquad \Pi(\vec{x},\eta) = z^2(\eta)\zeta'(\vec{x},\eta)$$

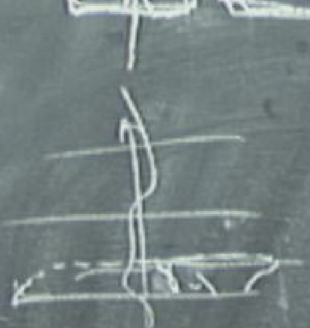
$$[\zeta(\vec{x},\eta), \zeta(\vec{x}',\eta)] = [\Pi(\vec{x},\eta), \Pi(\vec{x}',\eta)] = 0$$

$$[\zeta(\vec{x},\eta), \Pi(\vec{x}',\eta)] = i\hbar\,\delta^{(3)}(\vec{x} - \vec{x}')$$

$$\text{"}1\text{"} \rightarrow \boxed{\zeta}, \boxed{h_{ij}}$$



$115 \rightarrow \boxed{\zeta}, \boxed{h_{ij}}$



0

$$\zeta(\eta,\vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}}\, \zeta_{\vec{k}}(\eta)\, e^{i\vec{k}\cdot\vec{x}}$$

$\left[z^2 \eta^{\mu\nu} \zeta_{,\mu} \zeta_{,\nu} \right]$

$\eta)\zeta'(\vec{x},\eta)$

$,\Pi(\vec{x}',\eta)] = 0$

$^{(3)}(\vec{x}-\vec{x}')$

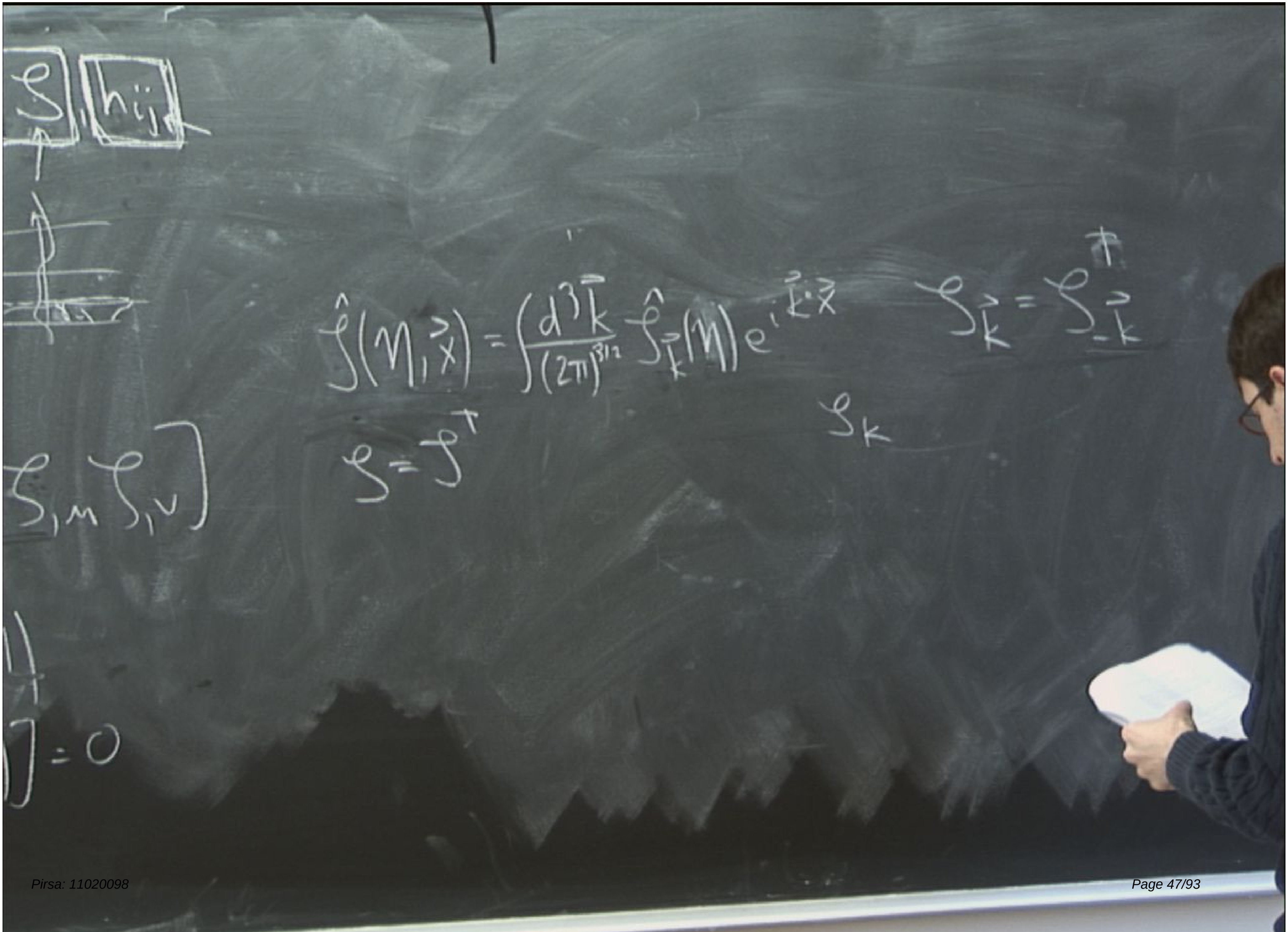
$\boxed{\zeta}, \boxed{h_{ij}}$

$$\hat{\zeta}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\zeta}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}} \qquad \zeta_{\vec{k}} = \zeta^{\dagger}_{-\vec{k}}$$

$$\zeta = \zeta^{\dagger}$$

$\zeta_{,\mu} \zeta_{,\nu}]$

$] = 0$



ζ, h_{ij}
$\hat{\zeta}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\zeta}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$
$\zeta_{\vec{k}} = \zeta^\dagger_{-\vec{k}}$
$\zeta = \zeta^\dagger$
ζ_k
$\zeta_{,\mu} \zeta_{,\nu}]$
$] = 0$

$$\hat{\zeta}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\zeta}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

$$\zeta_{\vec{k}} = \zeta^{\dagger}_{-\vec{k}}$$

$$\hat{\zeta}_k(\eta)$$

$$\zeta = \zeta^{\dagger}$$

$\boxed{\zeta}, \boxed{h_{ij}}$

$\zeta_{,\mu} \zeta_{,\nu}]$

$] = 0$

$\boxed{\zeta}, \boxed{h_{ij}}$

$\zeta_{,\mu}\zeta_{,\nu}]$

$] = 0$

$$\hat{\zeta}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\zeta}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

$$\zeta = \zeta^{\dagger}$$

$$\boxed{\zeta_{\vec{k}} = \zeta^{\dagger}_{-\vec{k}}}$$

$$\hat{\zeta}_k(\eta) =$$

$\boxed{\zeta}$, $\boxed{h_{ij}}$

$\zeta_{,\mu}\zeta_{,\nu}]$

$] = 0$

$$\hat{\zeta}(\eta,\vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}}\, \hat{\zeta}_{\vec{k}}(\eta)\, e^{i\vec{k}\cdot\vec{x}}$$

$$\boxed{\zeta_{\vec{k}} = \zeta^{\dagger}_{-\vec{k}}}$$

$$\zeta = \zeta^{\dagger}$$

$$\hat{\zeta}_k(\eta) = \zeta_{\vec{k}}(\eta)\, \hat{a}_{\vec{k}}$$

h_{ij}

$$\hat{\zeta}(\eta,\vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}}\, \hat{\zeta}_{\vec{k}}(\eta)\, e^{i\vec{k}\cdot\vec{x}}$$

$$\zeta = \zeta^\dagger$$

$$\boxed{\zeta_{\vec{k}} = \zeta^\dagger_{-\vec{k}}}$$

$$\hat{\zeta}_k(\eta) = \zeta_{\vec{k}}(\eta)\,\hat{a}_{\vec{k}} + \zeta^*_{-\vec{k}}(\eta)\,\hat{a}^\dagger_{\vec{k}}$$

$\zeta_{,\mu}\,\zeta_{,\nu}\,]$

$= 0$

$\boxed{h_{ij}}$

$,_\mu \zeta_{,\nu}]$

$= 0$

$$\hat{\zeta}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\zeta}_{\vec{k}}(\eta)\, e^{i\vec{k}\cdot\vec{x}}$$

$$\zeta = \zeta^\dagger$$

$$\boxed{\zeta_{\vec{k}} = \zeta^\dagger_{-\vec{k}}}$$

$$\hat{\zeta}_k(\eta) = \zeta_{\vec{k}}(\eta)\, \hat{a}_{\vec{k}} + \zeta^*_{-\vec{k}}(\eta)\, \hat{a}_{\vec{k}}$$

$\boxed{h_{ij}}$

$$\hat{\zeta}(\eta,\vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}}\, \hat{\zeta}_{\vec{k}}(\eta)\, e^{i\vec{k}\cdot\vec{x}}$$

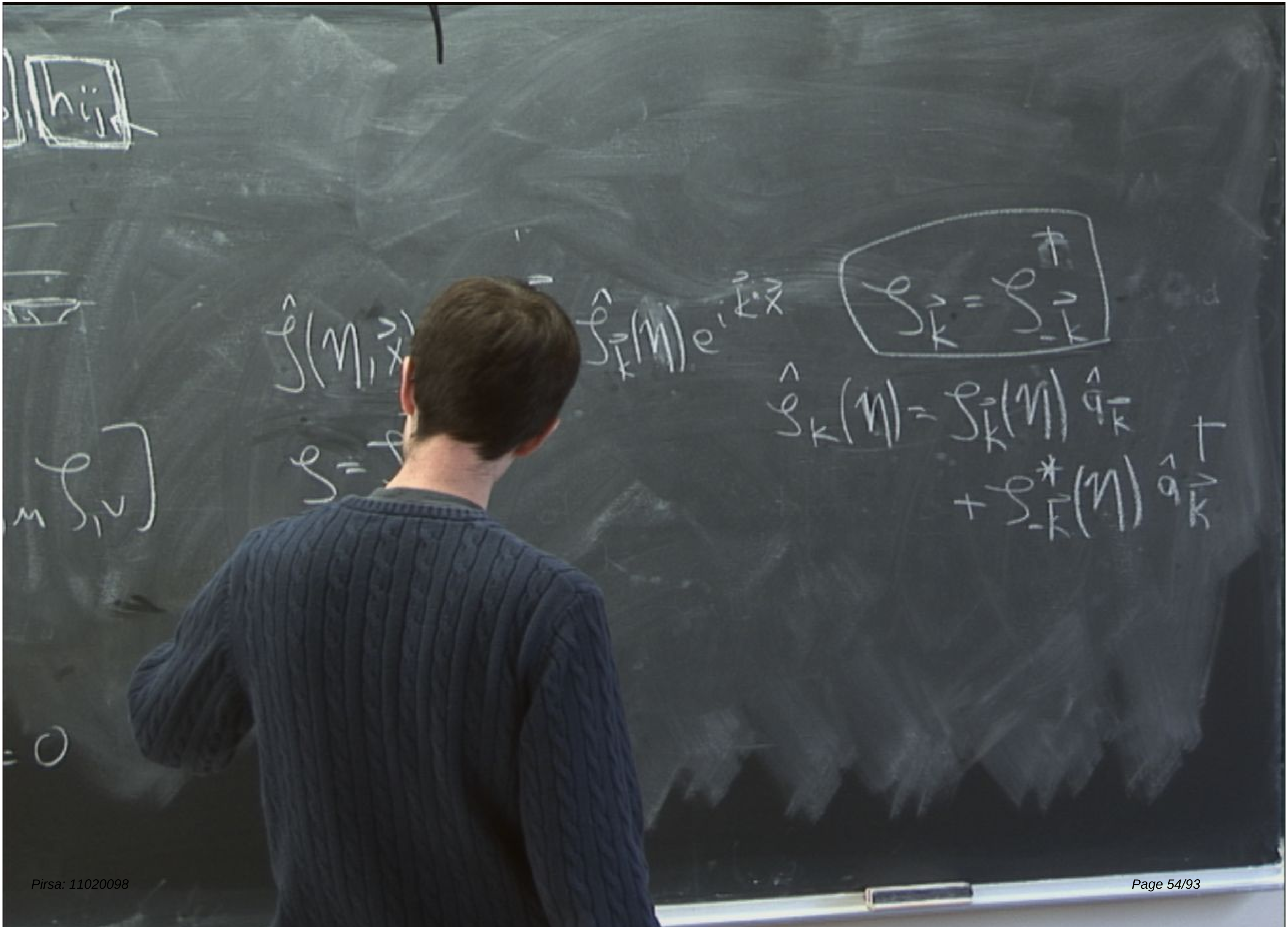
$$\boxed{\zeta_{\vec{k}} = \zeta^{\dagger}_{-\vec{k}}}$$

$$\zeta = \zeta^{\dagger}$$

$$\hat{\zeta}_k(\eta) = \zeta_{\vec{k}}(\eta)\, \hat{a}_{\vec{k}} + \zeta^{*}_{-\vec{k}}(\eta)\, \hat{a}^{\dagger}_{\vec{k}}$$

$$\zeta_{,\mu}\, \zeta_{,\nu}]$$

$$= 0$$


h_{ij}
$\hat{\varsigma}(\eta,\vec{x})$
$\hat{\varsigma}_{\vec{k}}(\eta)e^{i\vec{k}\cdot\vec{x}}$
$\varsigma_{\vec{k}} = \varsigma^{\dagger}_{-\vec{k}}$
$\hat{\varsigma}_k(\eta) = \varsigma_{\vec{k}}(\eta)\,\hat{a}_{\vec{k}}$
$+\,\varsigma^{*}_{-\vec{k}}(\eta)\,\hat{a}^{\dagger}_{\vec{k}}$

$\hat{h}_{ij}$

$$\hat{\varrho}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\varrho}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

$$\boxed{\varrho_{\vec{k}} = \varrho^{\dagger}_{-\vec{k}}}$$

$$\hat{\varrho}_k(\eta) = \varrho_{\vec{k}}(\eta)\, \hat{a}_{\vec{k}} + \varrho^{*}_{-\vec{k}}(\eta)\, \hat{a}^{\dagger}_{\vec{k}}$$

$$\varrho = \varrho^{\dagger}$$

$$\left[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}\right] = \left[\hat{a}^{\dagger}_{\vec{k}}, a^{\dagger}_{\vec{k}'}\right] = 0$$

$$\left[\hat{a}_{\vec{k}}, \hat{a}^{\dagger}_{\vec{k}'}\right] = i\,\delta^{(3)}(\vec{k} - \vec{k}')$$

$\varrho_{,\mu}\, \varrho_{,\nu}]$

$= 0$

$\boxed{h_{ij}}$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$\hat{\varphi}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \, \hat{\varphi}_{\vec{k}}(\eta) \, e^{i\vec{k}\cdot\vec{x}}$$

$$\boxed{\varphi_{\vec{k}} = \varphi^\dagger_{-\vec{k}}}$$

$$\hat{\varphi}_k(\eta) = \varphi_{\vec{k}}(\eta)\, \hat{a}_{\vec{k}} + \varphi^*_{-\vec{k}}(\eta)\, \hat{a}^\dagger_{\vec{k}}$$

$$\varphi = \varphi^\dagger$$

$${}_{,\mu} \varphi_{,\nu}]$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = \delta^{(3)}(\vec{k} - \vec{k}')$$

$$= 0$$

$$\zeta_k'' + 2\frac{z'}{z}\zeta_k' + k^2\zeta_k = 0$$

$$V(q) = \frac{1}{2} m\omega^2 q^2$$

$$\hat{\zeta}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\zeta}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

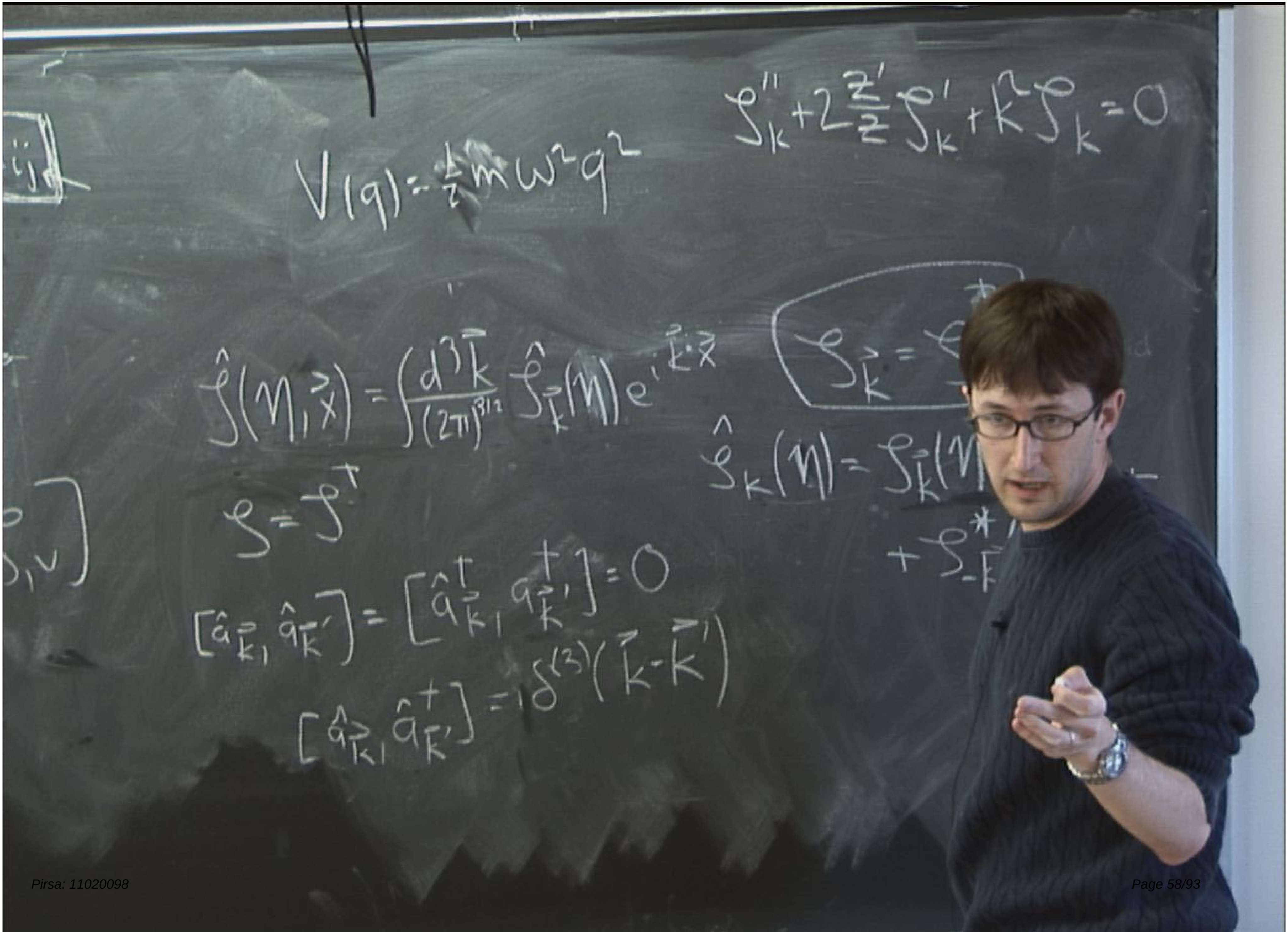
$$\boxed{\zeta_{\vec{k}} = \zeta^{\dagger}_{-\vec{k}}}$$

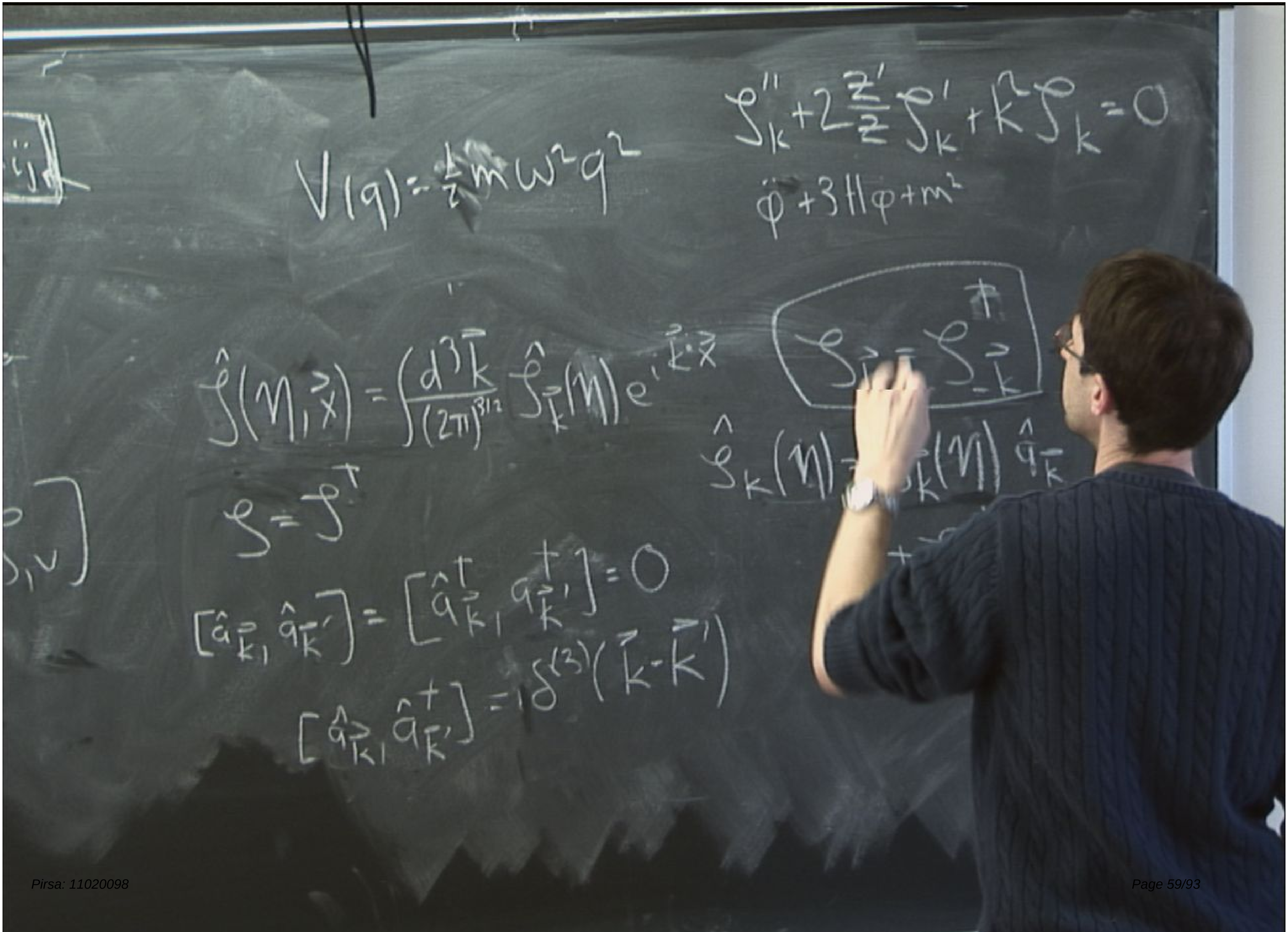
$$\hat{\zeta}_k(\eta) = \zeta_{\vec{k}}(\eta)\,\hat{a}_{\vec{k}} + \zeta^*_{-\vec{k}}(\eta)\,\hat{a}^{\dagger}_{\vec{k}}$$

$$\zeta = \zeta^{\dagger}$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^{\dagger}_{\vec{k}}, a^{\dagger}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}^{\dagger}_{\vec{k}'}] = i\delta^{(3)}(\vec{k} - \vec{k}')$$


$\rho''_k + 2\frac{z'}{z}\rho'_k + k^2\rho_k = 0$
$V(q) = \frac{1}{2} m \omega^2 q^2$
$\hat{\rho}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\rho}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$
$\rho = \rho^\dagger$
$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$
$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = \delta^{(3)}(\vec{k} - \vec{k}')$


$\varsigma_k'' + 2\frac{z'}{z}\varsigma_k' + k^2\varsigma_k = 0$
$V(q) = \frac{1}{2} m\omega^2 q^2$
$\ddot\phi + 3H\dot\phi + m^2$
$\varsigma_{\vec k} = \varsigma^\dagger_{-\vec k}$
$\hat\varsigma(\eta,\vec x) = \int \frac{d^3\vec k}{(2\pi)^{3/2}} \hat\varsigma_{\vec k}(\eta) e^{i\vec k\cdot\vec x}$
$\varsigma = \varsigma^\dagger$
$[\hat a_{\vec k}, \hat a_{\vec k'}] = [\hat a^\dagger_{\vec k}, a^\dagger_{\vec k'}] = 0$
$[\hat a_{\vec k}, \hat a^\dagger_{\vec k'}] = \delta^{(3)}(\vec k - \vec k')$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$\varrho_k'' + 2\frac{z'}{z}\varrho_k' + k^2 \varrho_k = 0$$

$$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2 \varphi = 0$$

$$\hat{\varrho}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\varrho}_{\vec{k}}(\eta)\, e^{i\vec{k}\cdot\vec{x}}$$

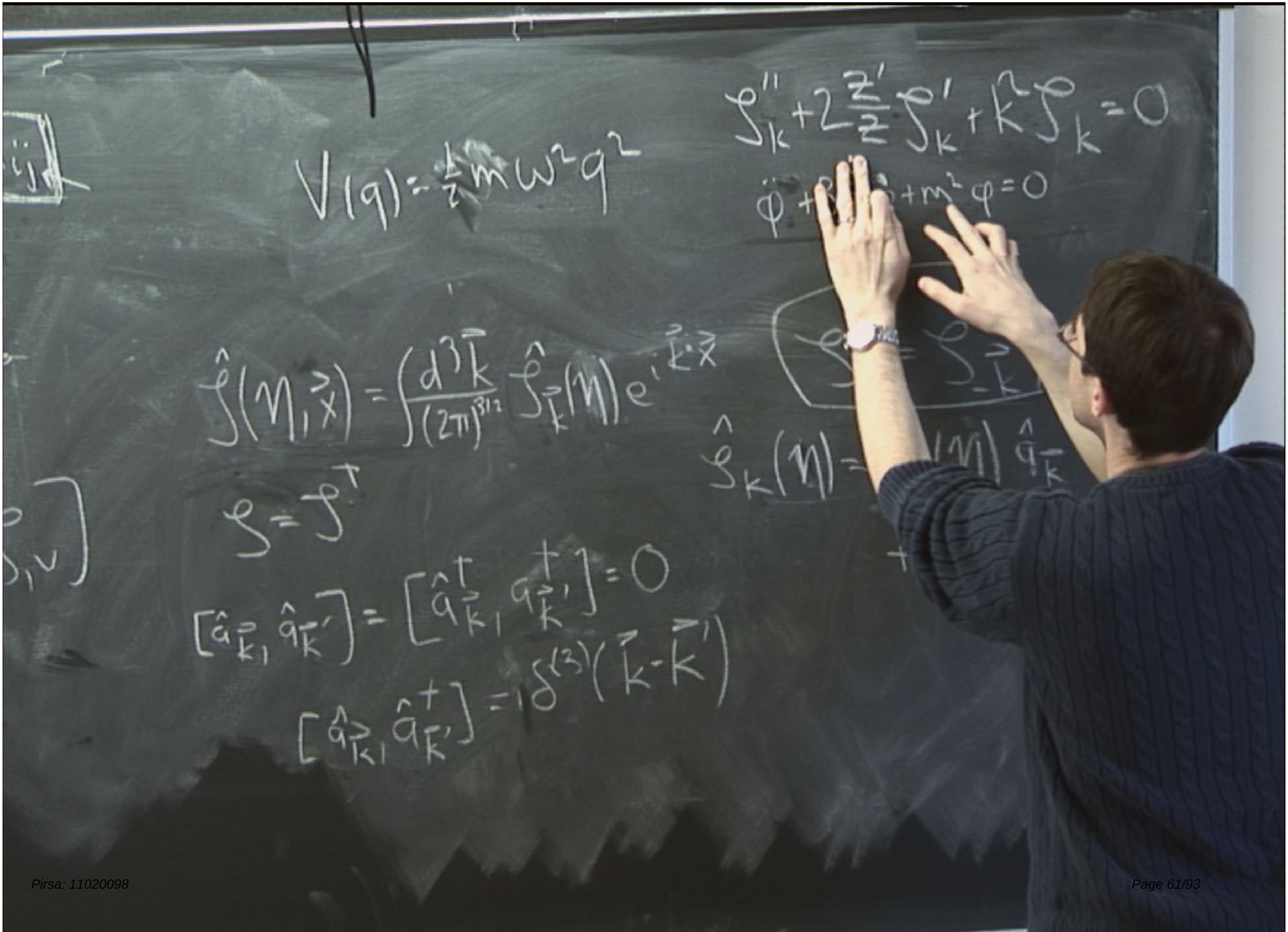
$$\boxed{\varrho_{\vec{k}} = \varrho^{\dagger}_{-\vec{k}}}$$

$$\hat{\varrho}_k(\eta) = \varrho_{\vec{k}}(\eta)\, \hat{a}_{\vec{k}} + \varrho^*_{-\vec{k}}(\eta)\, \hat{a}^{\dagger}_{\vec{k}}$$

$$\varrho = \varrho^{\dagger}$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^{\dagger}_{\vec{k}}, a^{\dagger}_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}^{\dagger}_{\vec{k}'}] = i\,\delta^{(3)}(\vec{k} - \vec{k}')$$


$V(q) = \frac{1}{2} m \omega^2 q^2$
$\rho_k'' + 2\frac{z'}{z}\rho_k' + k^2 \rho_k = 0$
$\hat{\rho}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\rho}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$
$\rho = \rho^\dagger$
$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$
$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = \delta^{(3)}(\vec{k} - \vec{k}')$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$\varsigma_k'' + 2\frac{z'}{z}\varsigma_k' + k^2 \varsigma_k = 0$$

$$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2 \varphi = 0$$

$$\hat{\varsigma}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\varsigma}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

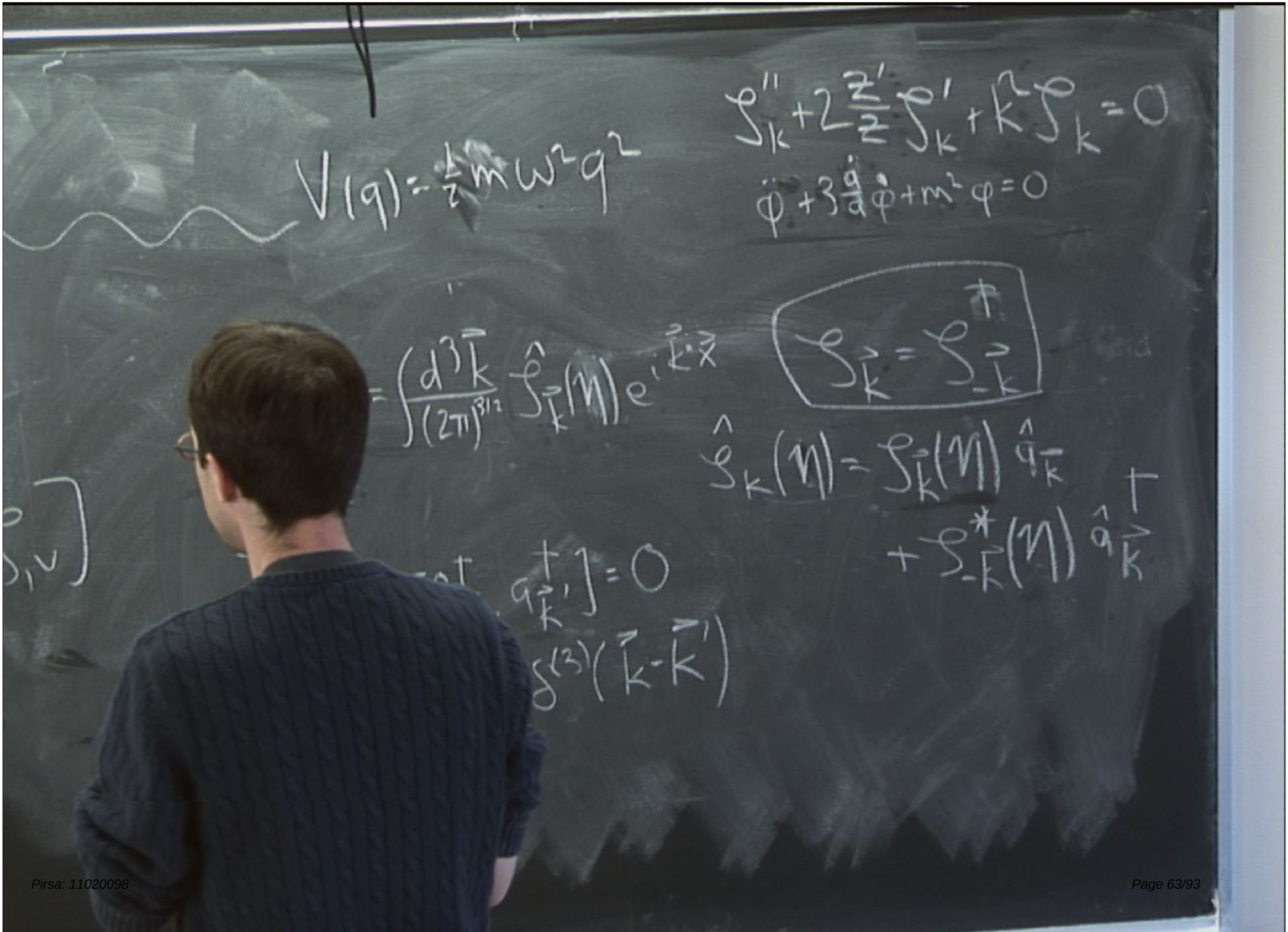
$$\boxed{\varsigma_{\vec{k}} = \varsigma^\dagger_{-\vec{k}}}$$

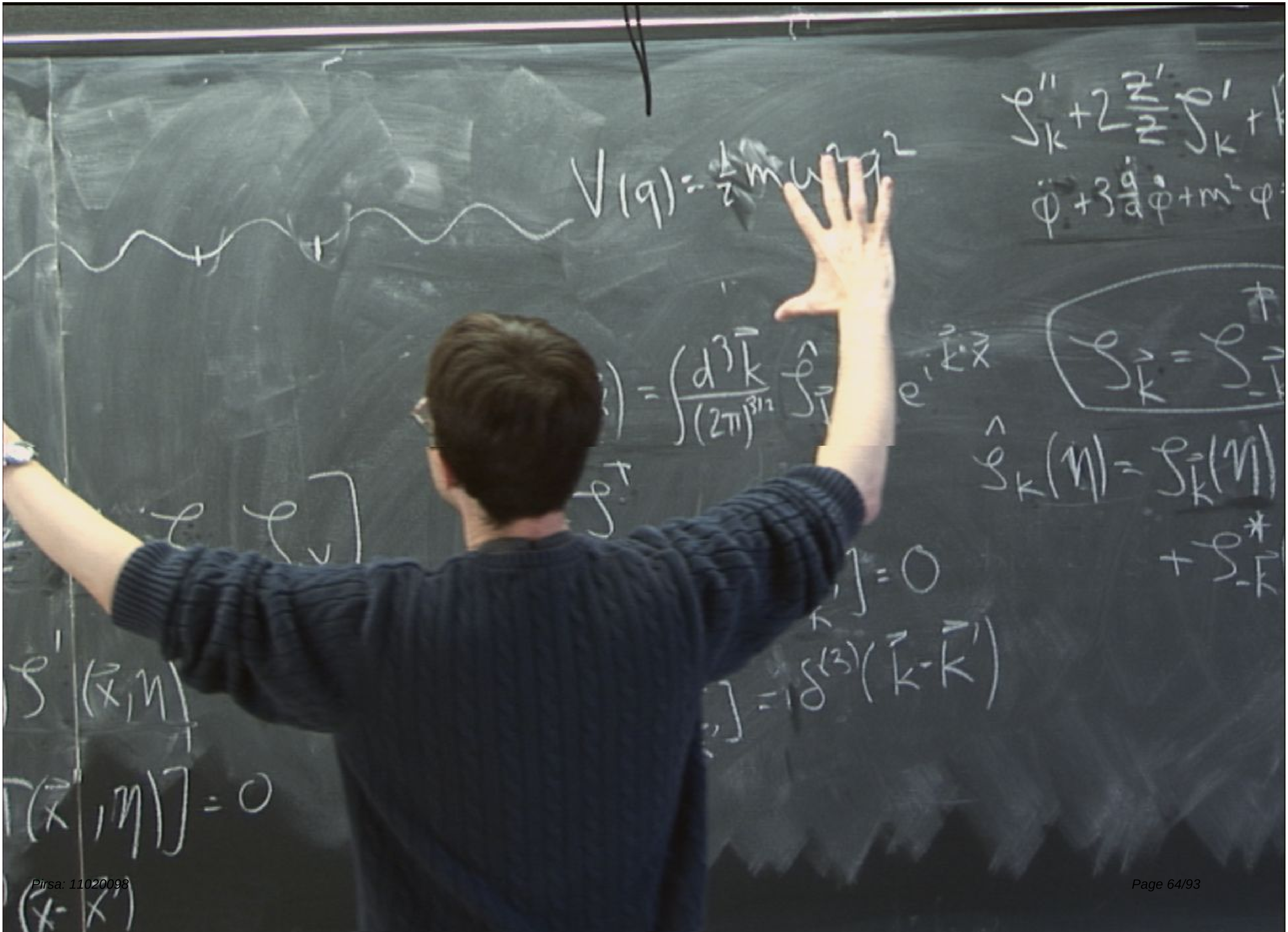
$$\varsigma = \varsigma^\dagger$$

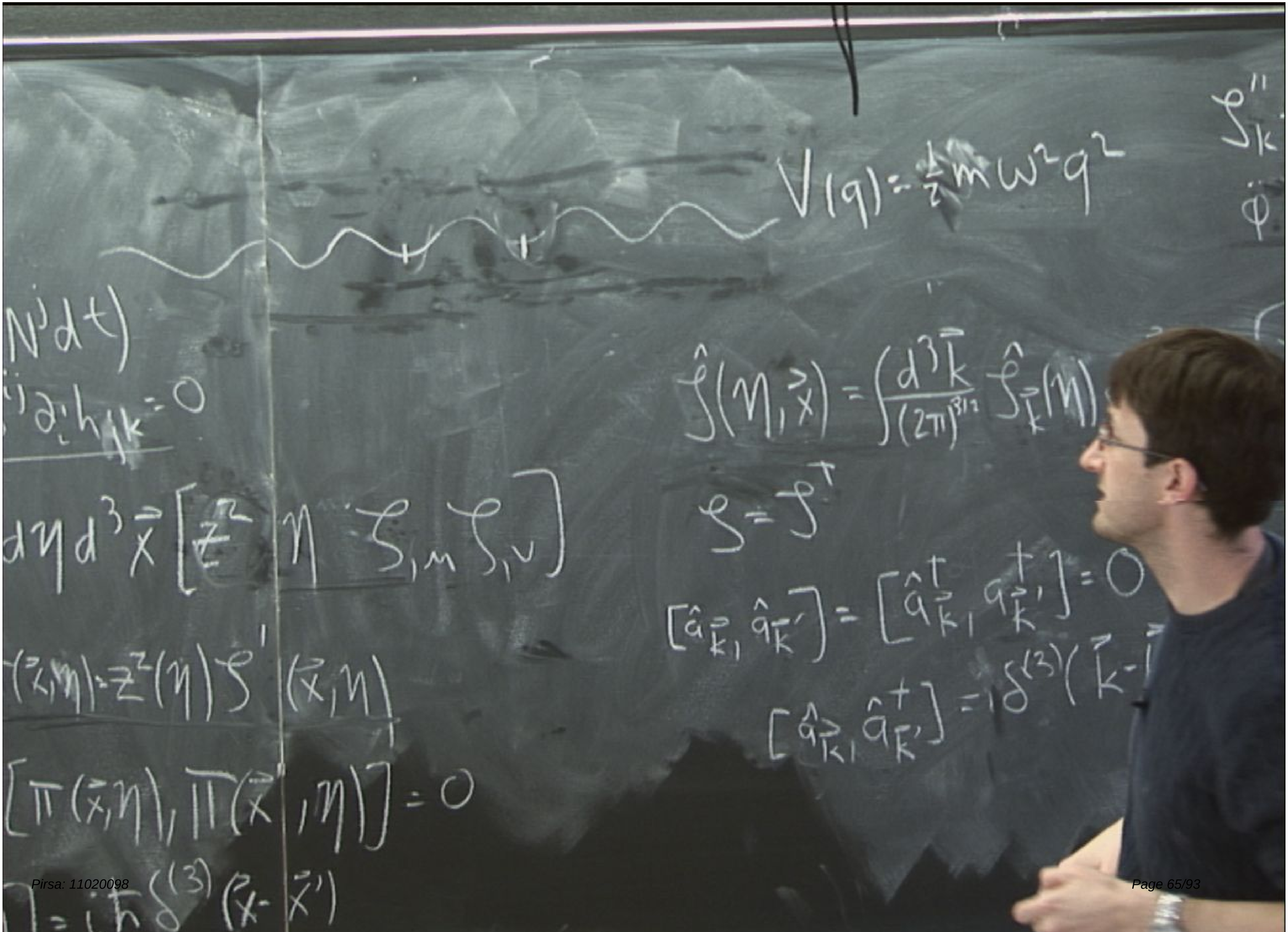
$$\hat{\varsigma}_k(\eta) = \varsigma_{\vec{k}}(\eta)\, \hat{a}_{\vec{k}} + \varsigma^*_{-\vec{k}}(\eta)\, \hat{a}^\dagger_{\vec{k}}$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = i\delta^{(3)}(\vec{k} - \vec{k}')$$


$\varsigma_k'' + 2\frac{z'}{z}\varsigma_k' + k^2\varsigma_k = 0$
$V(q) = \frac{1}{2} m \omega^2 q^2$
$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2\varphi = 0$
$\varsigma_{\vec{k}} = \varsigma_{-\vec{k}}^{\dagger}$
$= \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\varsigma}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$
$\hat{\varsigma}_k(\eta) = \varsigma_{\vec{k}}(\eta)\, \hat{a}_{\vec{k}}$
$+ \varsigma_{-\vec{k}}^{*}(\eta)\, \hat{a}_{\vec{k}}^{\dagger}$
$a_{\vec{k}'}^{\dagger}] = 0$
$\delta^{(3)}(\vec{k} - \vec{k}')$





$V(q) = \frac{1}{2} m \omega^2 q^2$
$\hat{\zeta}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\zeta}_{\vec{k}}(\eta)$
$\zeta = \zeta^\dagger$
$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$
$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = \delta^{(3)}(\vec{k} -$
$N^j dt)$
$\partial_i h_{jk} = 0$
$d\eta\, d^3\vec{x} \left[z^2(\eta)\, \zeta_{,\mu} \zeta_{,\nu} \right]$
$(\vec{x}, \eta) = z^2(\eta) \zeta'(\vec{x}, \eta)$
$[\pi(\vec{x}, \eta), \pi(\vec{x}', \eta)] = 0$
$] = i\hbar \delta^{(3)}(\vec{x} - \vec{x}')$

$V(q) = \frac{1}{2} m \omega^2 q^2$

ζ''_k

$\ddot{\varphi}$

$N^j dt)$

$\partial_i h_{jk} = 0$

$\hat{\zeta}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\zeta}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$

$\hat{\zeta}_k($

$d\eta\, d^3\vec{x} \left[z^2 \eta\ \zeta_{,\mu} \zeta_{,\nu} \right]$

$\zeta = \zeta^\dagger$

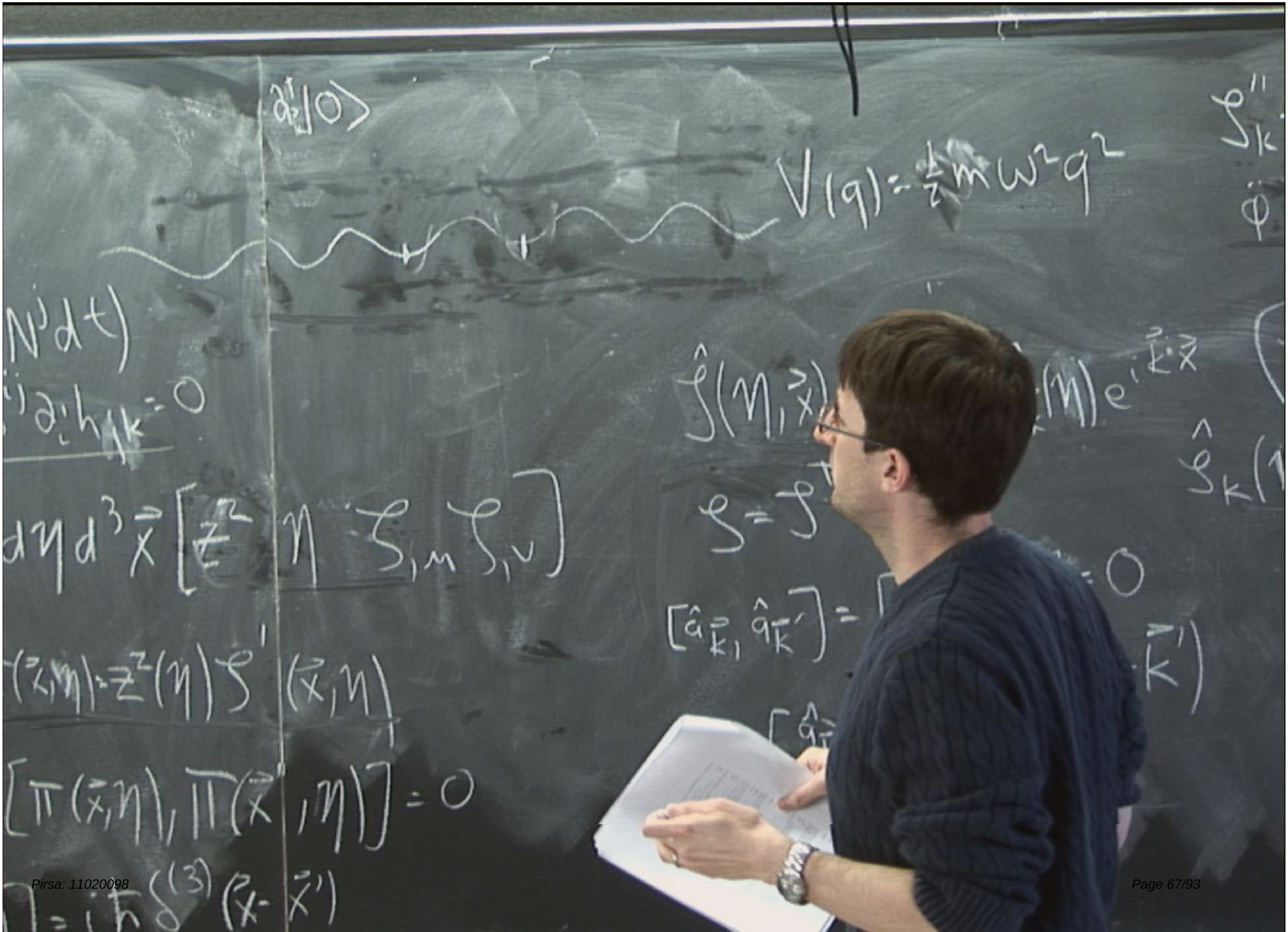
$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$

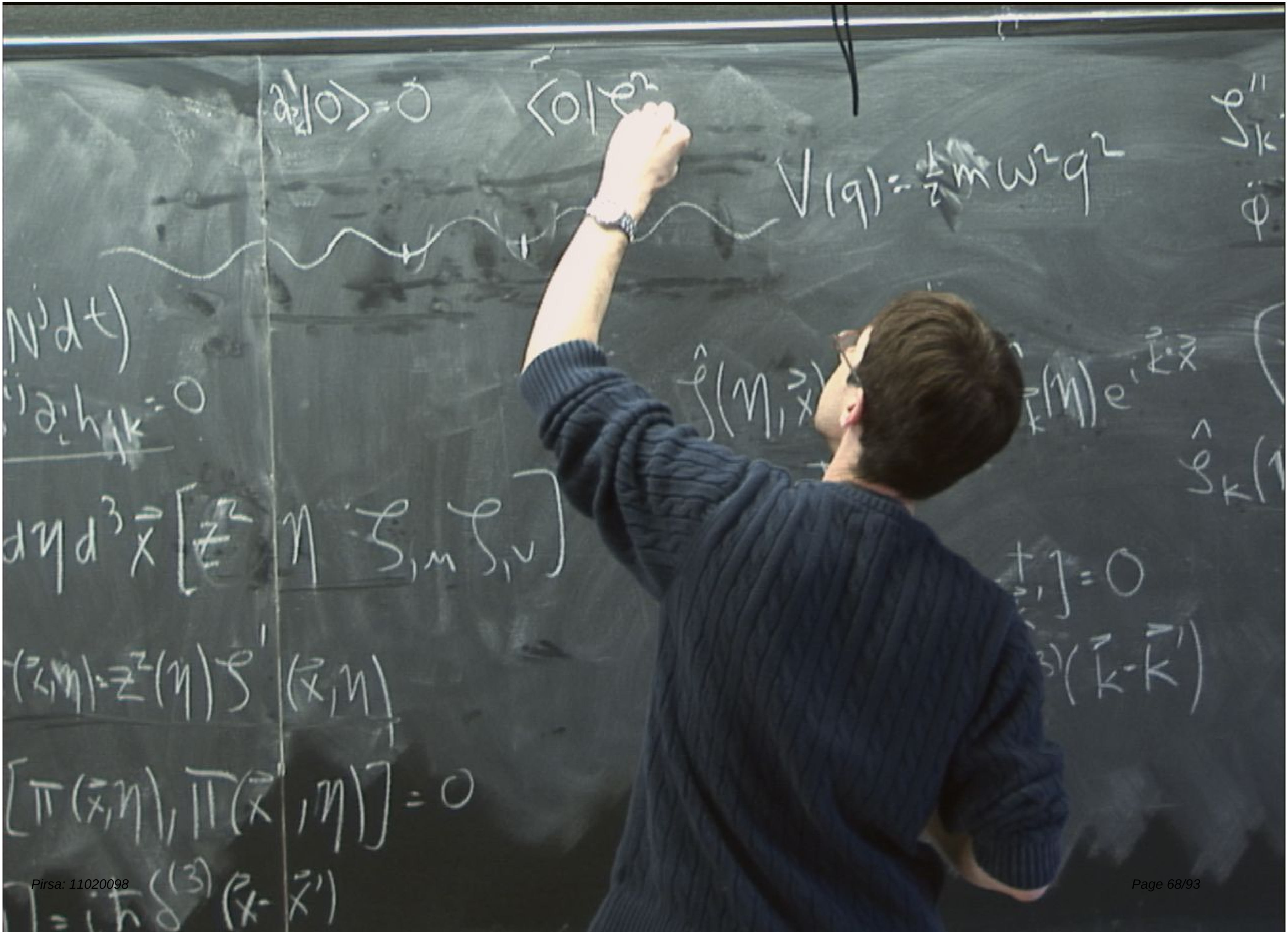
$(\vec{x}, \eta) = z^2(\eta)\zeta'(\vec{x}, \eta)$

$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = \delta^{(3)}(\vec{k} - \vec{k}')$

$[\pi(\vec{x}, \eta), \pi(\vec{x}', \eta)] = 0$

$] = i\hbar\, \delta^{(3)}(\vec{x} - \vec{x}')$


V(q) = ½ mω²q²
[π(x,η), π(x',η)] = 0


$\langle 0 | e^2$
$V(q) = \frac{1}{2} m \omega^2 q^2$
$[\pi(\vec{x},\eta), \pi(\vec{x}',\eta)] = 0$

$\hat{a}_{\vec{k}}|0\rangle = 0$ $\langle 0|\zeta^2(\vec{x},\eta)|0\rangle =$

$V(q) = \frac{1}{2} m \omega^2 q^2$

$N^j dt)$

$\partial_i h_{jk} = 0$

$d\eta\, d^3\vec{x} \left[z^2 \eta^{\mu\nu} \zeta_{,\mu} \zeta_{,\nu} \right]$

$(\vec{x},\eta) = z^2(\eta)\zeta'(\vec{x},\eta)$

$[\pi(\vec{x},\eta), \pi(\vec{x}',\eta)] = 0$

$] = i\hbar\,\delta^{(3)}(\vec{x}-\vec{x}')$

$$\hat{\zeta}(\eta,\vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\zeta}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

$\zeta = \zeta^\dagger$

$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$

$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = \delta^{(3)}(\vec{k}-\vec{k}')$

ζ_k''

$\ddot{\phi}$

$\hat{\zeta}_k($

$$\langle 0 | \zeta^2(\vec{x}, \eta) | 0 \rangle =$$

$$V(q) = \frac{1}{2} m \omega^2 q^2$$

$$\zeta_k'' + 2\frac{z'}{z}\zeta_k' + \ldots \zeta_k = 0$$

$$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2 \ldots 0$$

$$\hat{\zeta}(\eta, \vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\zeta}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

$$\boxed{\zeta_{\vec{k}} = \zeta_{-\ldots}}$$

$$\hat{\zeta}_k(\eta) = \zeta_{\vec{k}}(\eta)\, \hat{a}_{\vec{k}} + \zeta^*_{-\vec{k}}(\eta)\, \hat{a}_{\vec{k}}$$

$$m\, \zeta, \nu]$$

$$\zeta = \zeta^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = \delta^{(3)}(\vec{k} - \vec{k}')$$

0

$$\langle 0|\zeta^2(\vec{x},\eta)|0\rangle = \int_0^\infty 4\pi k^2 dk (\ldots)$$

$$= \int_0^\infty \frac{dk}{k}(\ldots)$$

$$= \int_{-\infty}^{\infty} d(\ln k)(\ldots)$$

$$\zeta_k'' + 2\frac{z'}{z}\zeta_k' + k^2\zeta_k = 0 \qquad k^2 \to \vec{k}^2$$

$$\ddot\varphi + 3\frac{\dot a}{a}\dot\varphi + m^2\varphi = 0$$

$$\boxed{\zeta_{\vec{k}} = \zeta^\dagger_{-\vec{k}}}$$

$$\hat\zeta(\eta,\vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat\zeta_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$$

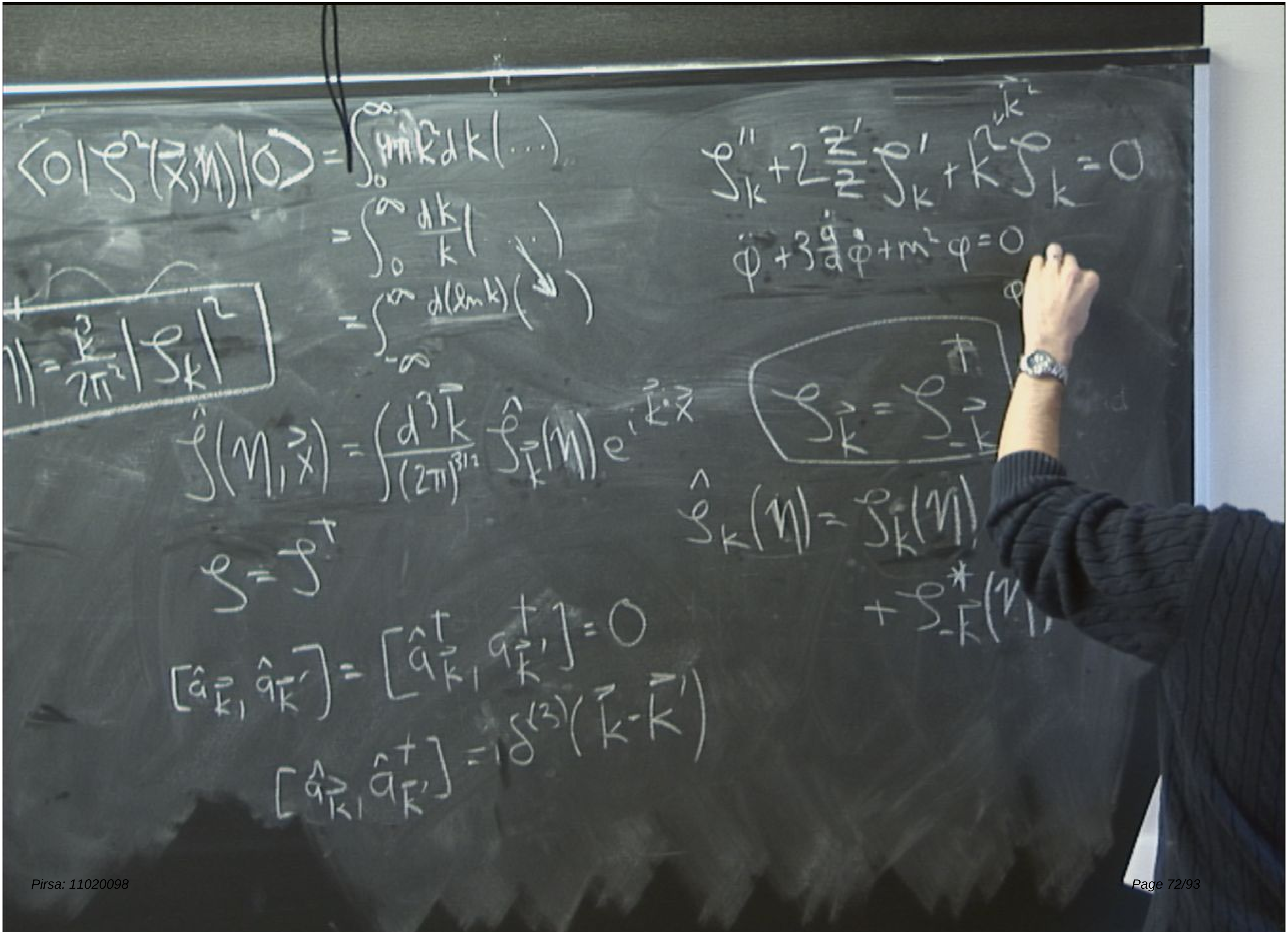
$$\hat\zeta_k(\eta) = \zeta_k(\eta)\hat a_{\vec{k}} + \zeta^*_{-\vec{k}}(\eta)\hat a^\dagger_{\vec{k}}$$

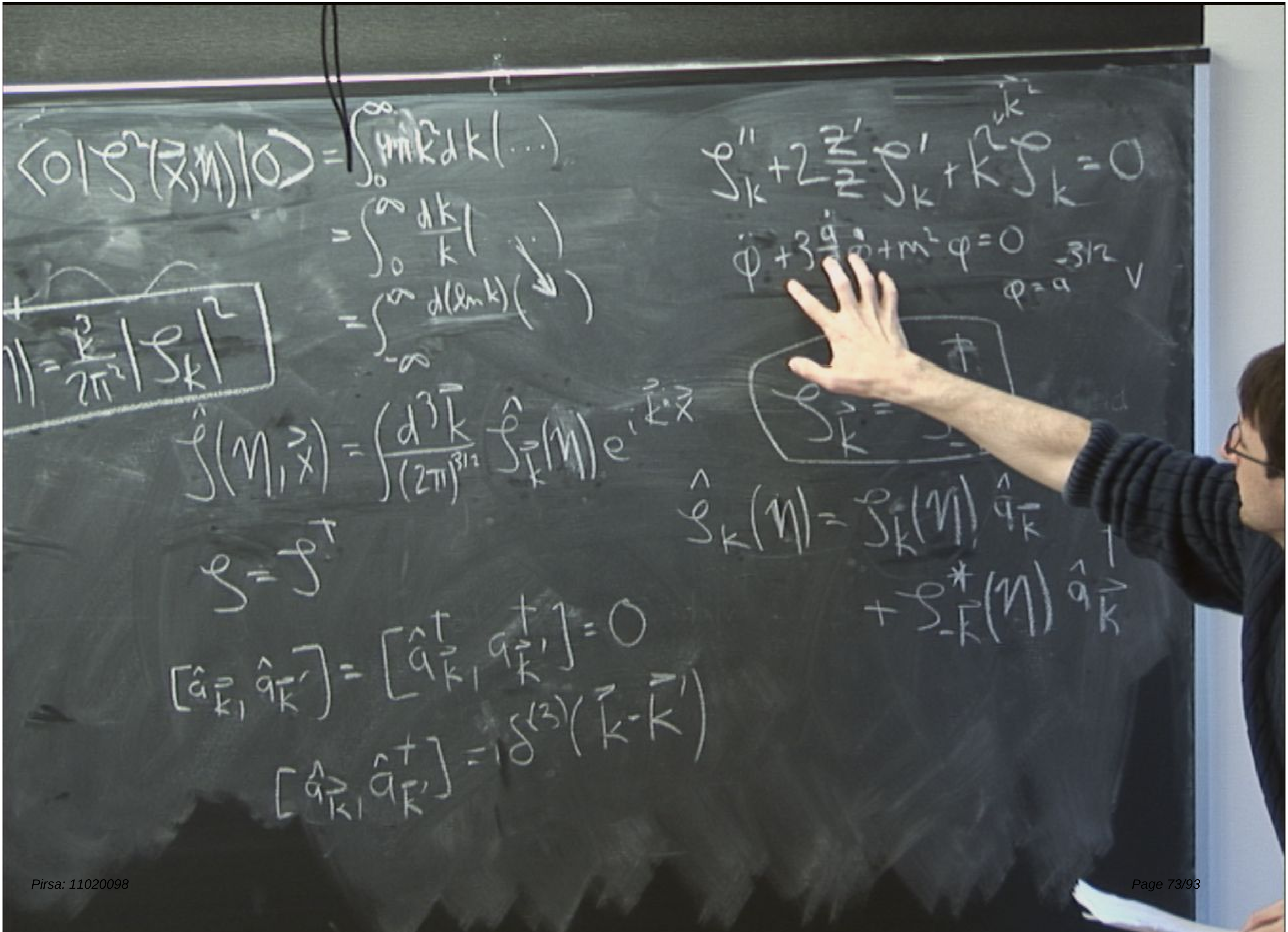
$$\zeta = \zeta^\dagger$$

$$\ldots \zeta_{,\nu}]$$

$$[\hat a_{\vec{k}}, \hat a_{\vec{k}'}] = [\hat a^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$$

$$[\hat a_{\vec{k}}, \hat a^\dagger_{\vec{k}'}] = i\delta^{(3)}(\vec{k}-\vec{k}')$$


$\langle 0|\varsigma^2(\vec{x},\eta)|0\rangle = \int_0^\infty 4\pi k^2 dk(\ldots)$
$= \int_0^\infty \frac{dk}{k}(\ldots)$
$= \int_{-\infty}^{\infty} d(\ln k)(\ \ )$
$\eta) = \frac{k^3}{2\pi^2}|\varsigma_k|^2$
$\hat{\varsigma}(\eta,\vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\varsigma}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$
$\varsigma = \varsigma^\dagger$
$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$
$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = \delta^{(3)}(\vec{k}-\vec{k}')$
$\varsigma''_k + 2\frac{z'}{z}\varsigma'_k + k^2\varsigma_k = 0$
$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2\varphi = 0$
$\varsigma^\dagger_{\vec{k}} = \varsigma_{-\vec{k}}$
$\hat{\varsigma}_k(\eta) = \varsigma_k(\eta)$
$+ \varsigma^*_{-\vec{k}}(\eta)$


$\langle 0|\varphi^2(\vec{x},\eta)|0\rangle = \int_0^\infty 4\pi k^2 dk (\ldots)$
$= \int_0^\infty \frac{dk}{k}(\ldots)$
$= \int_{-\infty}^{\infty} d(\ln k)(\ldots)$
$= \frac{k^3}{2\pi^2}|\varphi_k|^2$
$\hat{\varphi}(\eta,\vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\varphi}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$
$\varphi = \varphi^\dagger$
$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$
$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = \delta^{(3)}(\vec{k}-\vec{k}')$
$\varphi_k'' + 2\frac{z'}{z}\varphi_k' + k^2\varphi_k = 0$
$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2\varphi = 0$
$\varphi = a^{-3/2} v$
$\hat{\varphi}_k(\eta) = \varphi_k(\eta)\,\hat{a}_{\vec{k}} + \varphi^*_{-\vec{k}}(\eta)\,\hat{a}^\dagger_{\vec{k}}$

$$\langle 0|\zeta^2(\vec{x},\eta)|0\rangle = \int_0^\infty 4\pi k^2 dk(\ldots) = \int_0^\infty \frac{dk}{k}(\ldots) = \int_{-\infty}^{\infty} d(\ln k)(\ldots)$$

$$\ldots) = \frac{k^3}{2\pi^2}|\zeta_k|^2$$

$$\hat{\zeta}(\eta,\vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}}\hat{\zeta}_{\vec{k}}(\eta)e^{i\vec{k}\cdot\vec{x}}$$

$$\zeta = \zeta^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = i\delta^{(3)}(\vec{k}-\vec{k}')$$

$$\zeta_k'' + 2\frac{z'}{z}\zeta_k' + k^2\zeta_k = 0$$

$$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2\varphi = 0$$

$$\varphi = a^{-3/2}v$$

$$\zeta_{\vec{k}} = \zeta^\dagger_{-\vec{k}}$$

$$\hat{\zeta}_k(\eta) = \zeta_k(\eta)\ldots + \zeta^*_{-k}\ldots$$

$$\langle 0|\zeta^2(\vec x,\eta)|0\rangle = \int_0^\infty 4\pi k^2\, dk\,(\dots)$$

$$= \int_0^\infty \frac{dk}{k}(\dots)$$

$$= \int_{-\infty}^{\infty} d(\ln k)(\dots)$$

$$\boxed{\dots) = \frac{k^3}{2\pi^2}|\zeta_k|^2}$$

$$\hat\zeta(\eta,\vec x) = \int \frac{d^3\vec k}{(2\pi)^{3/2}}\, \hat\zeta_{\vec k}(\eta)\, e^{i\vec k\cdot\vec x}$$

$$\zeta = \zeta^\dagger$$

$$[\hat a_{\vec k}, \hat a_{\vec k'}] = [\hat a^\dagger_{\vec k}, a^\dagger_{\vec k'}] = 0$$

$$[\hat a_{\vec k}, \hat a^\dagger_{\vec k'}] = \delta^{(3)}(\vec k - \vec k')$$

$$\zeta_k'' + 2\frac{z'}{z}\zeta_k' + k^2\zeta_k = 0$$

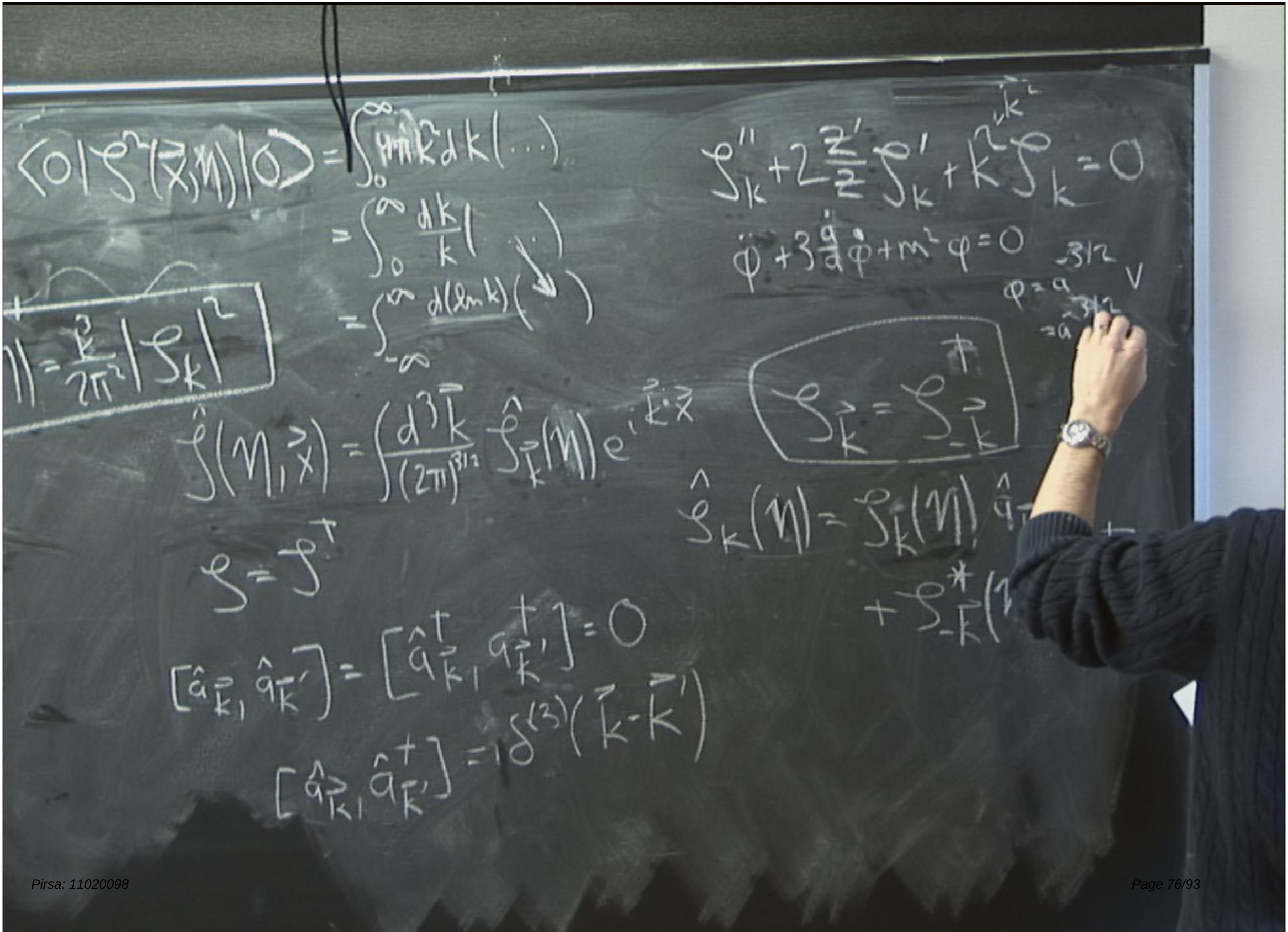
$$\ddot\varphi + 3\frac{\dot a}{a}\dot\varphi + m^2\varphi = 0$$

$$\varphi = a^{-3/2}\, v$$

$$\boxed{\zeta_{\vec k} = \zeta^\dagger_{-\vec k}}$$

$$\hat\zeta_k(\eta) = \zeta_k(\eta)\dots$$

$$+\, \zeta^*_{-k}\dots$$


$\langle 0|\zeta^2(\vec{x},\eta)|0\rangle = \int_0^\infty 4\pi k^2 dk(\ldots)$
$= \int_0^\infty \frac{dk}{k}(\ldots)$
$= \int_{-\infty}^{\infty} d(\ln k)(\ldots)$
$= \frac{k^3}{2\pi^2}|\zeta_k|^2$
$\hat{\zeta}(\eta,\vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\zeta}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$
$\zeta = \zeta^\dagger$
$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$
$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = \delta^{(3)}(\vec{k}-\vec{k}')$
$\zeta''_k + 2\frac{z'}{z}\zeta'_k + k^2\zeta_k = 0$
$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2\varphi = 0$
$\varphi = a^{-3/2} v$
$\zeta_{\vec{k}} = \zeta^\dagger_{-\vec{k}}$
$\hat{\zeta}_k(\eta) = \zeta_k(\eta)\,\hat{a}_{\vec{k}} + \zeta^*_{-\vec{k}}(\eta)\ldots$

$$\langle 0|\varrho^2(\vec x,\eta)|0\rangle = \int_0^\infty 4\pi k^2\, dk\,(\dots)$$

$$= \int_0^\infty \frac{dk}{k}(\dots)$$

$$= \int_{-\infty}^{\infty} d(\ln k)(\dots)$$

$$\boxed{\dots) = \frac{k^3}{2\pi^2}|\varrho_k|^2}$$

$$\hat\varrho(\eta,\vec x) = \int \frac{d^3\vec k}{(2\pi)^{3/2}}\, \hat\varrho_{\vec k}(\eta)\, e^{i\vec k\cdot\vec x}$$

$$\varrho = \varrho^\dagger$$

$$[\hat a_{\vec k}, \hat a_{\vec k'}] = [\hat a^\dagger_{\vec k}, a^\dagger_{\vec k'}] = 0$$

$$[\hat a_{\vec k}, \hat a^\dagger_{\vec k'}] = \delta^{(3)}(\vec k - \vec k')$$

$$\varrho_k'' + 2\frac{z'}{z}\varrho_k' + k^2\varrho_k = 0$$

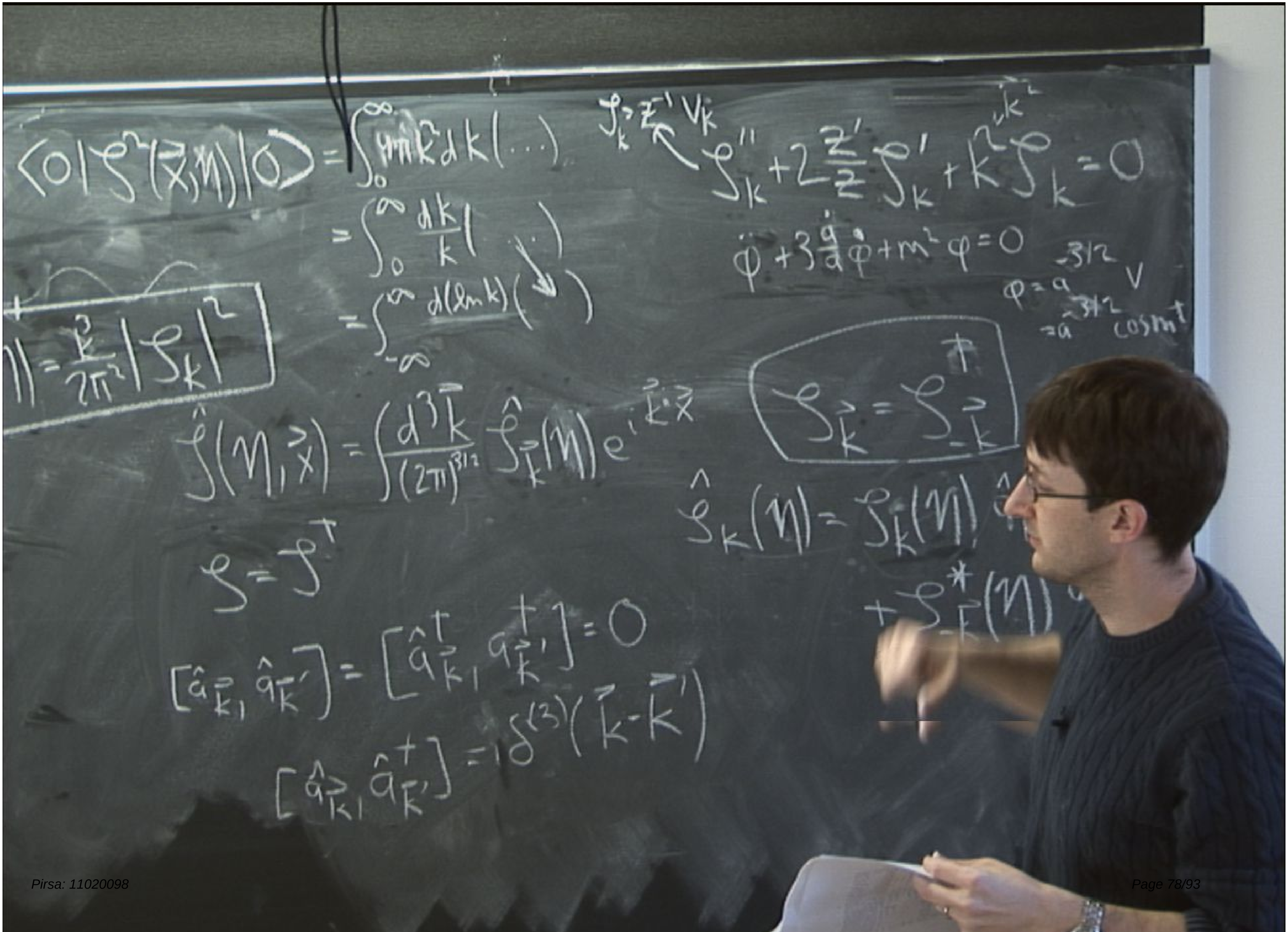
$$\ddot\varphi + 3\frac{\dot a}{a}\dot\varphi + m^2\varphi = 0$$

$$\varphi = a^{-3/2} V$$

$$= a^{-3/2}\cos mt$$

$$\boxed{\varrho_{\vec k} = \varrho^\dagger_{-\vec k}}$$

$$\hat\varrho_k(\eta) = \varrho_k(\eta)\,\hat a_{\vec k} + \varrho^*_{-\vec k}(\eta)\,\hat a^\dagger_{\vec k}$$



$\zeta_k = z^{-1} v_k$
$\langle 0|\zeta^2(\vec{x},\eta)|0\rangle = \int_0^\infty 4\pi k^2 dk (\dots)$
$= \int_0^\infty \frac{dk}{k} (\dots)$
$= \int_{-\infty}^{\infty} d(\ln k) (\dots)$
$= \frac{k^3}{2\pi^2} |\zeta_k|^2$
$\zeta_k'' + 2\frac{z'}{z}\zeta_k' + k^2 \zeta_k = 0$
$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2\varphi = 0$
$\varphi = a^{-3/2} v$
$= a^{-3/2} \cos mt$
$\zeta_{\vec{k}} = \zeta^\dagger_{-\vec{k}}$
$\hat{\zeta}(\eta,\vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \hat{\zeta}_{\vec{k}}(\eta) e^{i\vec{k}\cdot\vec{x}}$
$\hat{\zeta}_k(\eta) = \zeta_k(\eta)$
$+ \zeta^*_{-\vec{k}}(\eta)$
$\zeta = \zeta^\dagger$
$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$
$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = \delta^{(3)}(\vec{k}-\vec{k}')$

$$\langle 0|\varsigma^2(\vec{x},\eta)|0\rangle = \int_0^\infty 4\pi k^2\, dk\,(\ldots)$$

$$= \int_0^\infty \frac{dk}{k}(\ldots)$$

$$= \int_{-\infty}^{\infty} d(\ln k)\,(\ldots)$$

$$\boxed{\ldots) = \frac{k^3}{2\pi^2}|\varsigma_k|^2}$$

$$\hat{\varsigma}(\eta,\vec{x}) = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}}\,\hat{\varsigma}_{\vec{k}}(\eta)\,e^{i\vec{k}\cdot\vec{x}}$$

$$\varsigma = \varsigma^\dagger$$

$$[\hat{a}_{\vec{k}}, \hat{a}_{\vec{k}'}] = [\hat{a}^\dagger_{\vec{k}}, a^\dagger_{\vec{k}'}] = 0$$

$$[\hat{a}_{\vec{k}}, \hat{a}^\dagger_{\vec{k}'}] = \delta^{(3)}(\vec{k}-\vec{k}')$$

$$\varsigma_k = z^{-1} v_k$$

$$\varsigma_k'' + 2\frac{z'}{z}\varsigma_k' + k^2\varsigma_k = 0$$

$$\ddot{\varphi} + 3\frac{\dot{a}}{a}\dot{\varphi} + m^2\varphi = 0$$

$$\varphi = a^{-3/2}V = a^{-3/2}\cos mt$$

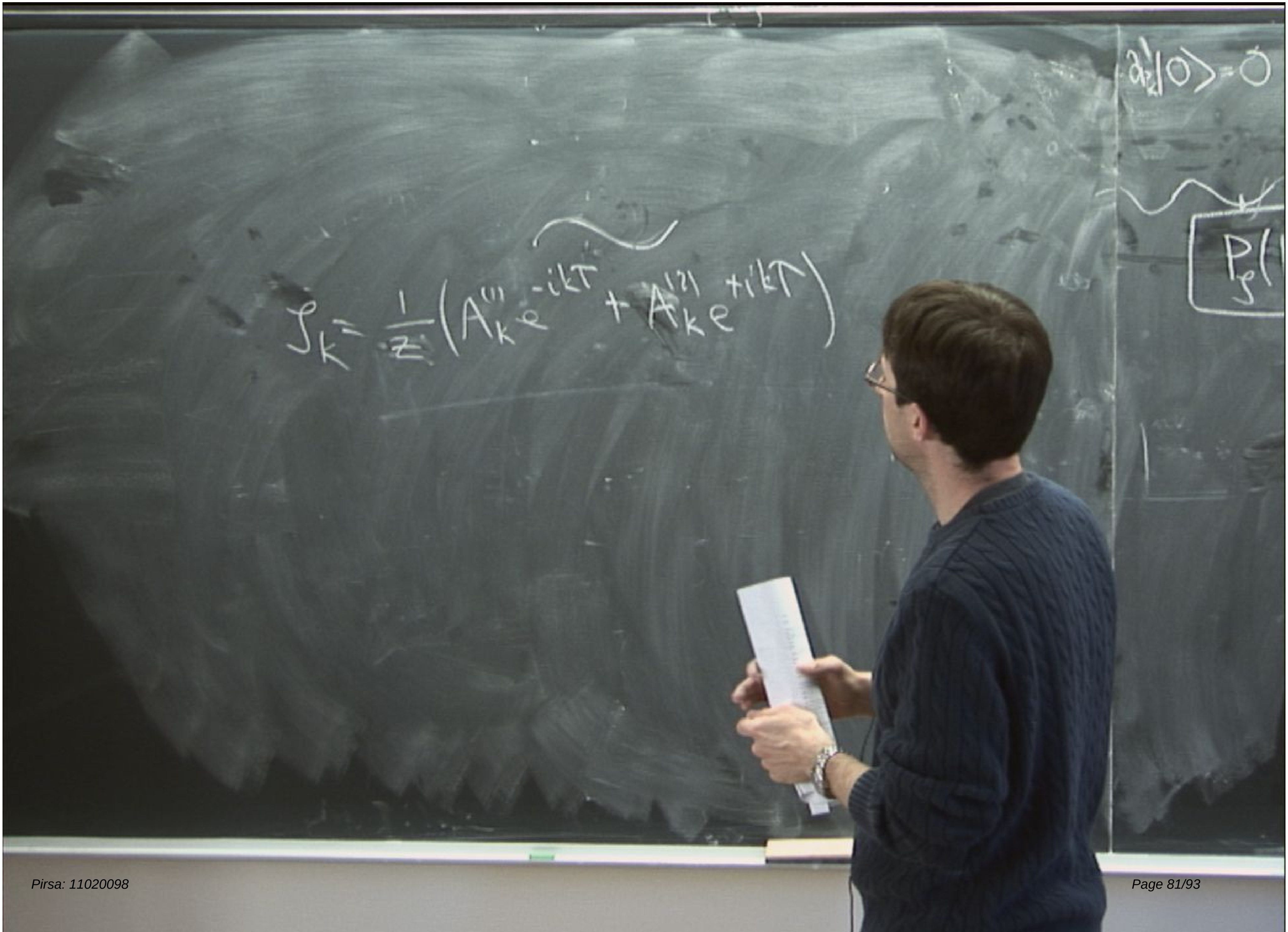
$$\boxed{\varsigma_{\vec{k}} = \varsigma^\dagger_{-\vec{k}}}$$

$$\hat{\varsigma}_k(\eta) = \varsigma_k(\eta)\,\hat{a}_{\vec{k}} + \varsigma^*_{-\vec{k}}(\eta)\,\hat{a}^\dagger_{\vec{k}}$$

$$\rho_k = \frac{1}{z}\left(A^{(1)}_k e^{-ik\tau} + A^{(2)}_k e^{+ik\tau}\right)$$

$a_k^\dagger |0\rangle = 0$

$P_\rho($



$a_k|0\rangle = 0$
$\varphi_k = \frac{1}{2}\left(A_k^{(1)} e^{-ik\tau} + A_k^{(2)} e^{+ik\tau}\right)$

$a_k|0\rangle = 0$

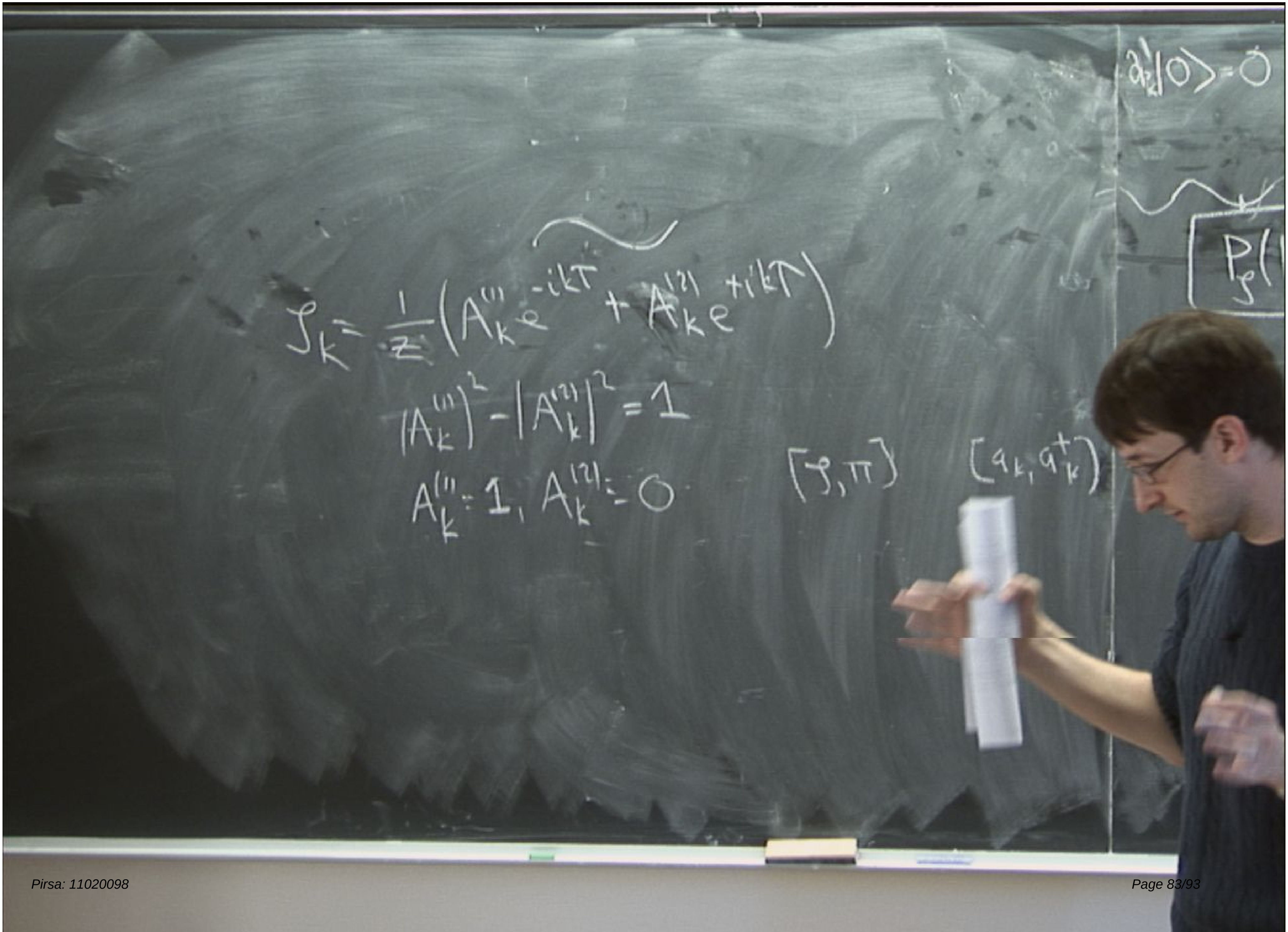
$$\varphi_k = \frac{1}{2}\left(A_k^{(1)} e^{-ik\tau} + A_k^{(2)} e^{+ik\tau}\right)$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1,\ A_k^{(2)} = 0$$

$[\varphi, \pi]$ $\quad$ $[a_k, a_k^\dagger]$

$\boxed{P_\varphi(}$


$a_k|0\rangle = 0$
$\varphi_k = \frac{1}{2}\left(A_k^{(1)} e^{-ik\tau} + A_k^{(2)} e^{+ik\tau}\right)$
$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$
$A_k^{(1)} = 1,\ A_k^{(2)} = 0$
$[\varphi, \pi]$
$[a_k, a_k^\dagger]$

$$e^{-i\omega t + i\vec{k}\cdot\vec{x}}$$

$$a_k|0\rangle = 0$$

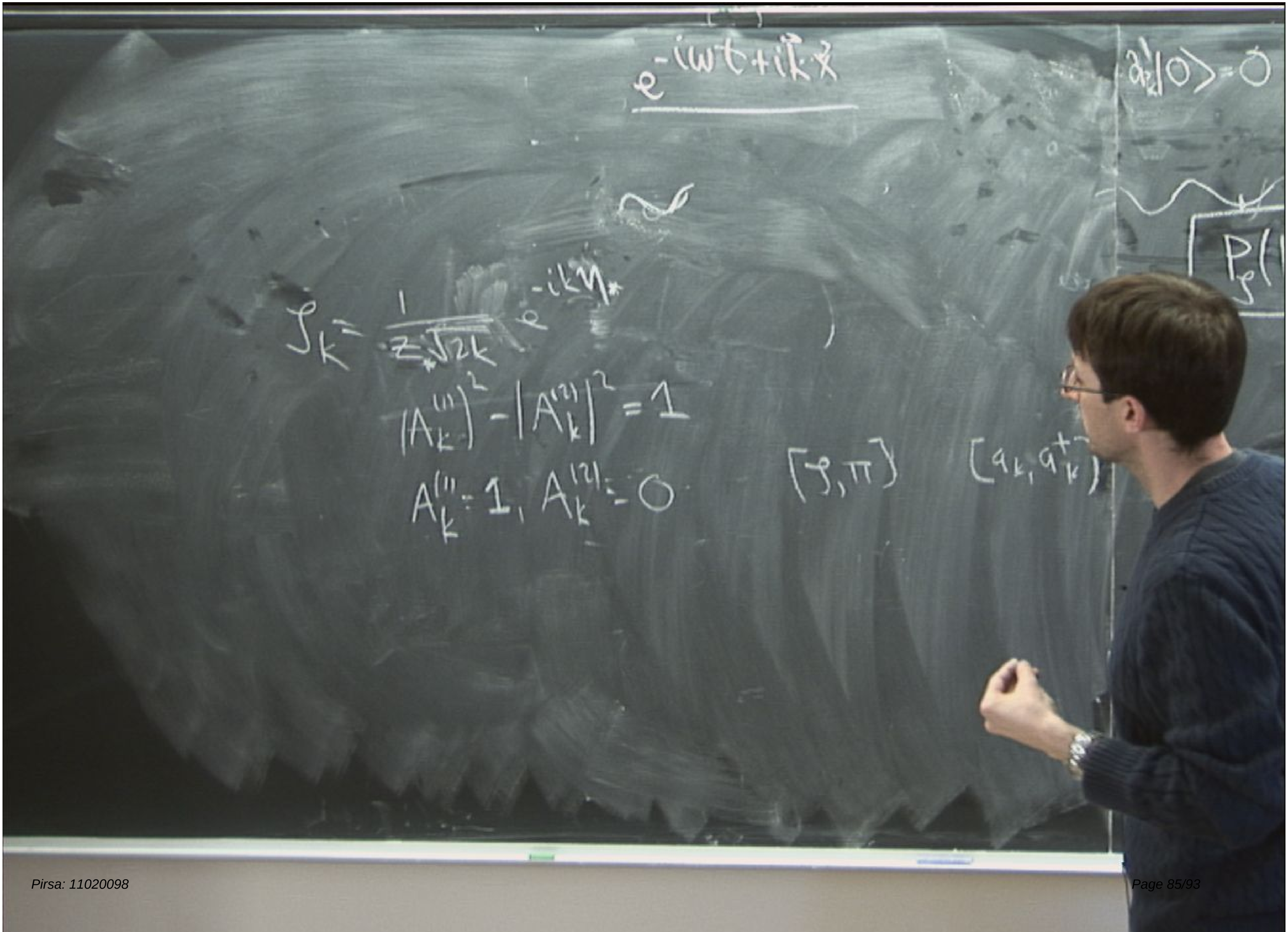
$$\boxed{P_\varphi(}$$

$$\varphi_k = \frac{1}{z\sqrt{2k}} e^{-ik\tau}$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, \; A_k^{(2)} = 0$$

$$[\varphi, \pi] \qquad [a_k, a_k^\dagger]$$


$e^{-i\omega t + i\vec{k}\cdot\vec{x}}$
$a_k|0\rangle = 0$
$\varphi_k = \frac{1}{z_*\sqrt{2k}} e^{-ik\eta_*}$
$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$
$A_k^{(1)} = 1,\ A_k^{(2)} = 0$
$[\varphi, \pi]$
$[a_k, a_k^+]$

$$e^{-i\omega t + i\vec{k}\cdot\vec{x}}$$

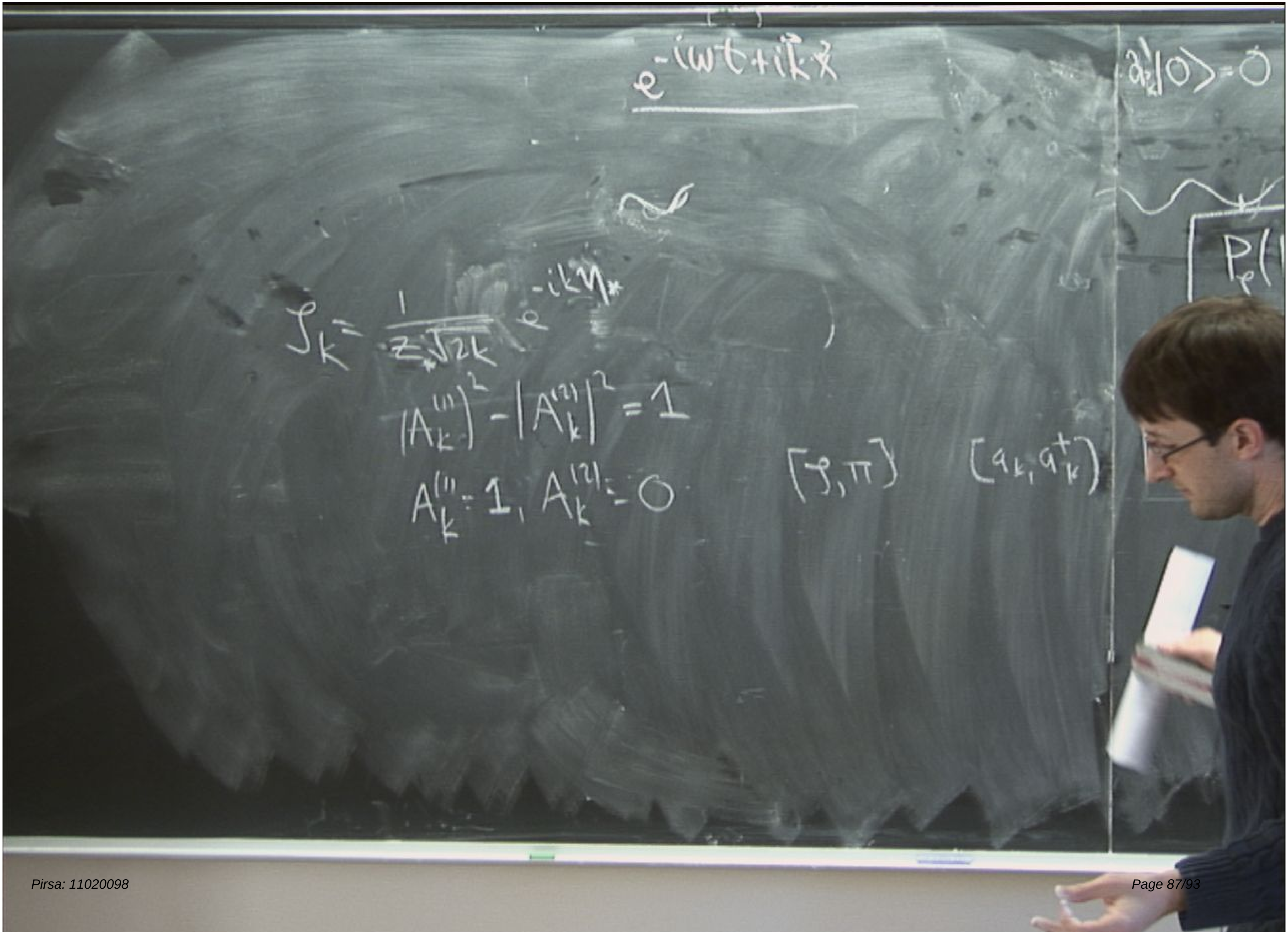
$$a_{\vec{k}}|0\rangle = 0$$

$$\zeta_k = \frac{1}{z_*\sqrt{2k}}\, e^{-ik\eta_*}$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1,\ A_k^{(2)} = 0 \qquad [\zeta, \pi] \qquad [a_k, a_k^\dagger]$$

$P_\zeta($


e^{-iωt+ik·x}
a_k|0> = 0
ρ_k = 1/(z_* √2k) e^{-ikη_*}
|A_k^(1)|^2 - |A_k^(2)|^2 = 1
A_k^(1) = 1, A_k^(2) = 0
[ρ, π]
[a_k, a_k^†]

$$e^{-i\omega t + i\vec{k}\cdot\vec{x}}$$

$$a_k|0\rangle = 0$$

$$\boxed{P_\varphi(}$$

$$\varphi_k = \frac{1}{z\sqrt{2k}} e^{-ik\eta_*}$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, \quad A_k^{(2)} = 0$$

$$[\varphi, \pi] \qquad [a_k, a_k^\dagger]$$

$$e^{-i\omega t + i\vec{k}\cdot\vec{x}}$$

$$a_k|0\rangle = 0$$

$$\zeta_k = \frac{1}{z\sqrt{2k}} e^{-ik\eta_*}$$

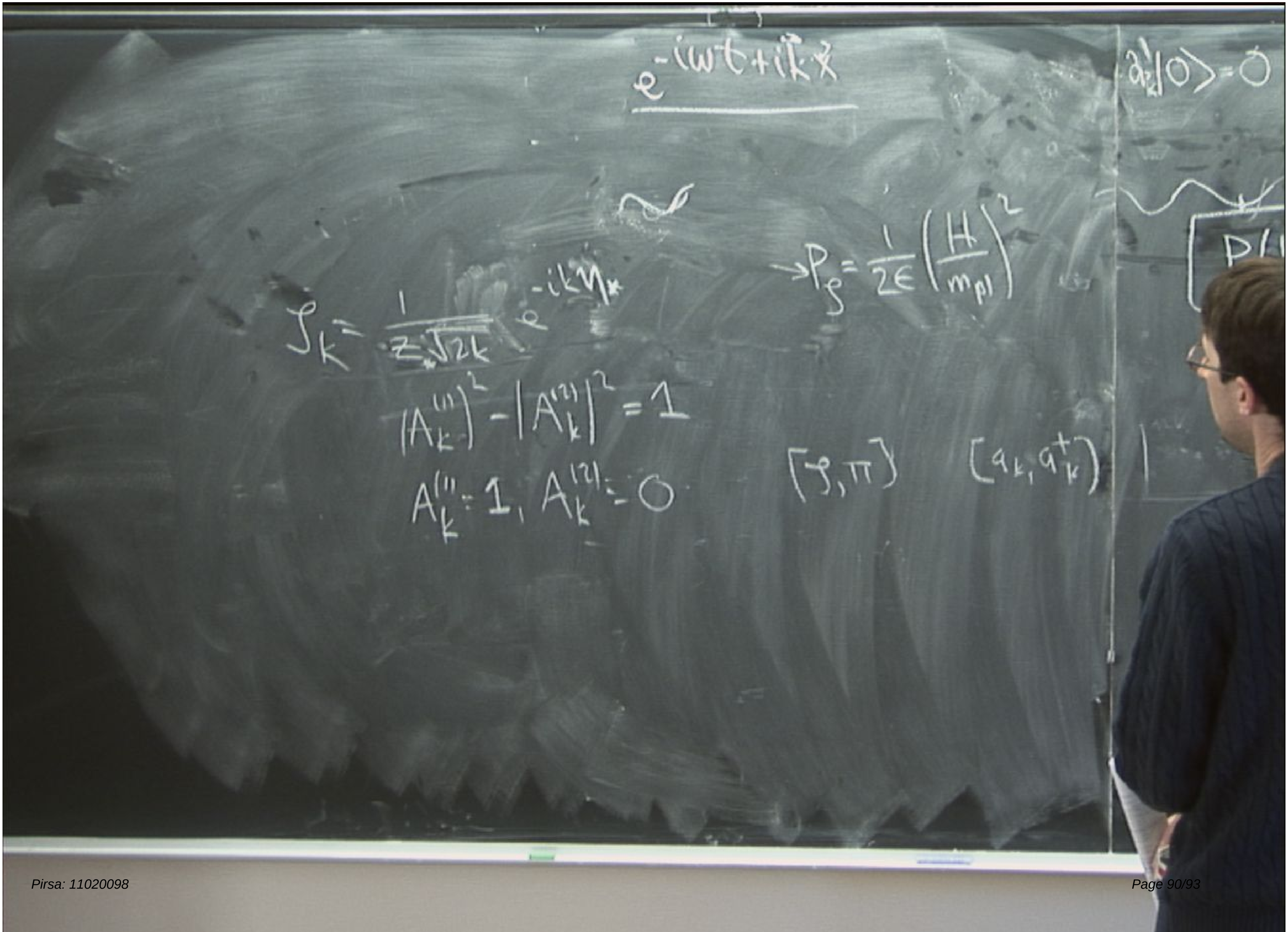
$$P_\zeta = \frac{1}{2\epsilon}\left(\frac{H}{m_{pl}}\right)^2$$

$$P_\zeta(\ldots$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1,\ A_k^{(2)} = 0$$

$$[\zeta, \pi] \qquad [a_k, a_k^\dagger]$$



$e^{-i\omega t + i\vec{k}\cdot\vec{x}}$
$a_k|0\rangle = 0$
$\zeta_k = \frac{1}{z_*\sqrt{2k}} e^{-ik\eta_*}$
$\to P_\zeta = \frac{1}{2\epsilon}\left(\frac{H}{m_{pl}}\right)^2$
$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$
$A_k^{(1)} = 1,\ A_k^{(2)} = 0$
$[\zeta, \pi]$
$[a_k, a_k^\dagger]$

$e^{-i\omega t + i\vec{k}\cdot\vec{x}}$

$\lambda = \frac{2\pi}{k}$

$a_k|0\rangle = 0$

$\zeta_k = \frac{1}{z_*\sqrt{2k}} e^{-ik\eta_*}$

$$\boxed{P_\zeta^{(k)} = \frac{1}{2\epsilon}\left(\frac{H}{m_{pl}}\right)^2}$$

$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$

$A_k^{(1)} = 1,\ A_k^{(2)} = 0$

$[\zeta, \pi]$ $\quad [a_k, a_k^\dagger]$

$P_\zeta($

$$e^{-i\omega t + i\vec{k}\cdot\vec{x}}$$

$$\lambda = \frac{2\pi}{k}$$

$$\hat{a}_k |0\rangle = 0$$

$$\boxed{P_\zeta^{(k)} = \frac{1}{2\epsilon}\left(\frac{H}{m_{pl}}\right)^2}$$

$$\boxed{P_\zeta(}$$

$$\zeta_k = \frac{1}{z_* \sqrt{2k}} e^{-ik\eta_*}$$

$$V(\phi)$$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1, \quad A_k^{(2)} = 0$$

$$[\zeta, \pi] \qquad [a_k, a_k^\dagger]$$

$$V(\varphi) = \frac{1}{2} m^2 \varphi^2$$

$e^{-i\omega t + i\vec{k}\cdot\vec{x}}$

$\lambda = \frac{2\pi}{k}$

$a_k^\dagger|0\rangle = 0$

$$\boxed{P_\zeta^{(k)} = \frac{1}{2\epsilon}\left(\frac{H}{m_{pl}}\right)^2}$$

$\boxed{P_\zeta(}$

$$\zeta_k = \frac{1}{z\sqrt{2k}} e^{-ik\eta_k}$$

$V(\varphi)$

$$|A_k^{(1)}|^2 - |A_k^{(2)}|^2 = 1$$

$$A_k^{(1)} = 1,\ A_k^{(2)} = 0$$

$[\zeta, \pi]$ $\qquad$ $[a_k, a_k^\dagger]$

$$\boxed{V(\varphi) = \frac{1}{2}\boxed{m^2}\varphi^2}$$