Title: Is the cosmic singularity the key?

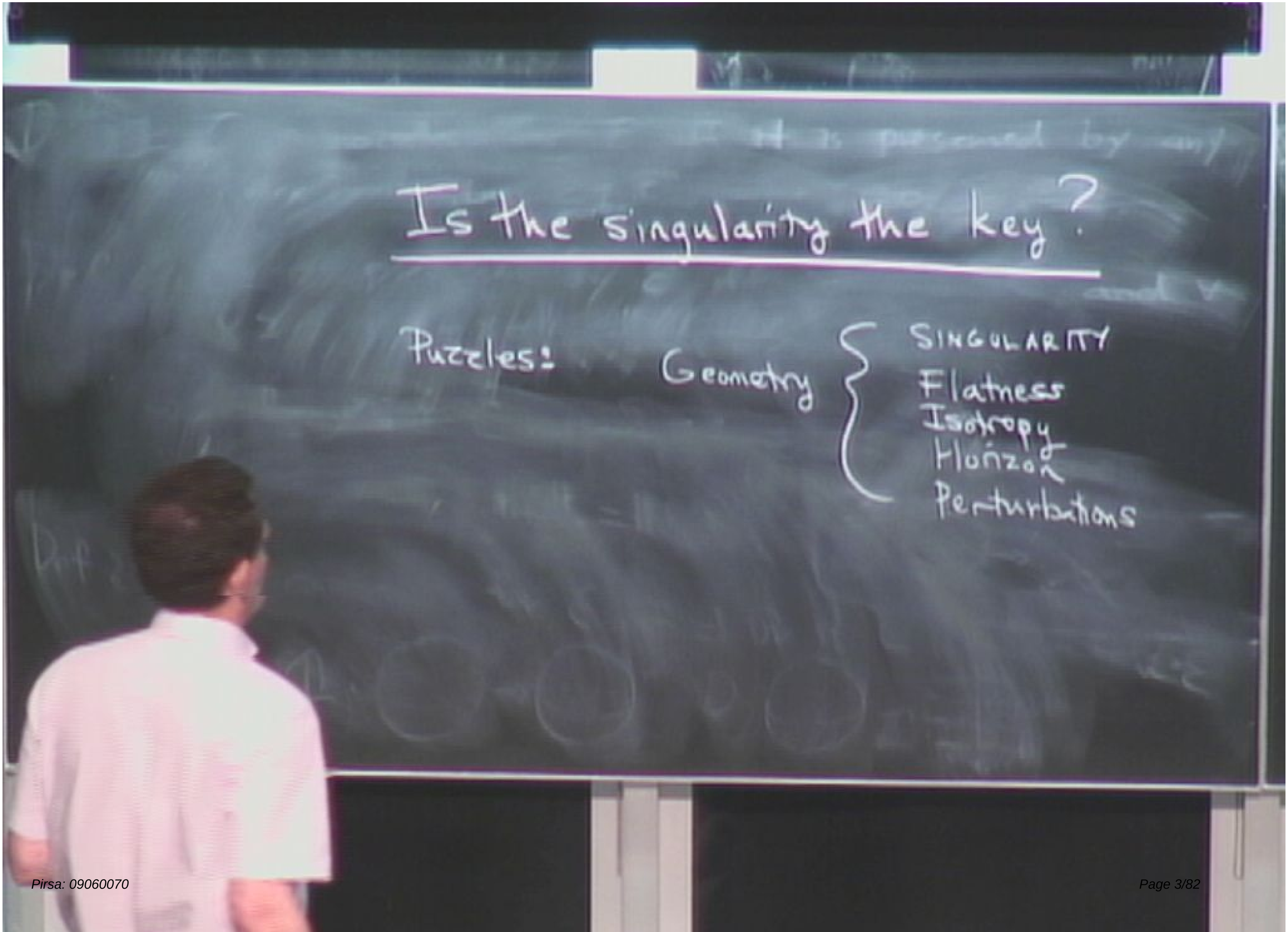
Date: Jun 25, 2009 02:30 PM

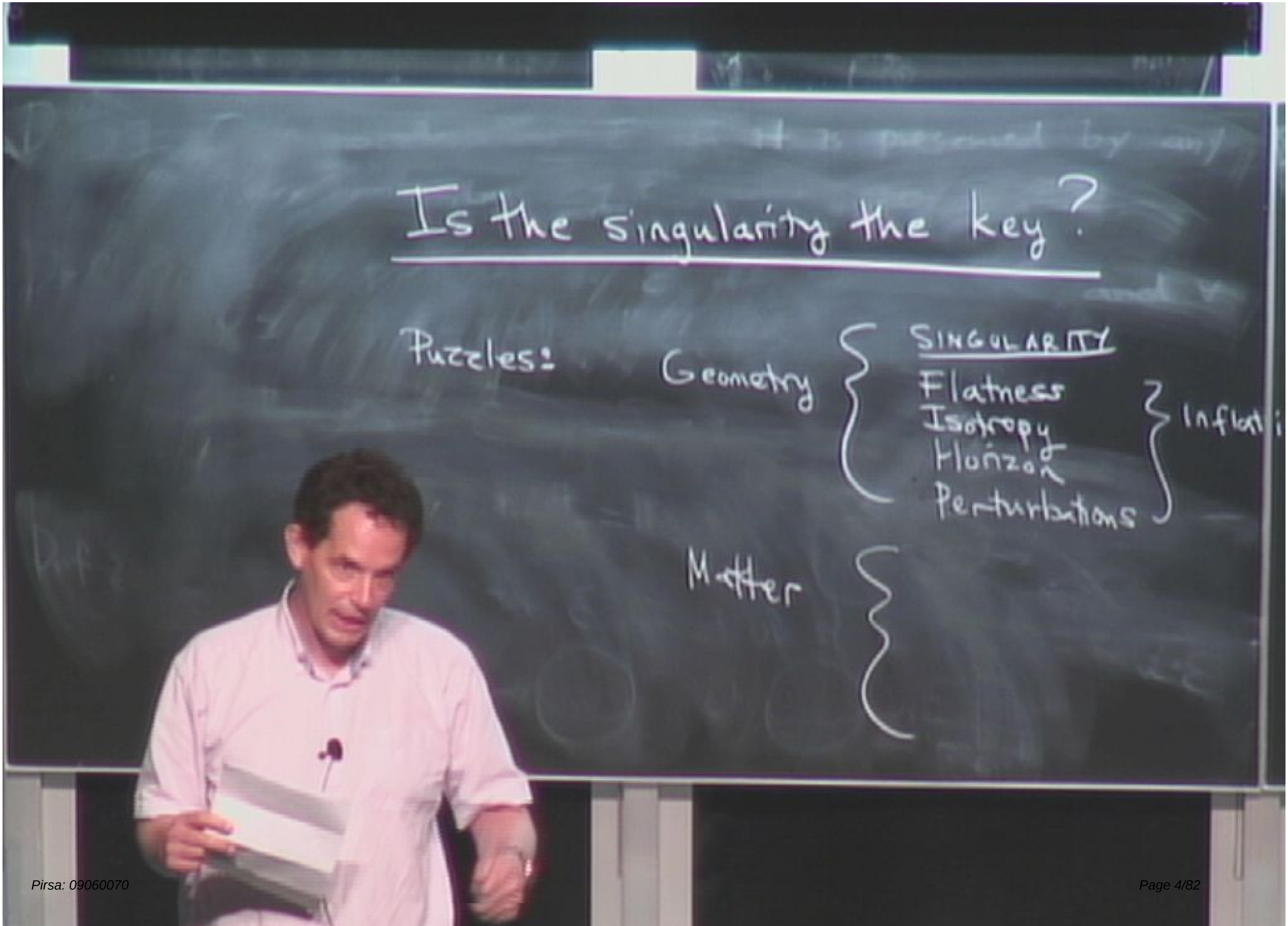
URL: http://pirsa.org/09060070

Abstract:

Is the singularity the key?

Puzzles: Geometry { SINGULARITY


Is the singularity the key?
Puzzles:
Geometry
SINGULARITY
Flatness
Isotropy
Horizon
Perturbations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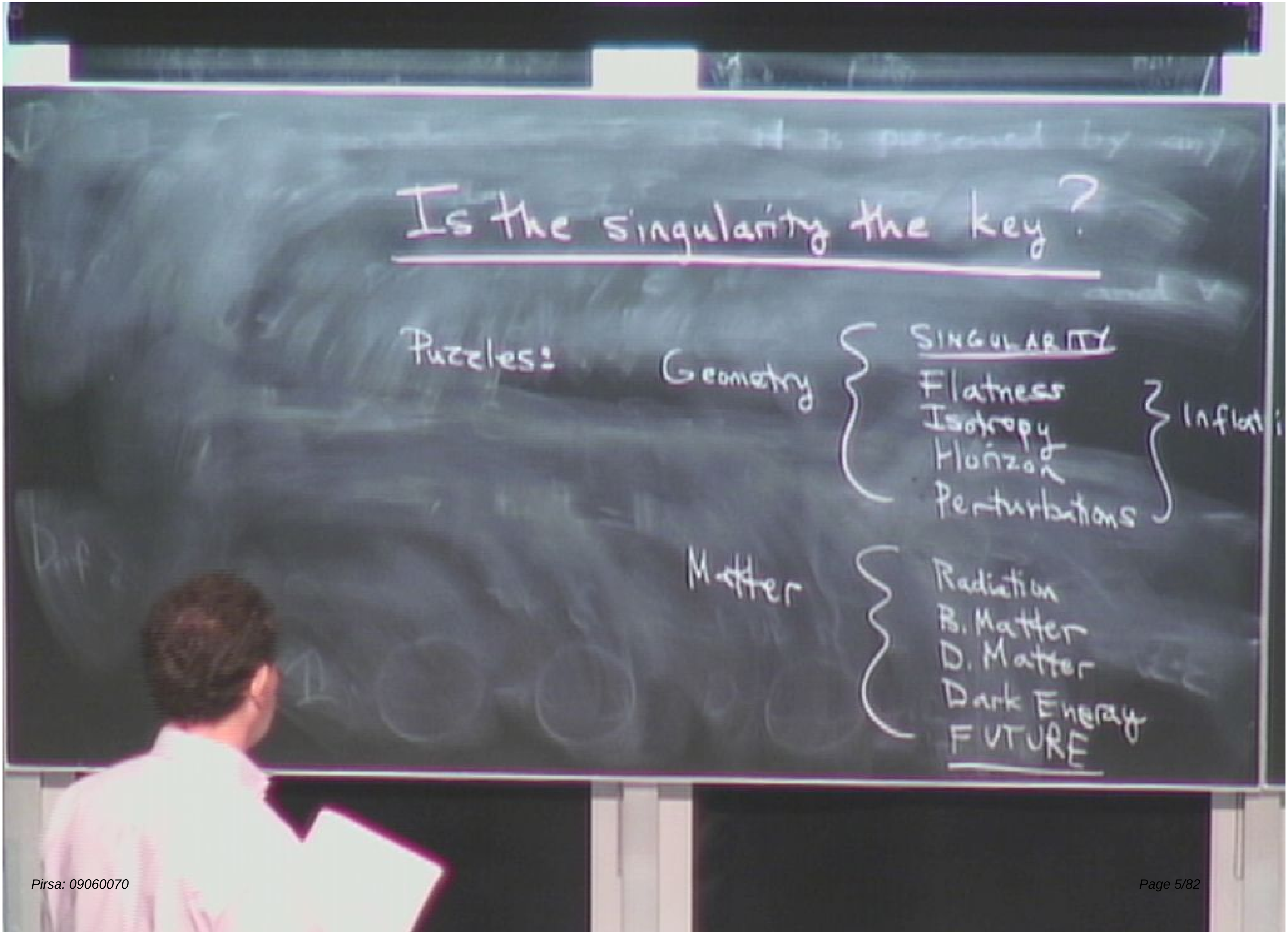
Inflat
Matter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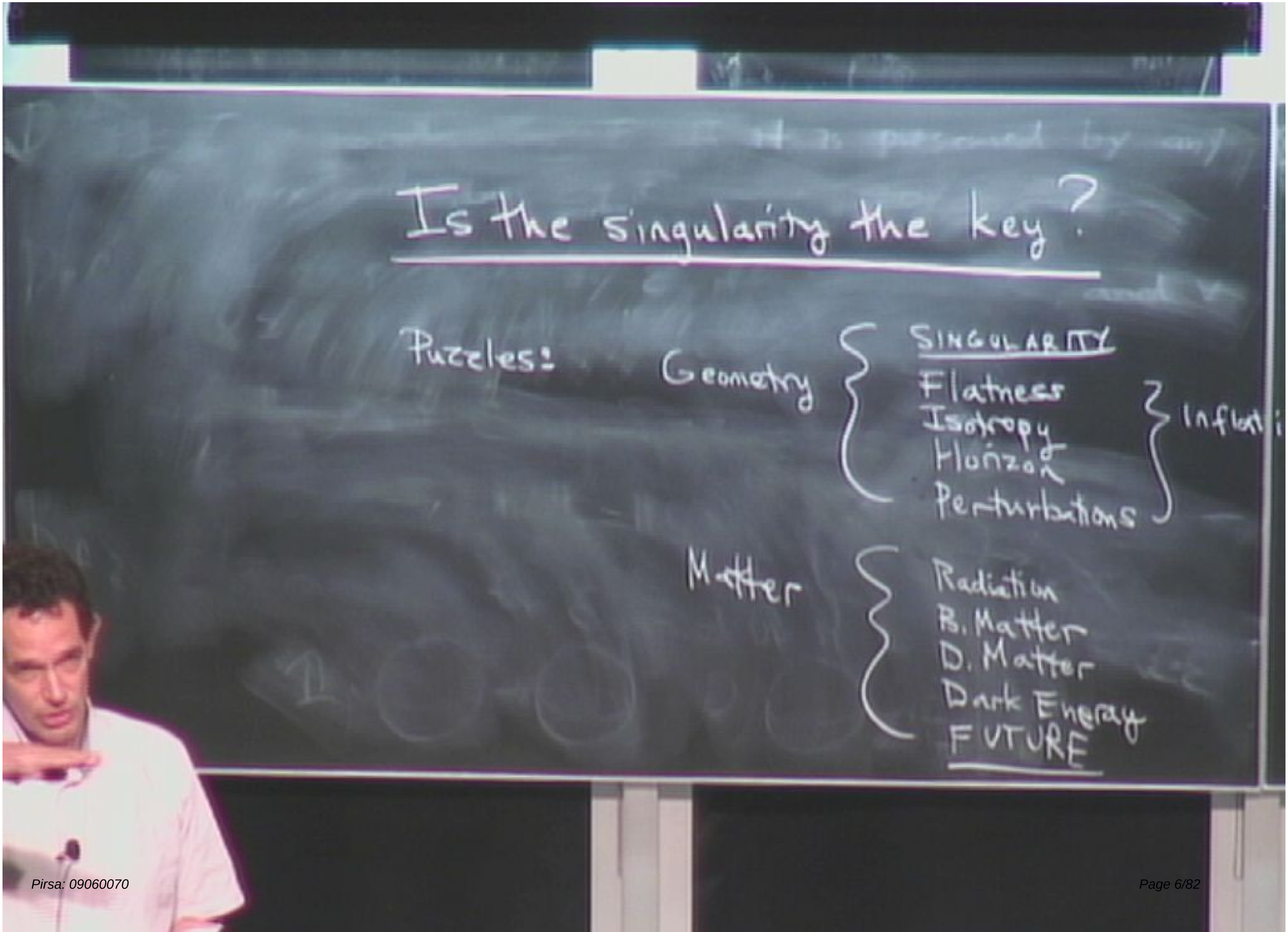
Horizon
Perturbations
Inflation
Matter
Radiation
B. Matter
D. Matter
Dark Energy
FUTURE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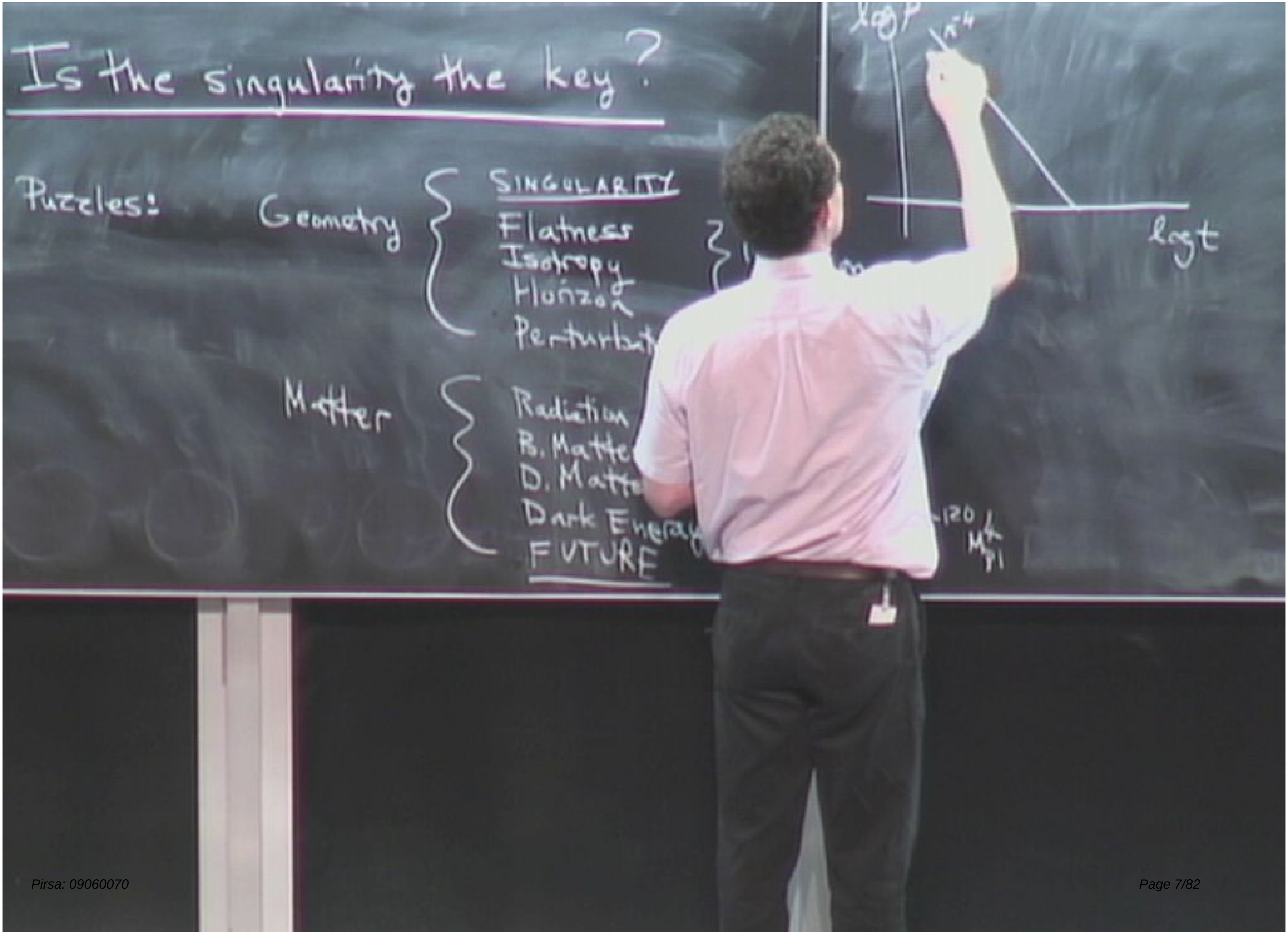
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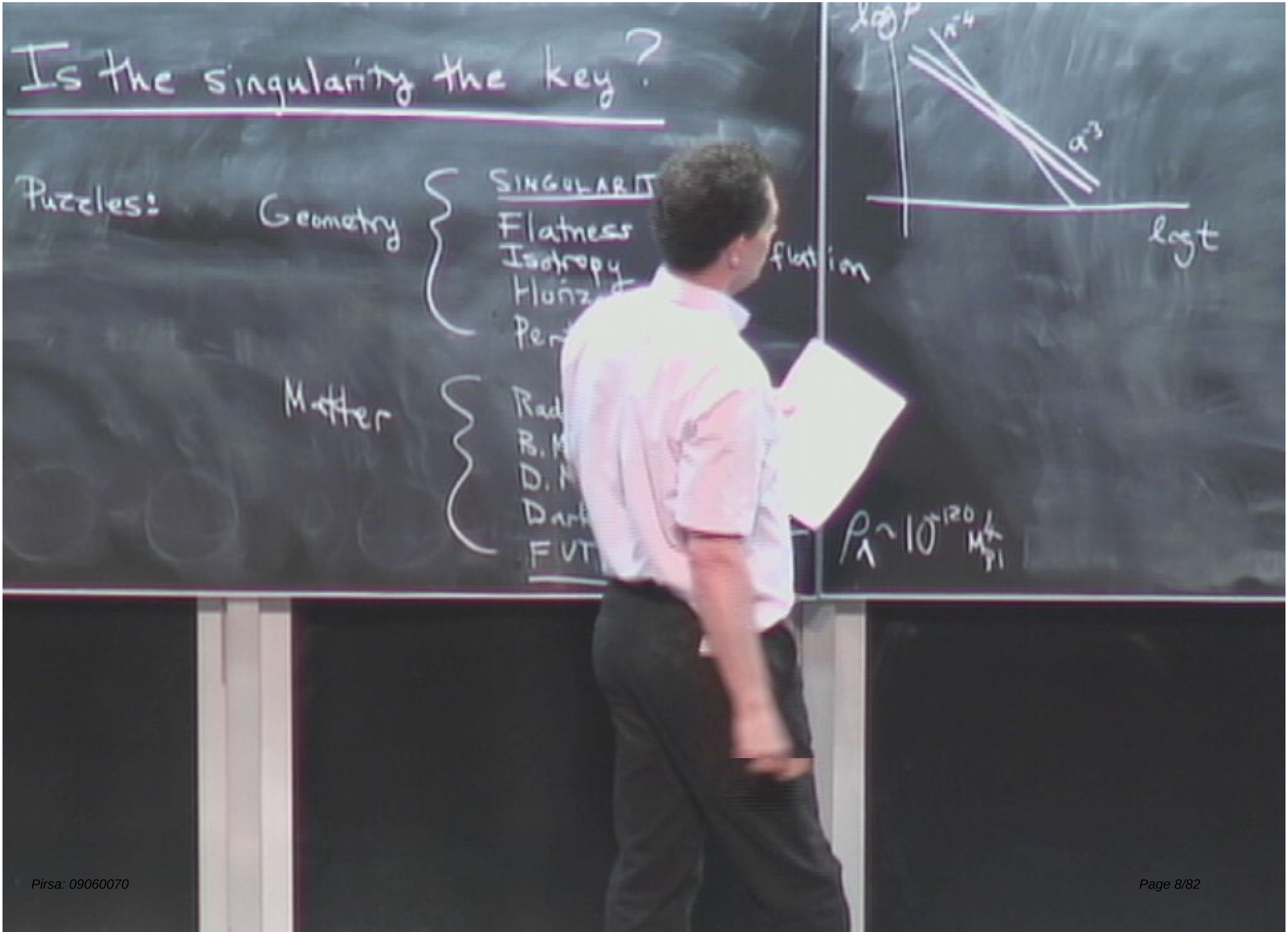
Dark Energy
FUTURE
log t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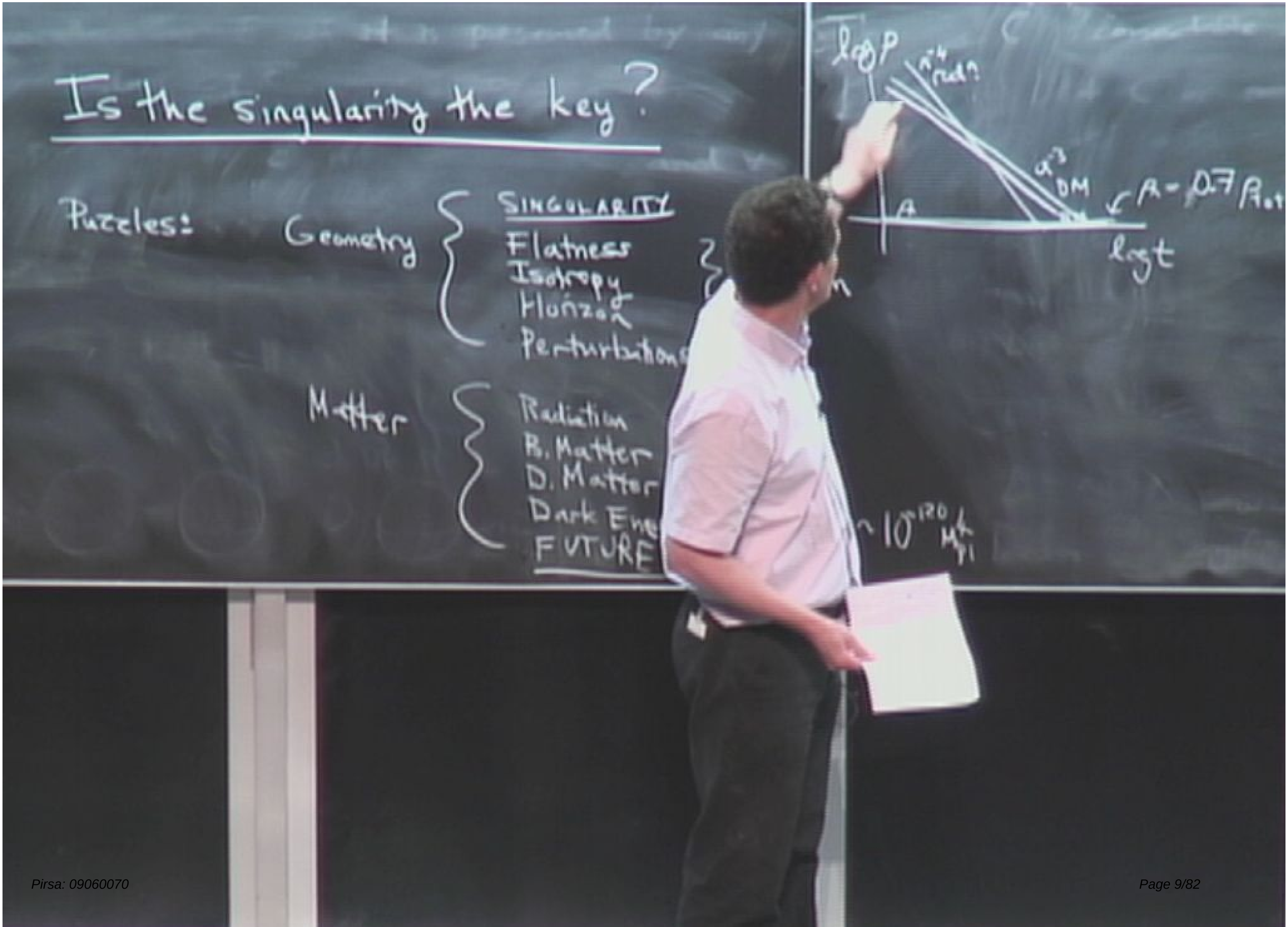
D.
Dark
FUT
log ρ
a^-4
a^-3
log t
ρ_Λ ~ 10^-120 M_Pl^4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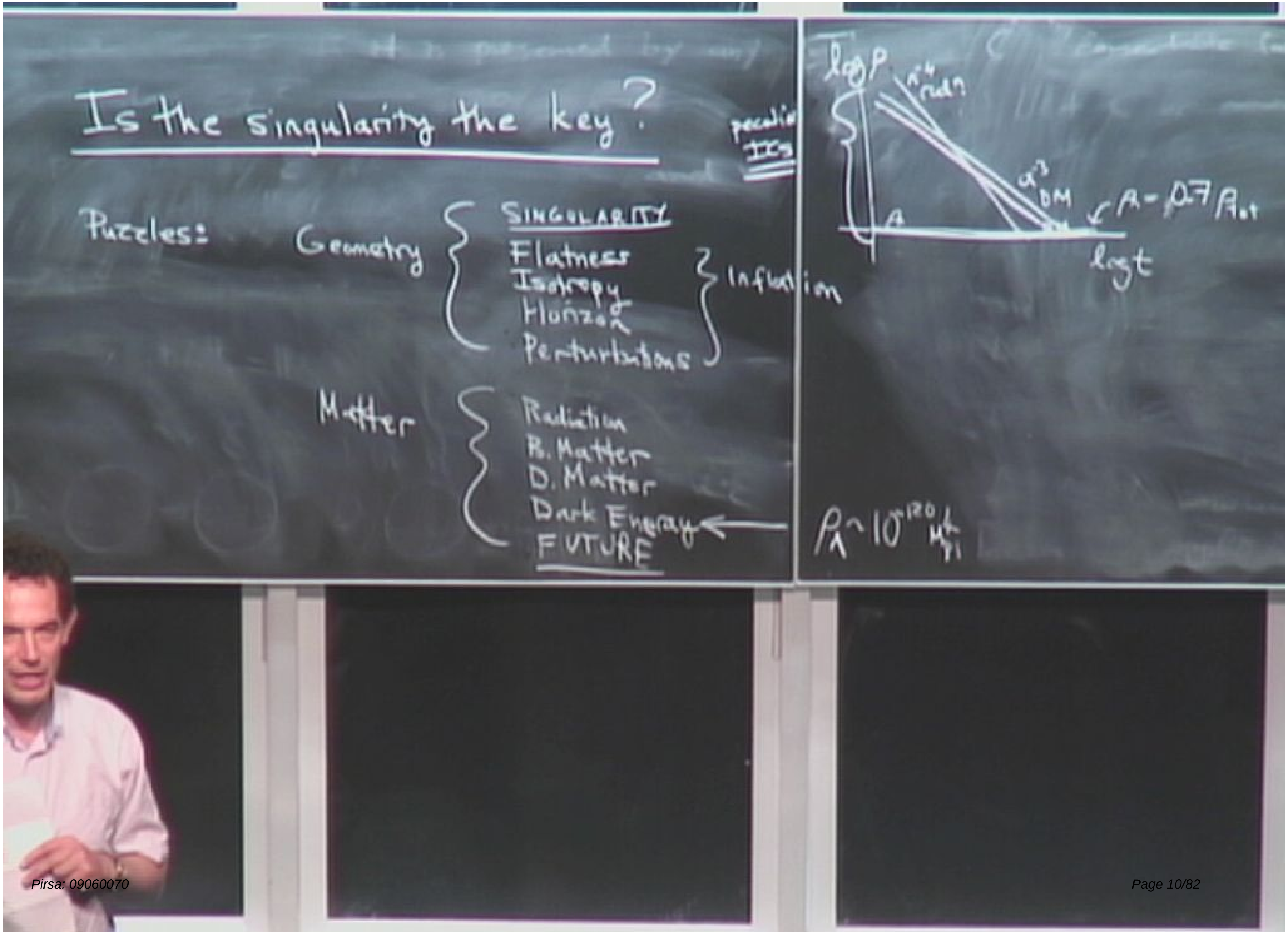
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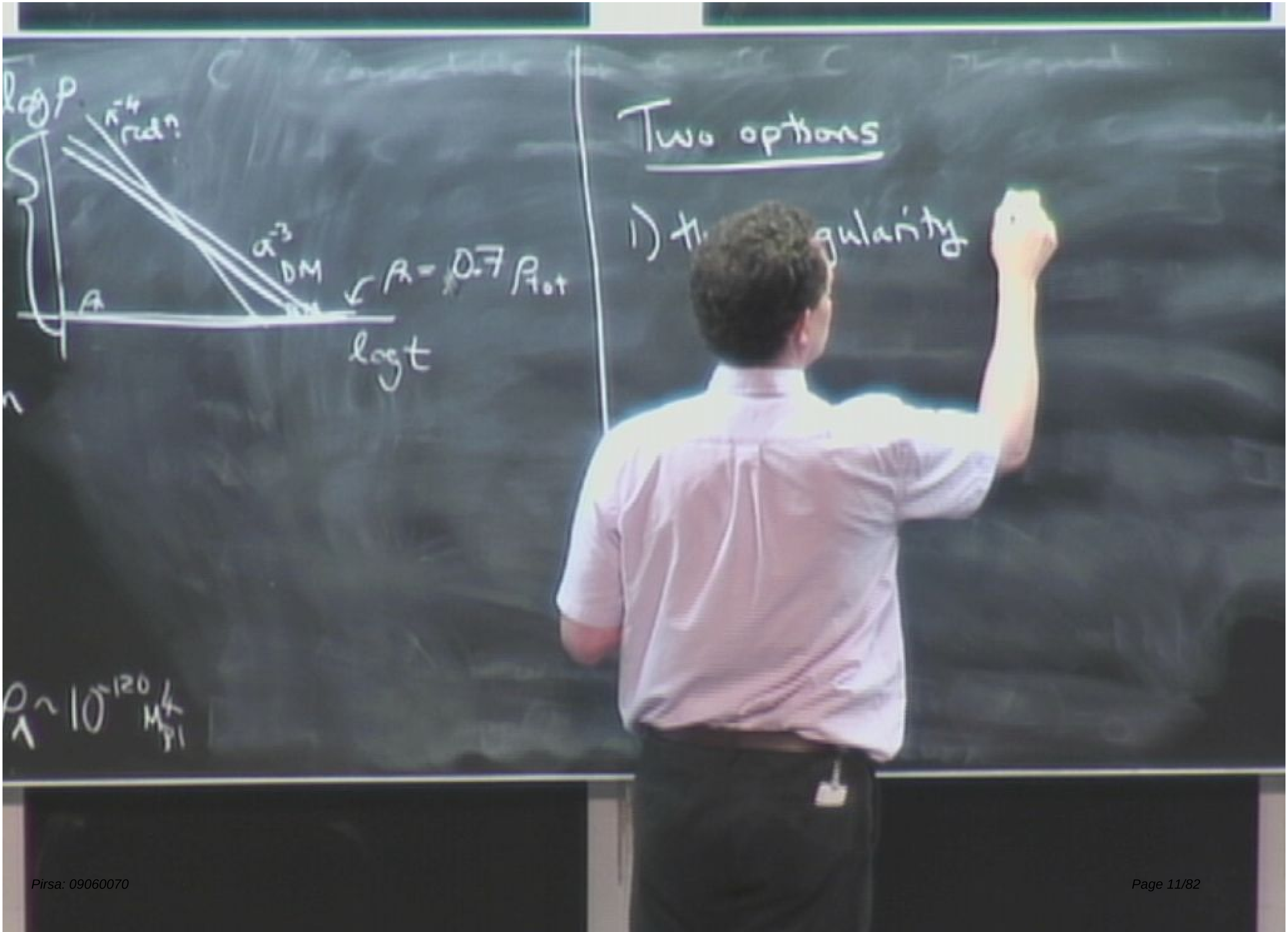
log ρ
log t
DM
ρ_Λ ~ 10^-120 M_Pl^4


log ρ
a^-4 rad?
a^-3 DM
ρ_Λ = 0.7 ρ_tot
log t
ρ_Λ ~ 10^-120 M_Pl^4
Two options
1) th gularity

Two options

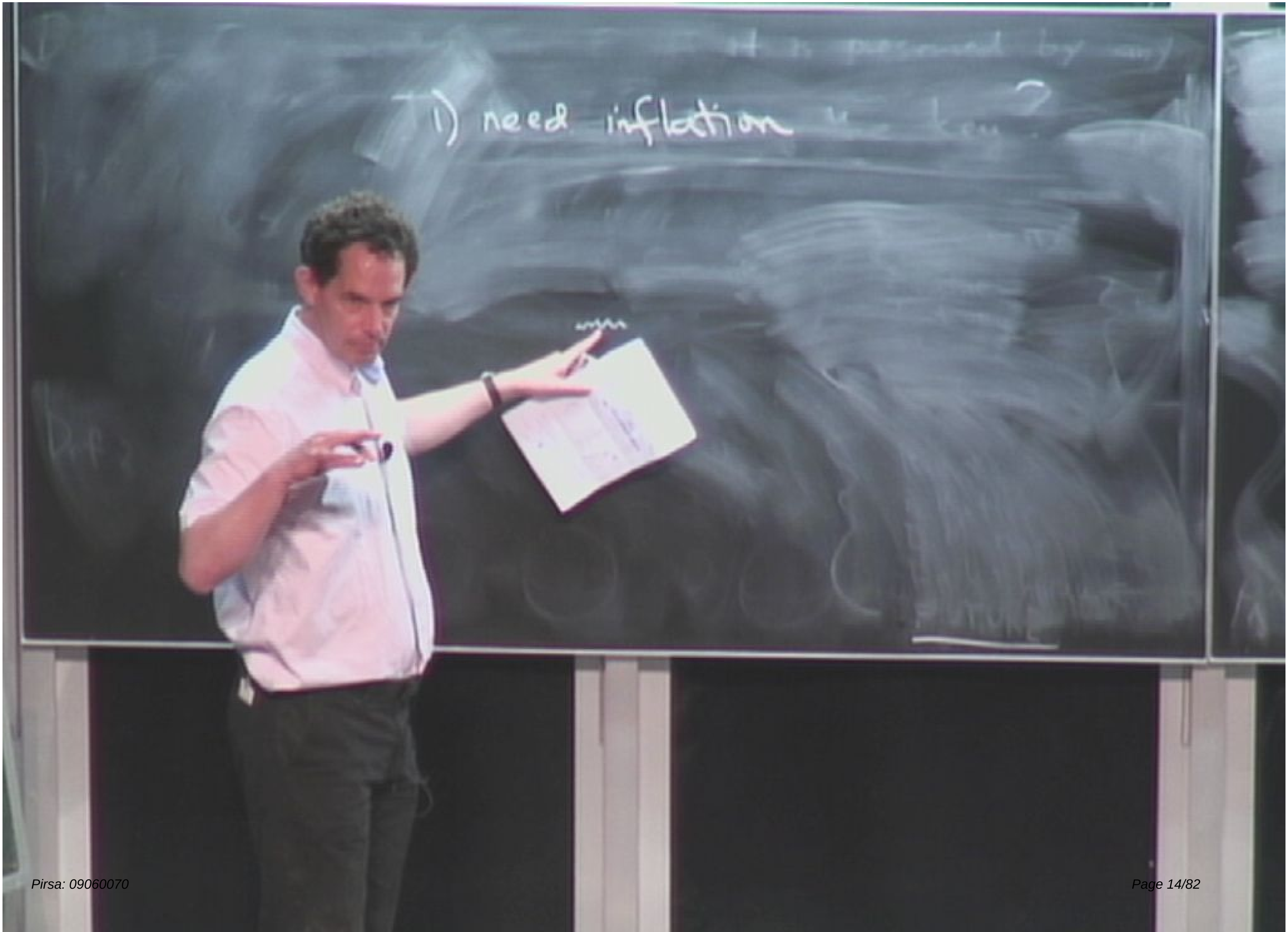
1) the singularity (or some smoothed out version) was the beginning

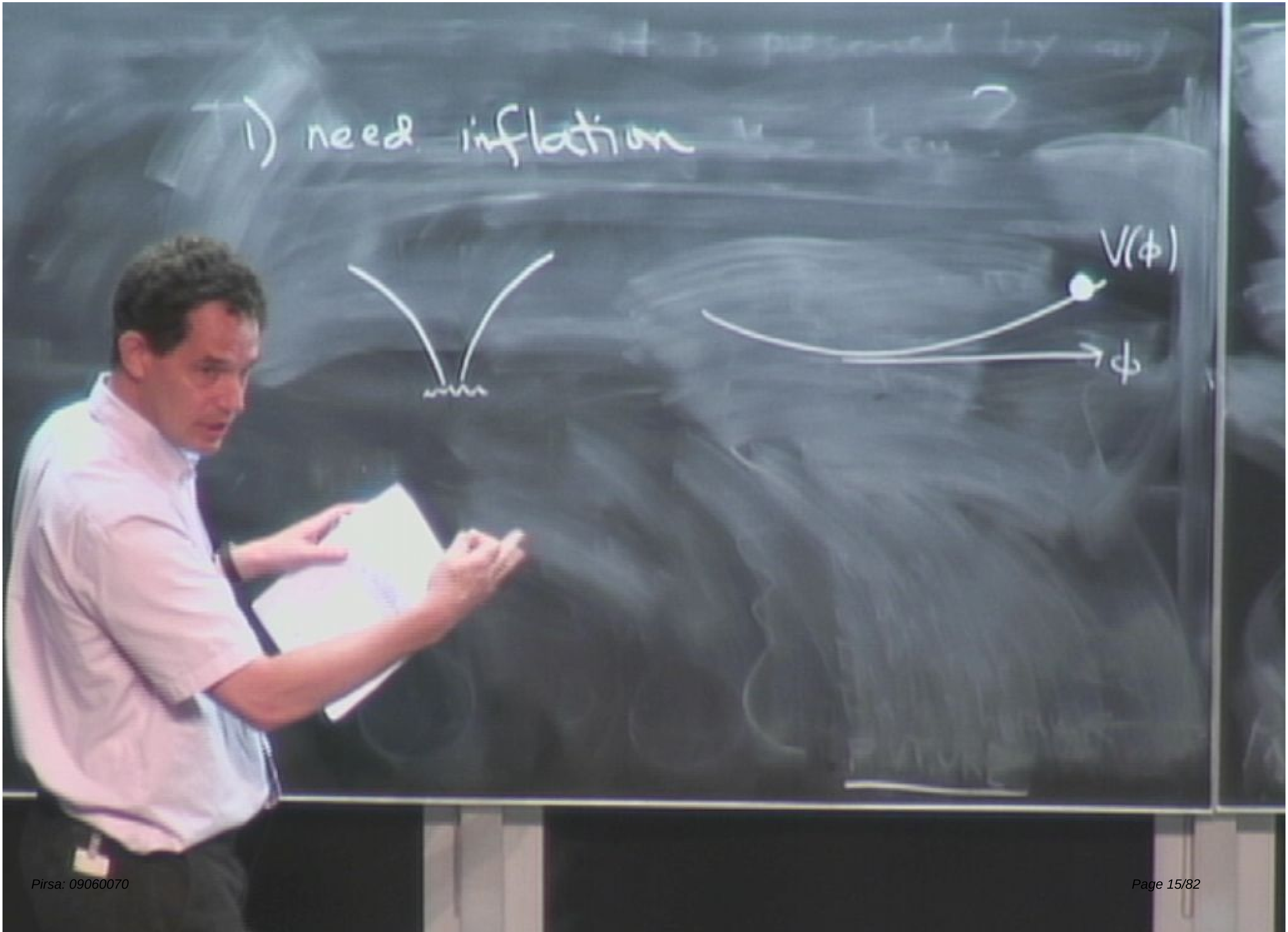
Two options

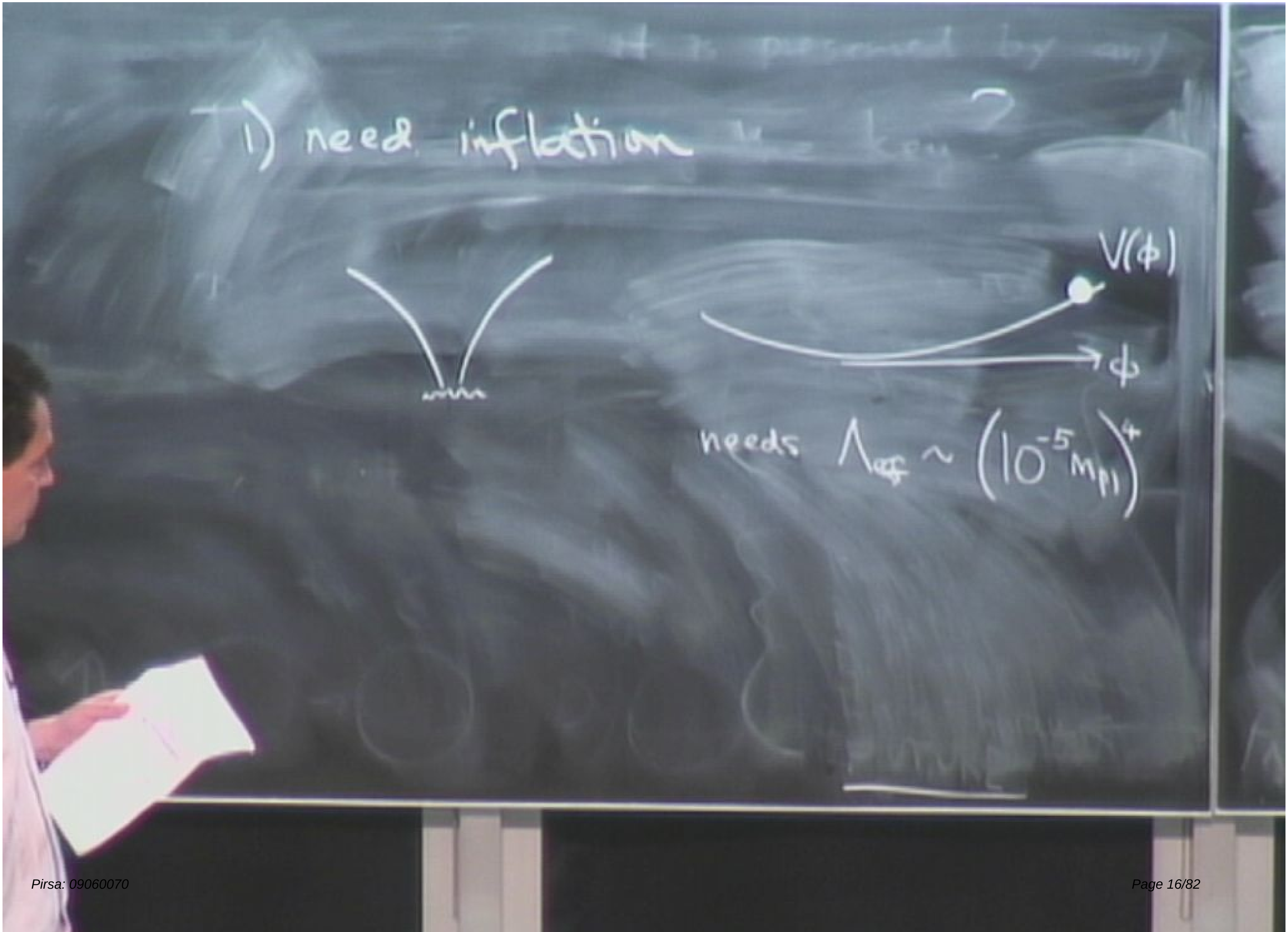
1) the singularity (or some smoothed out version) was the beginning

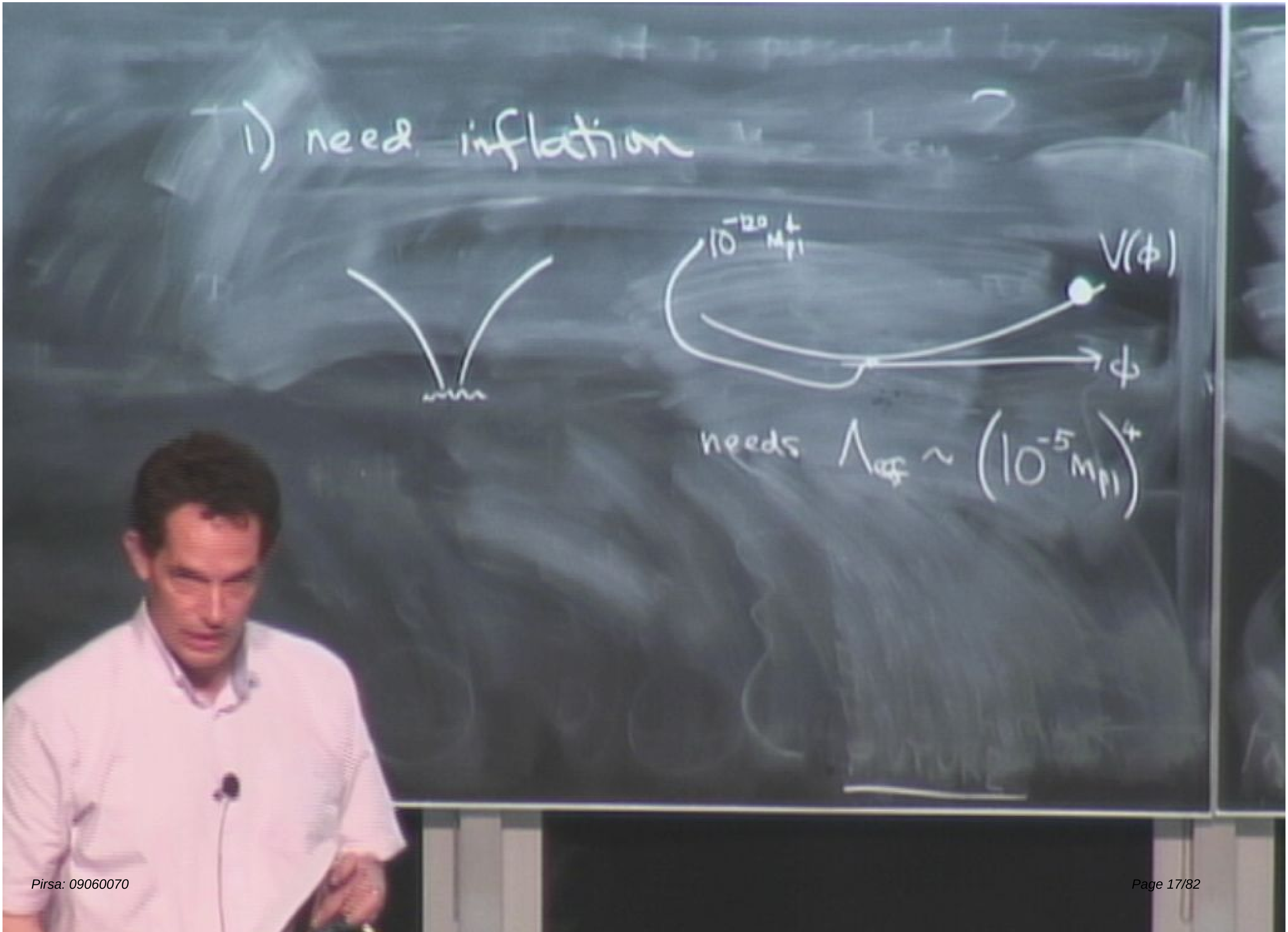
not

2)


1) need inflation


1) need inflation
V(ϕ)
ϕ


1) need inflation
$V(\phi)$
ϕ
needs $\Lambda_{eff} \sim \left(10^{-5} M_{pl}\right)^4$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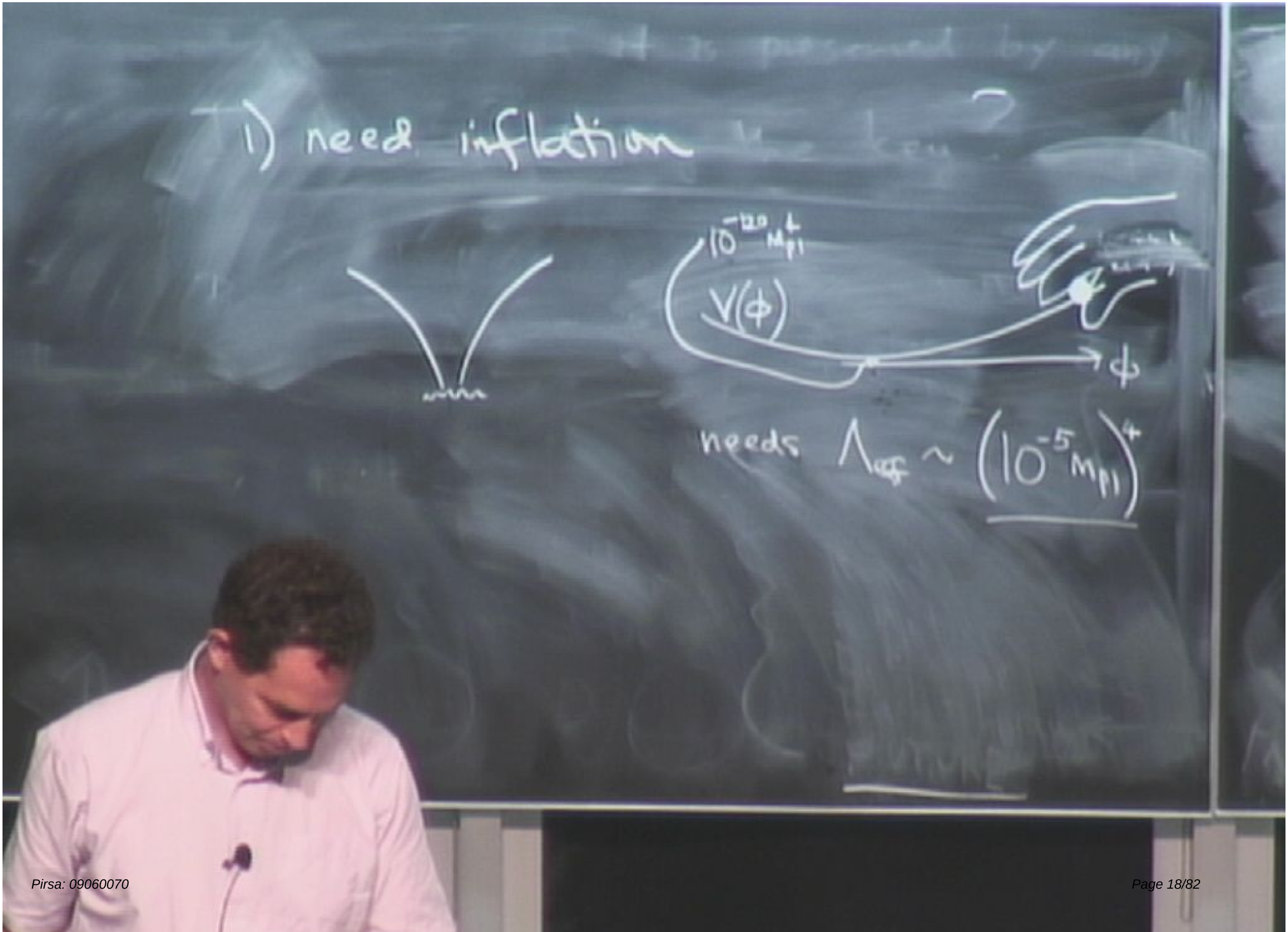
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$10^{-120} M_{pl}^4$
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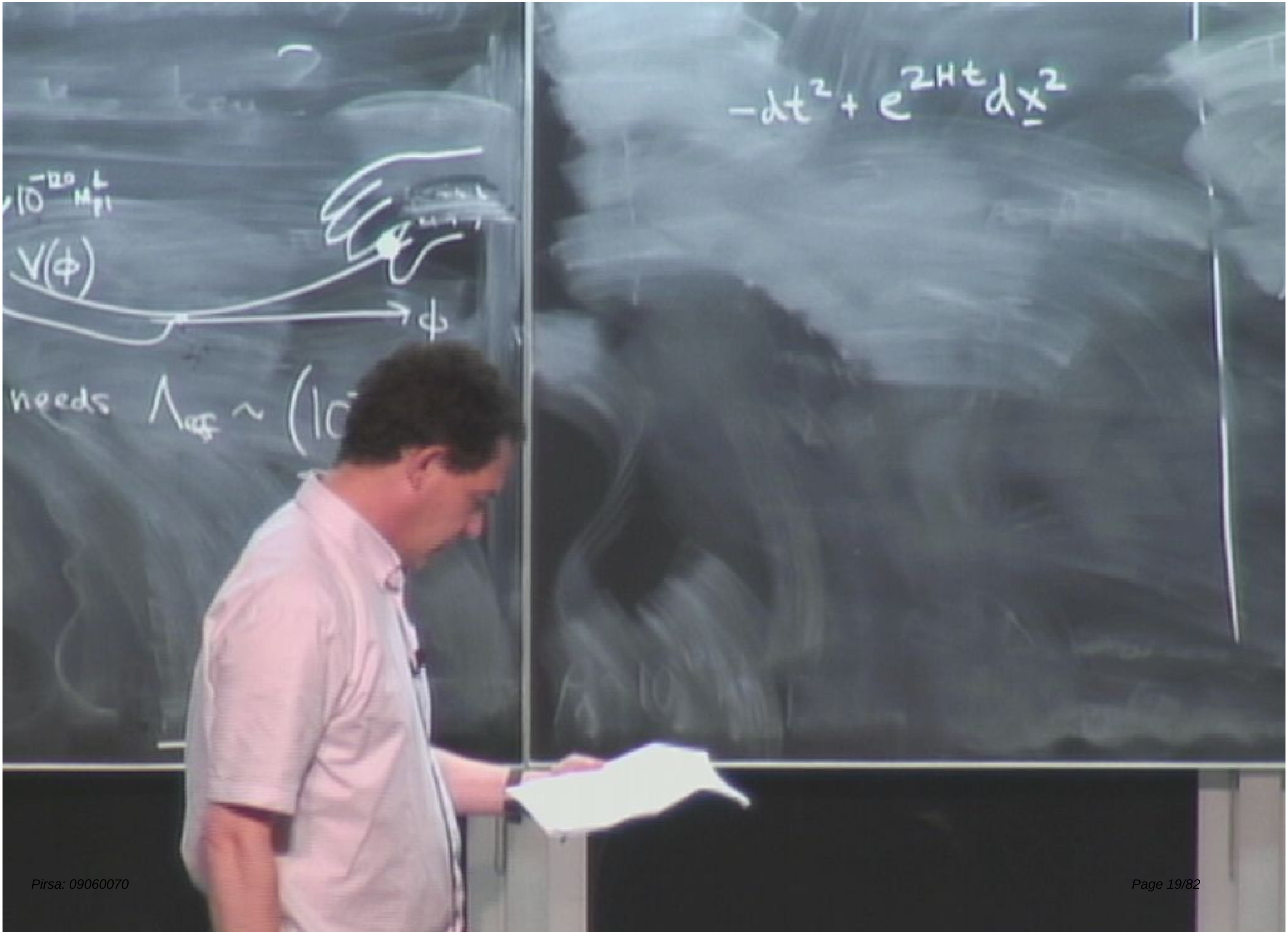
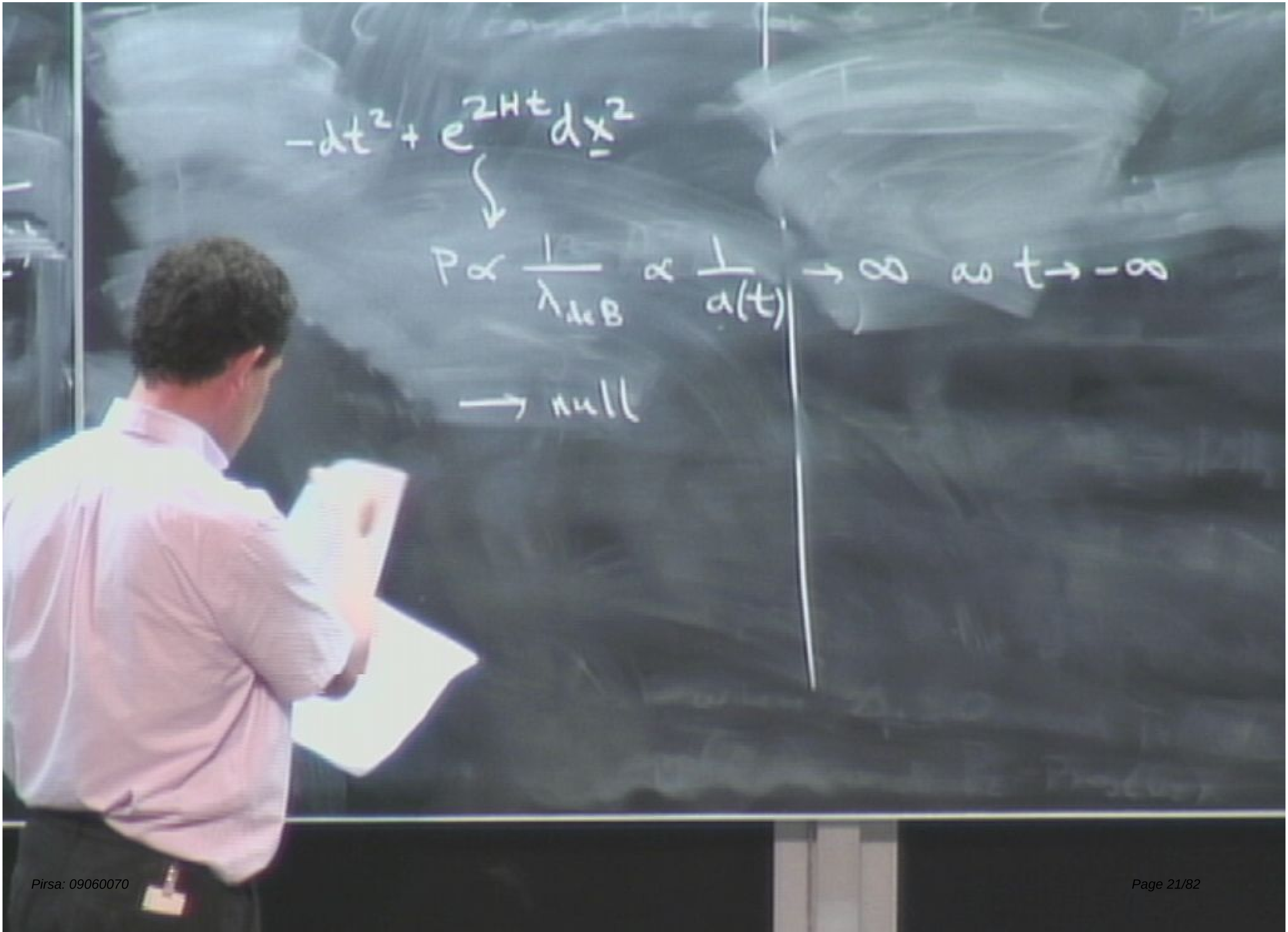

$10^{-120} M_{Pl}^4$
$V(\phi)$
ϕ
needs $\Lambda_{eff} \sim (10$
$-dt^2 + e^{2Ht} d\underline{x}^2$

$$\Lambda_{eff} \sim \left(10^{-5} M_{Pl}\right)^4$$

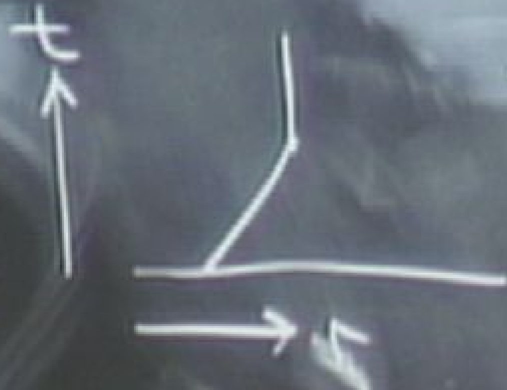
$$-dt^2 + e^{2Ht} d\underline{x}^2$$

$$p \propto \frac{1}{\lambda_{deB}} \propto \frac{1}{a(t)}$$


$-dt^2 + e^{2Ht} d\underline{x}^2$
$p \propto \frac{1}{\lambda_{deB}} \propto \frac{1}{a(t)} \rightarrow \infty$ as $t \rightarrow -\infty$
$\longrightarrow$ null

$$-dt^2 + e^{2Ht}\, d\underline{x}^2$$

$$P \propto \frac{1}{\lambda_{deB}} \propto \frac{1}{a(t)} \to \infty \quad \text{as } t \to -\infty$$



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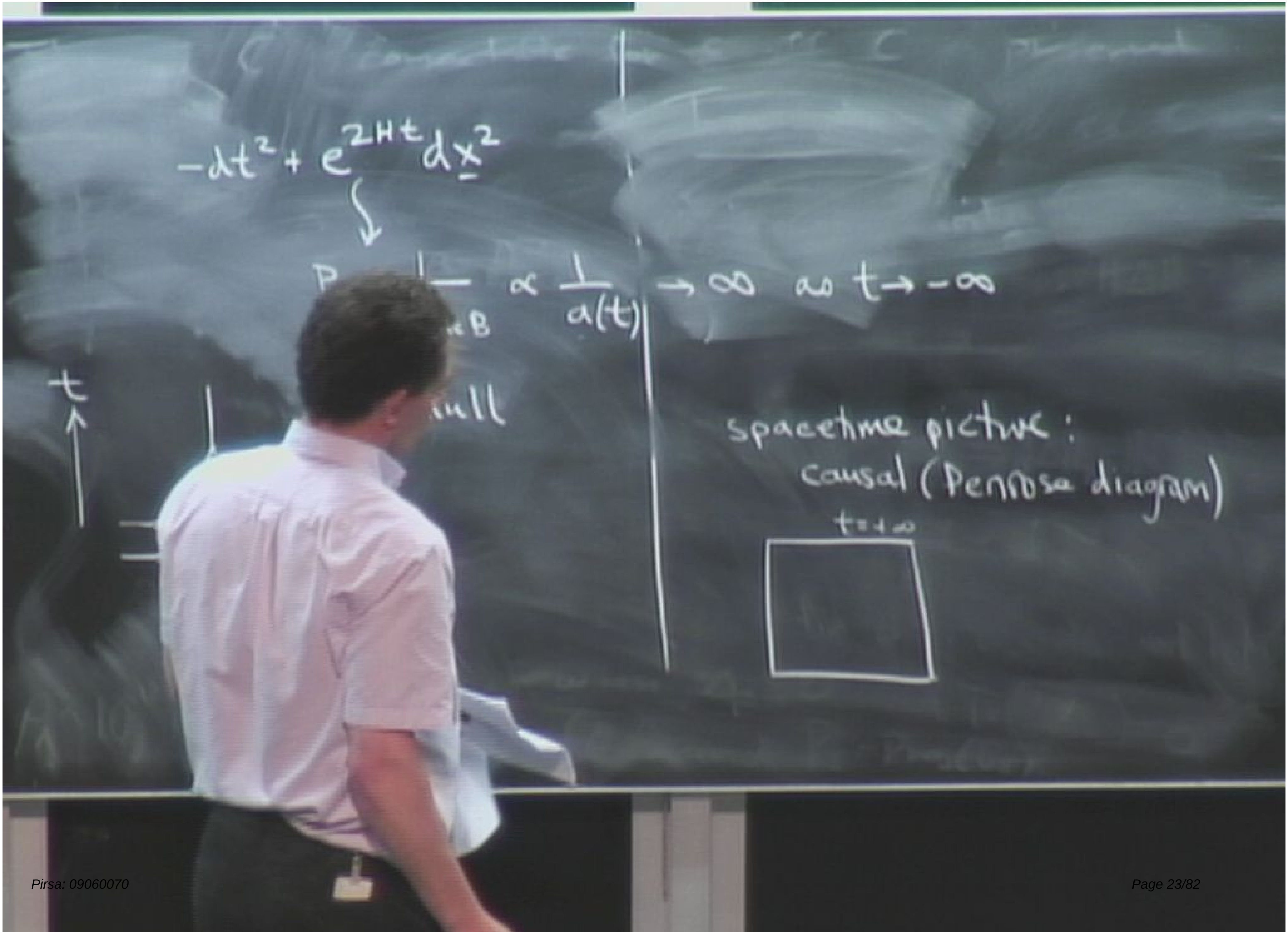
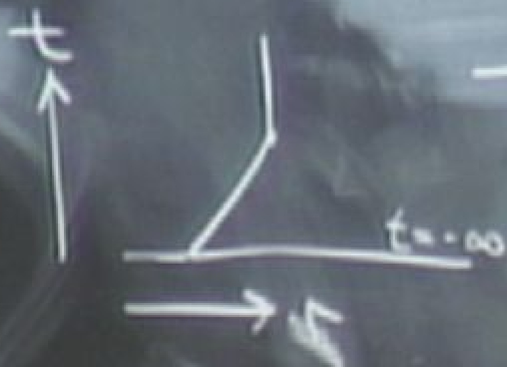


$-dt^2 + e^{2Ht} dx^2$
$\propto \frac{1}{a(t)} \to \infty$ as $t \to -\infty$
t
spacetime picture:
causal (Penrose diagram)
$t = +\infty$

$$-dt^2 + e^{2Ht}\,d\underline{x}^2$$

$$p \propto \frac{1}{\lambda_{deB}} \propto \frac{1}{a(t)} \to \infty \quad \text{as } t \to -\infty$$



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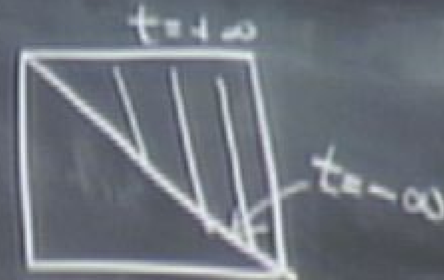

$$-dt^2 + e^{2Ht}\, d\underline{x}^2$$

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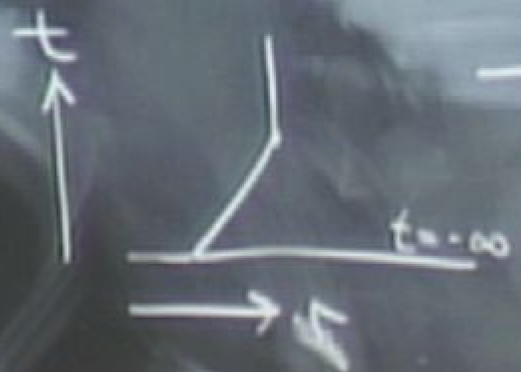

$\longrightarrow$ null

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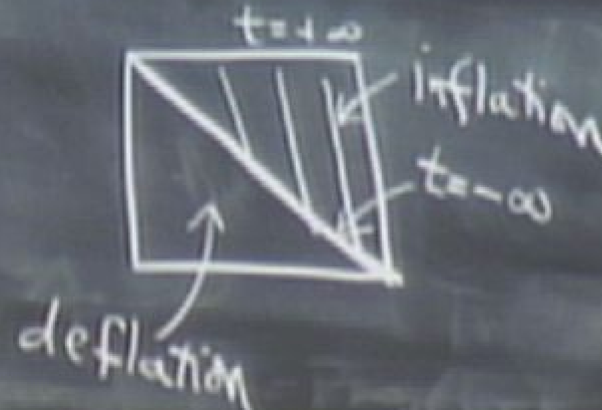
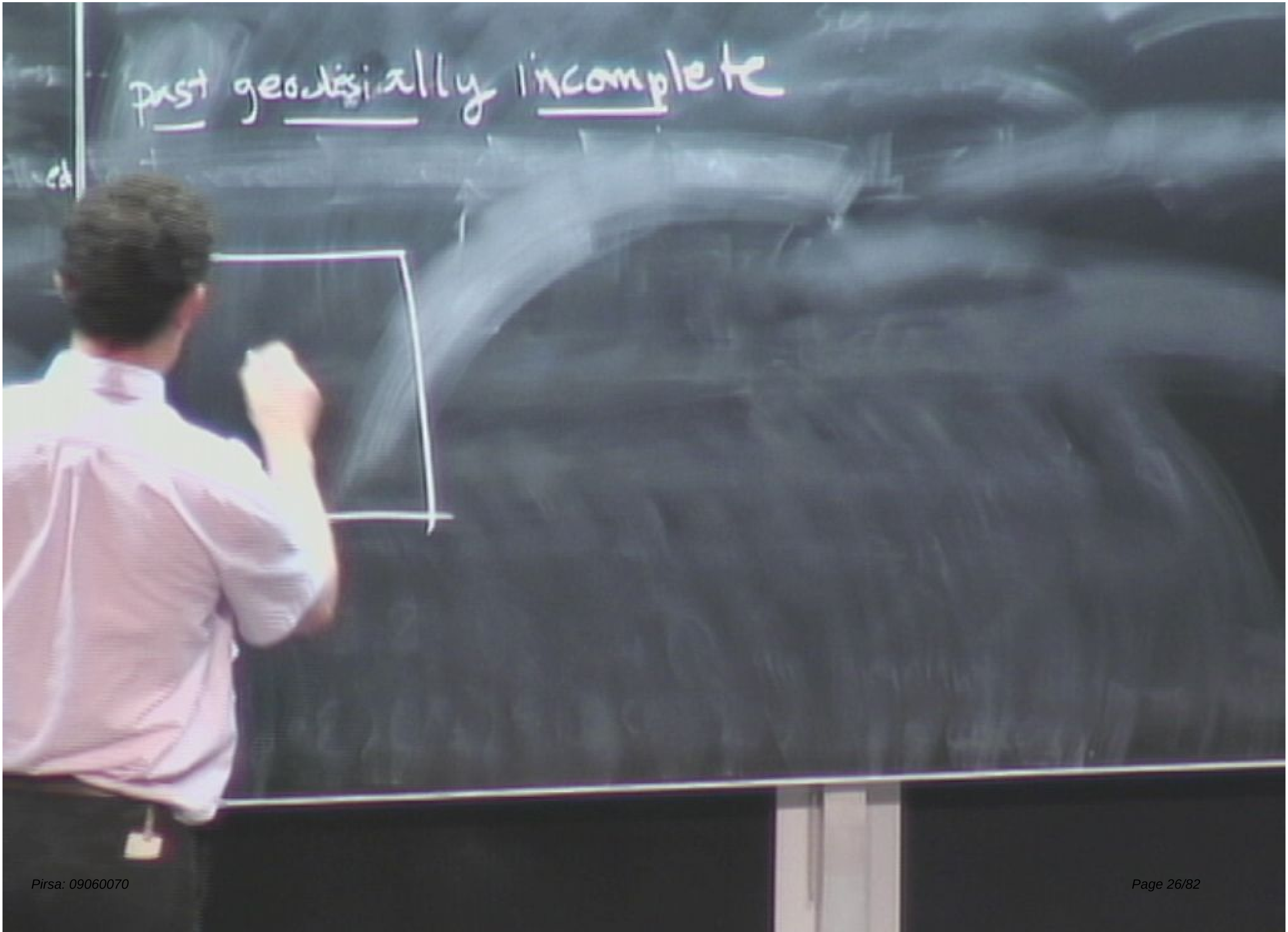
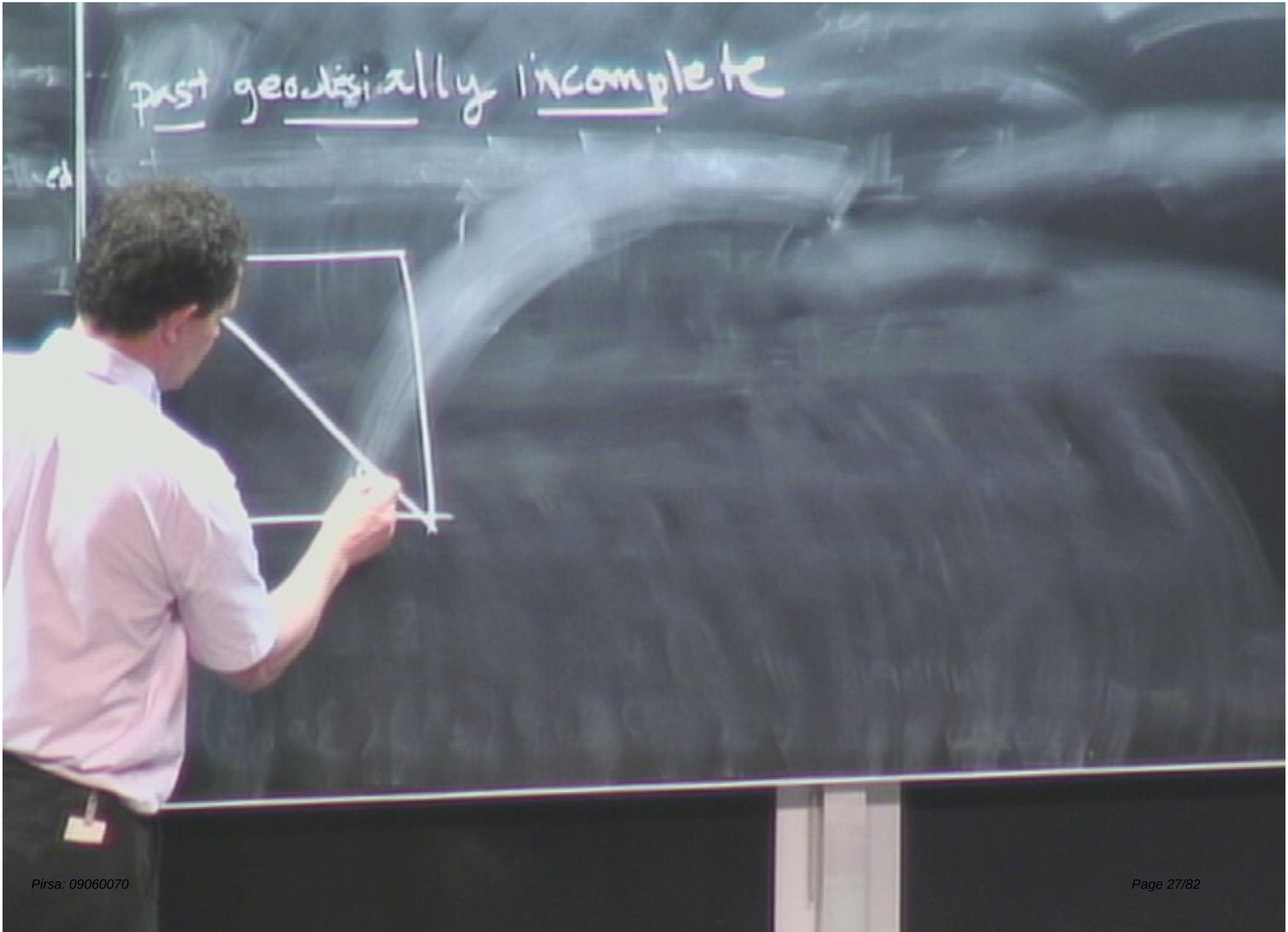



past geodesically incomplete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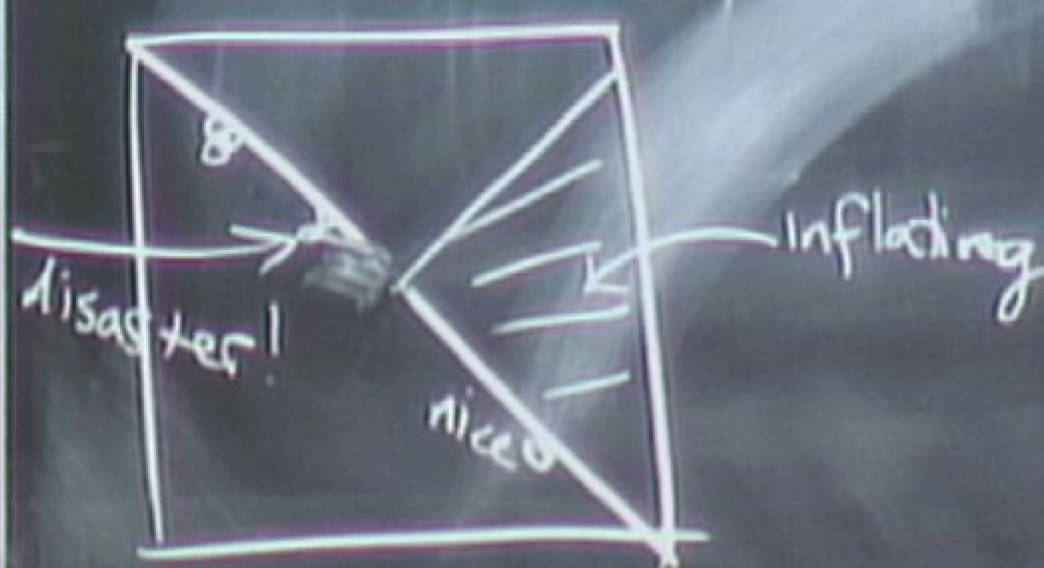
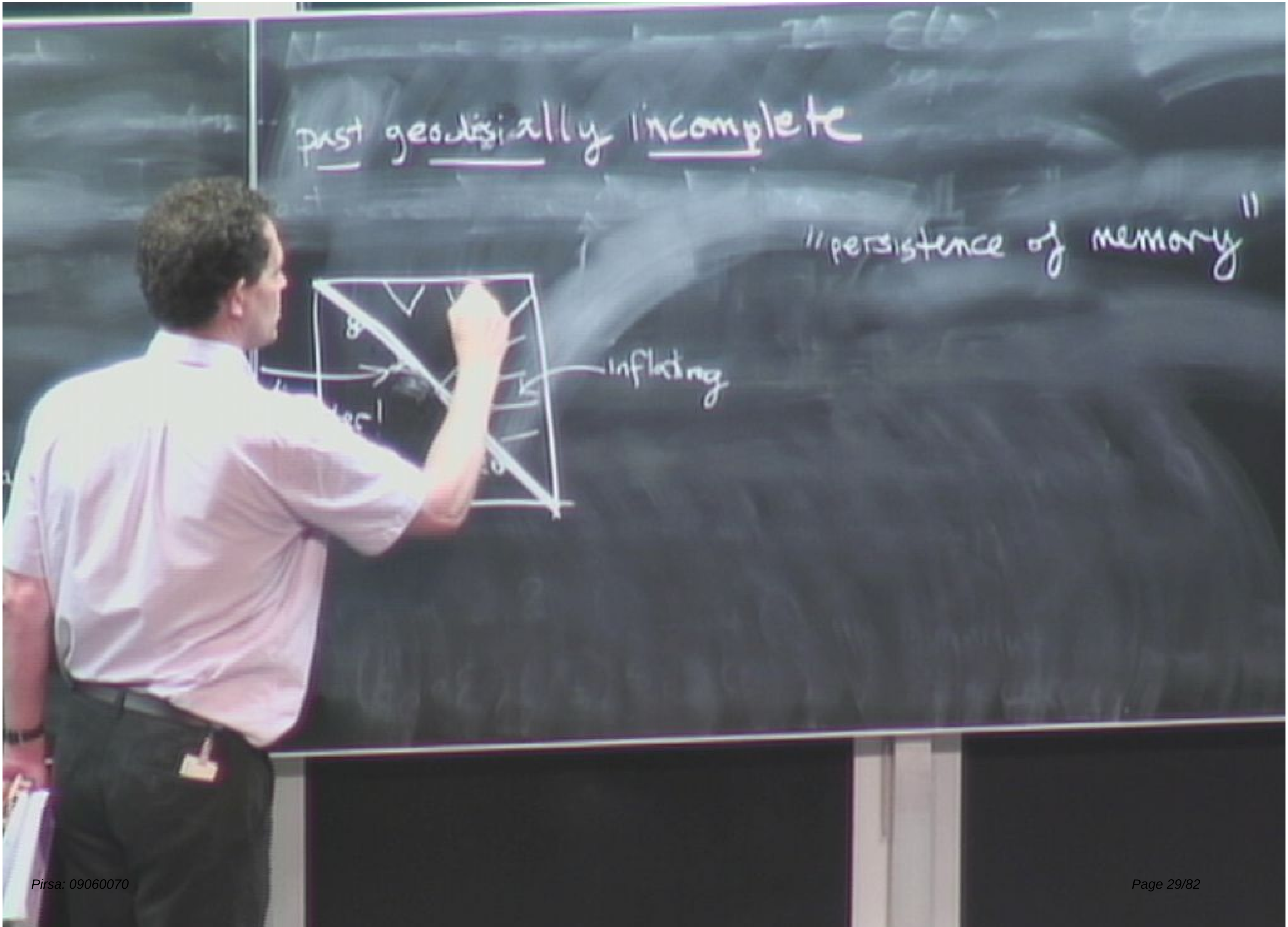
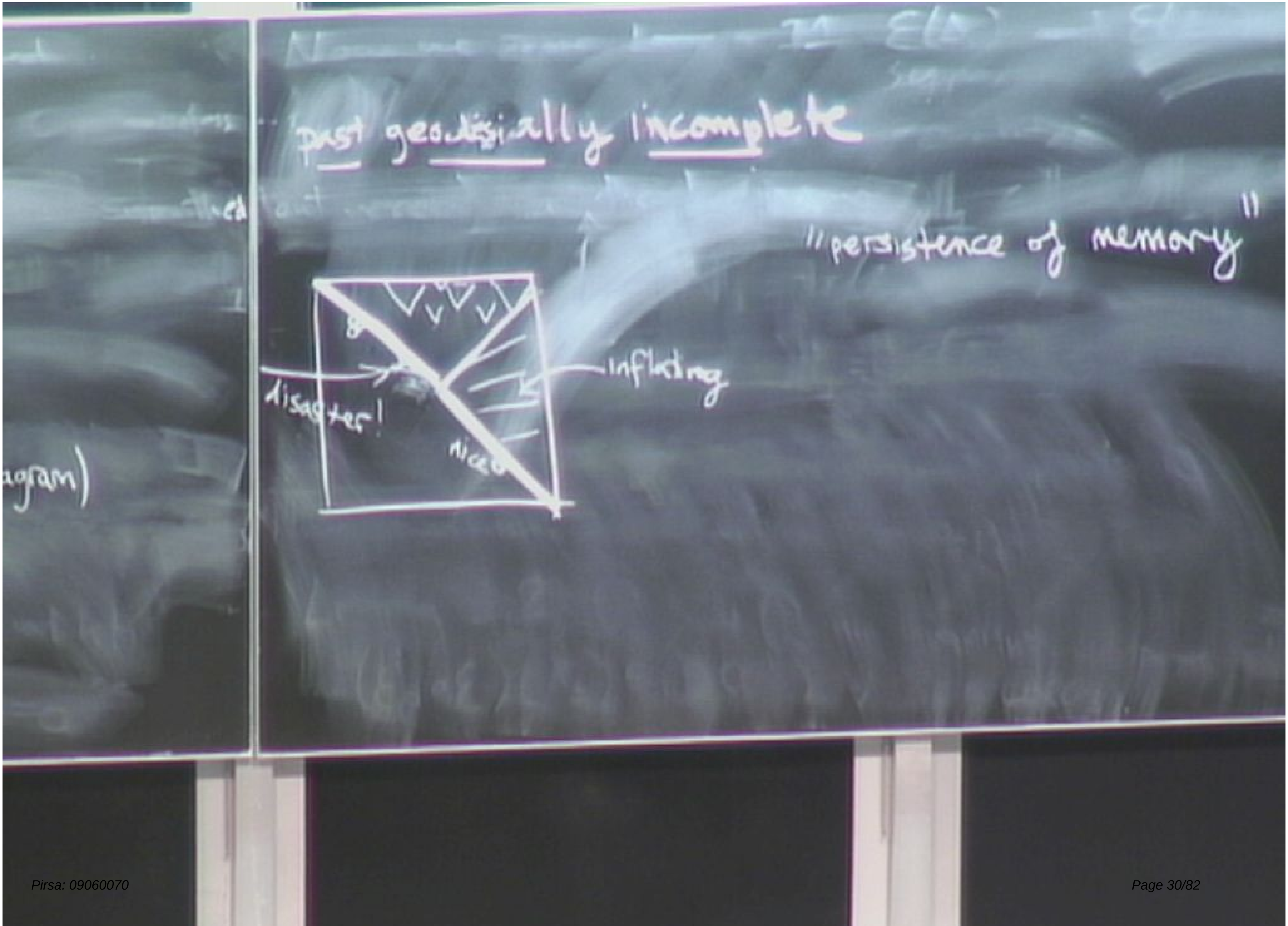



past geodesically incomplete
"persistence of memory"
inflating


past geodesically incomplete
"persistence of memory"
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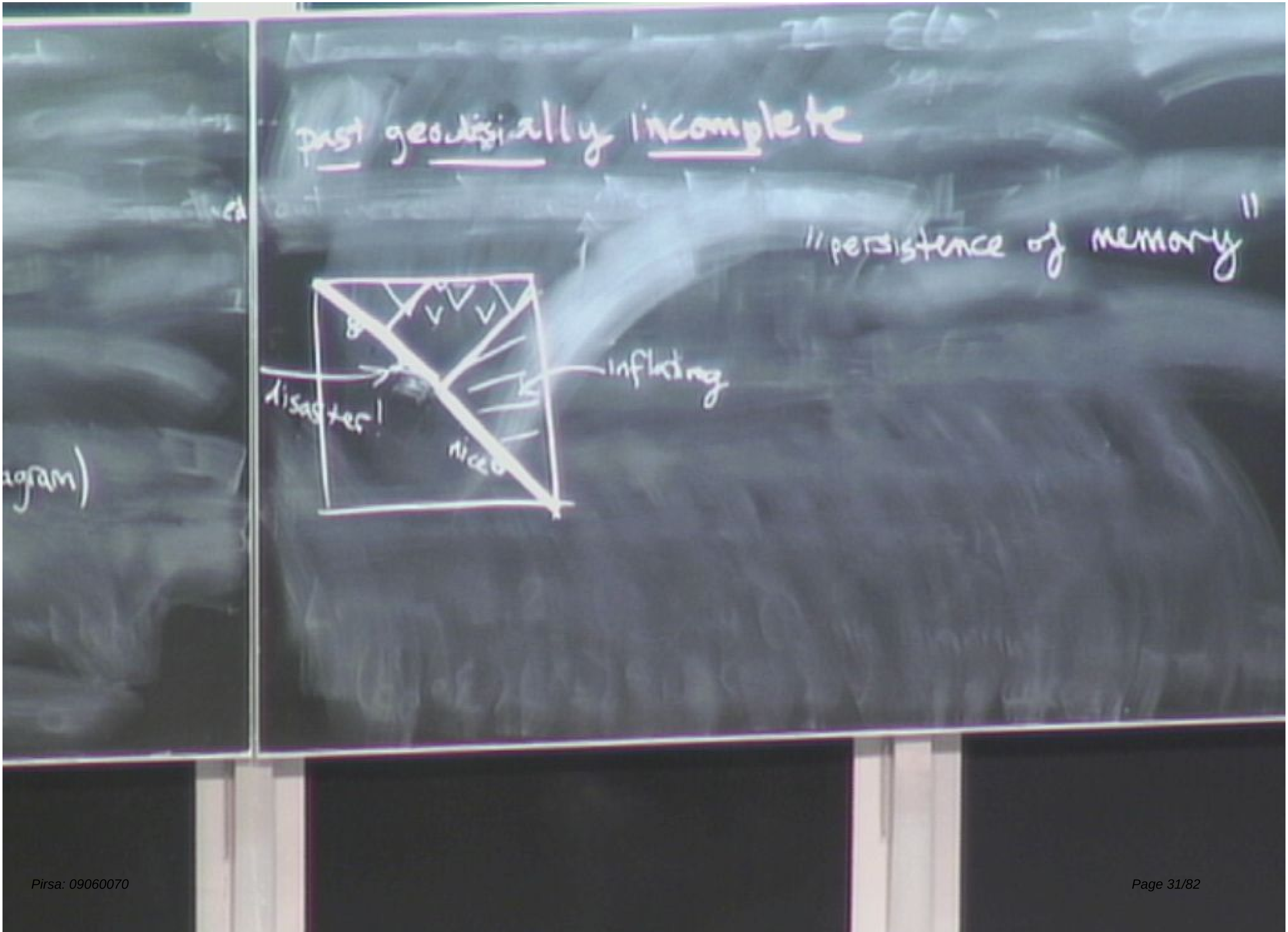
disaster!
nice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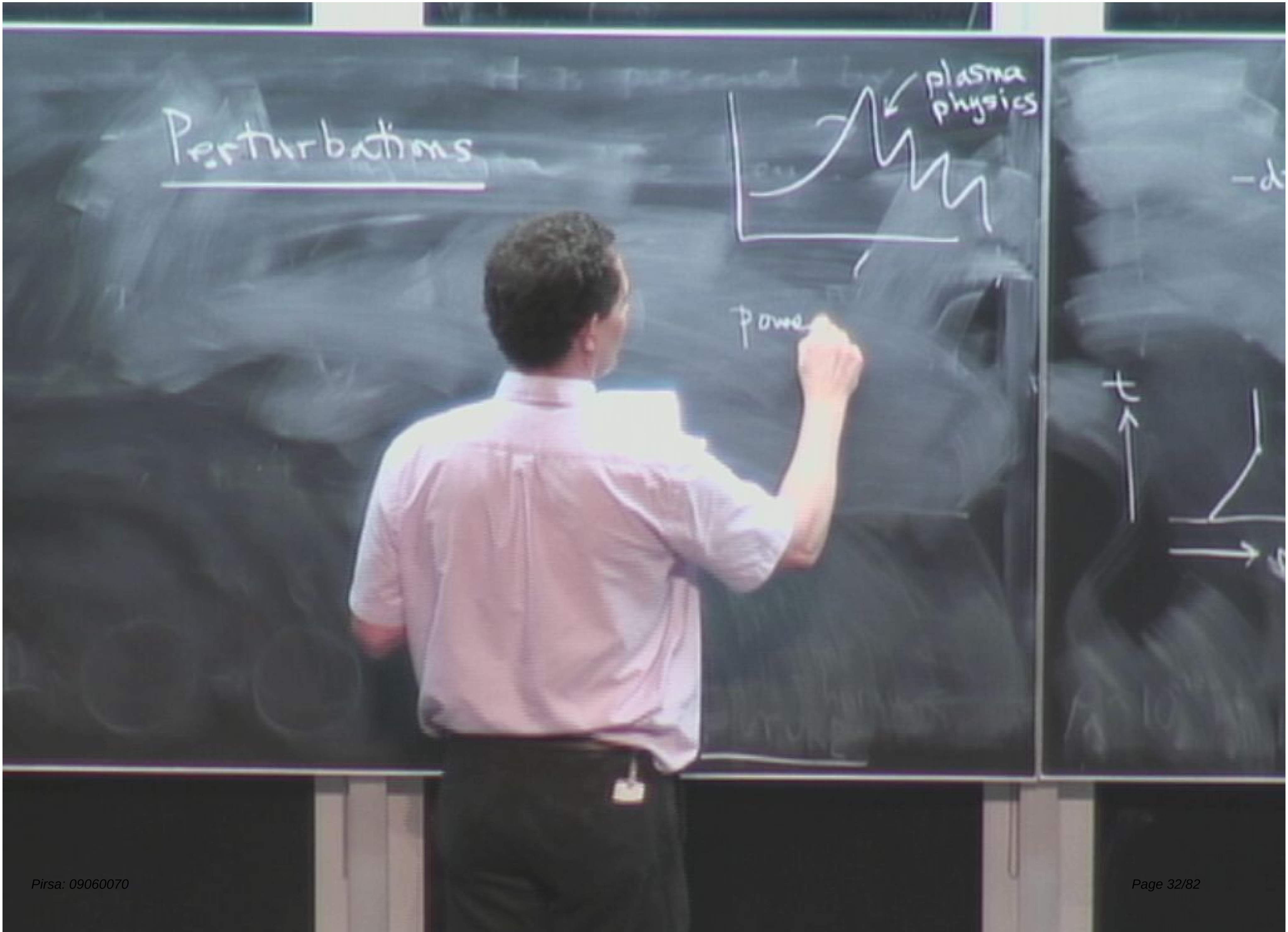
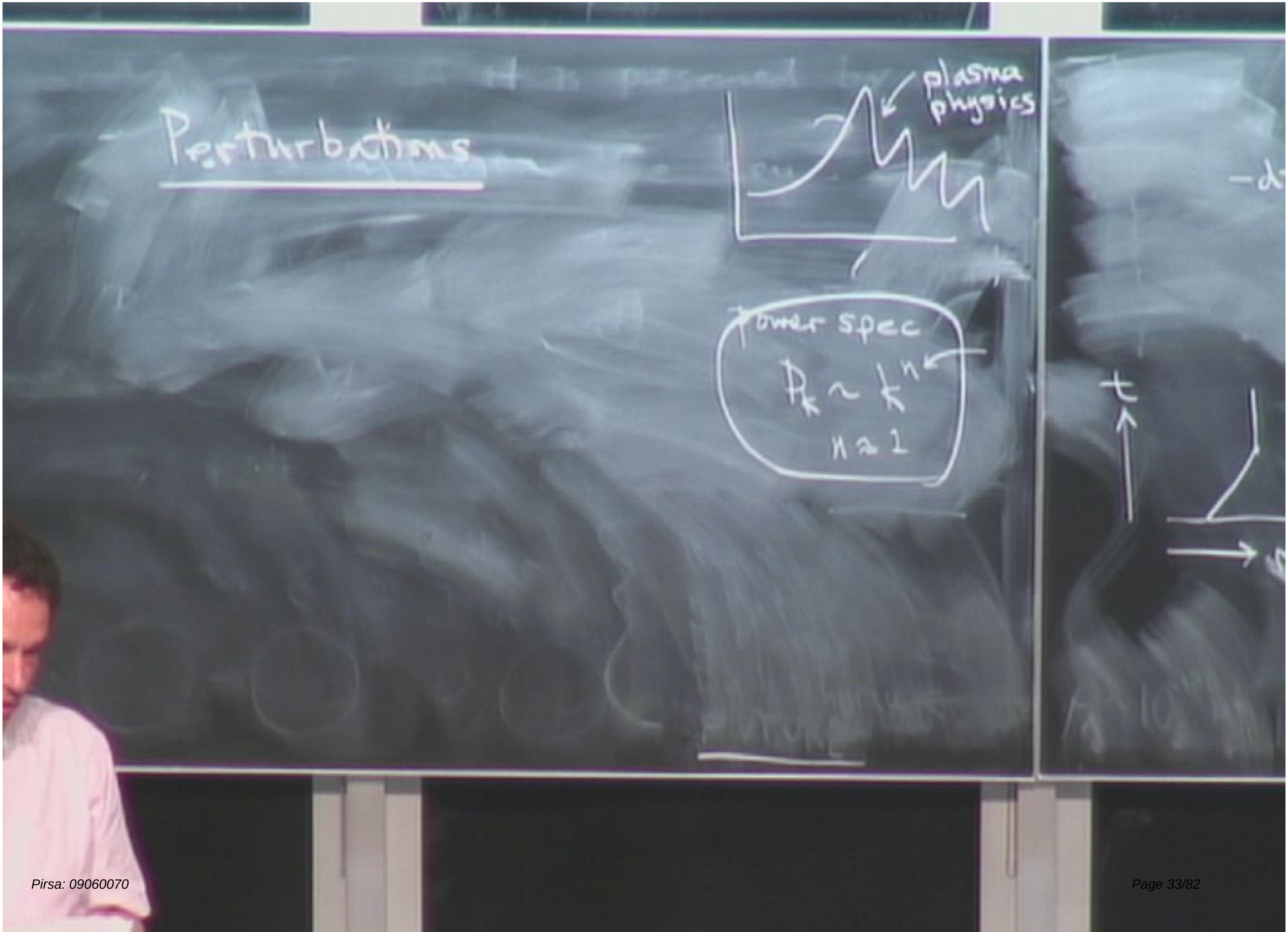
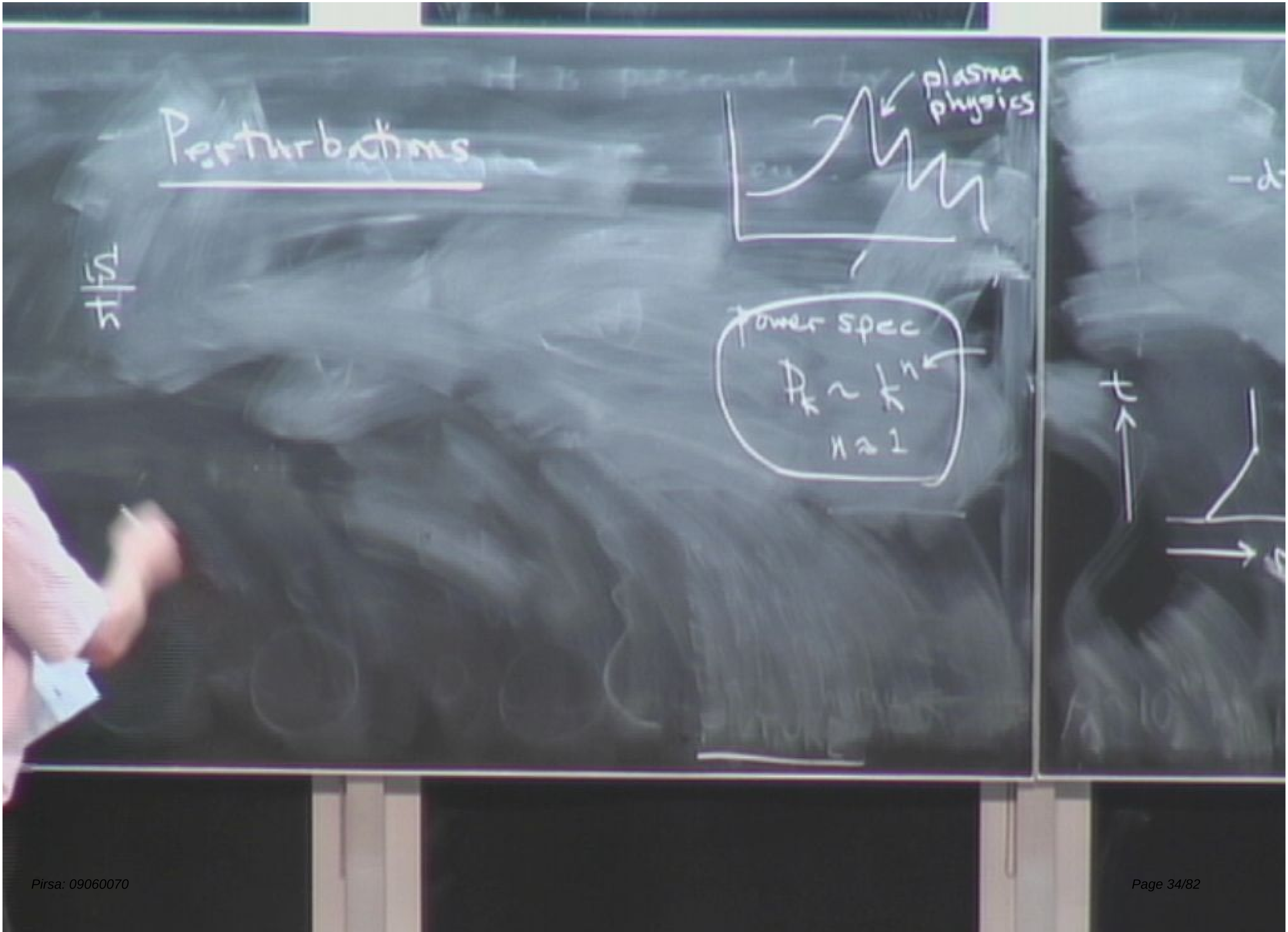

Perturbations
plasma physics
power
t


Perturbations
plasma physics
Power spec
$P_k \sim k^n$
$n \approx 1$
t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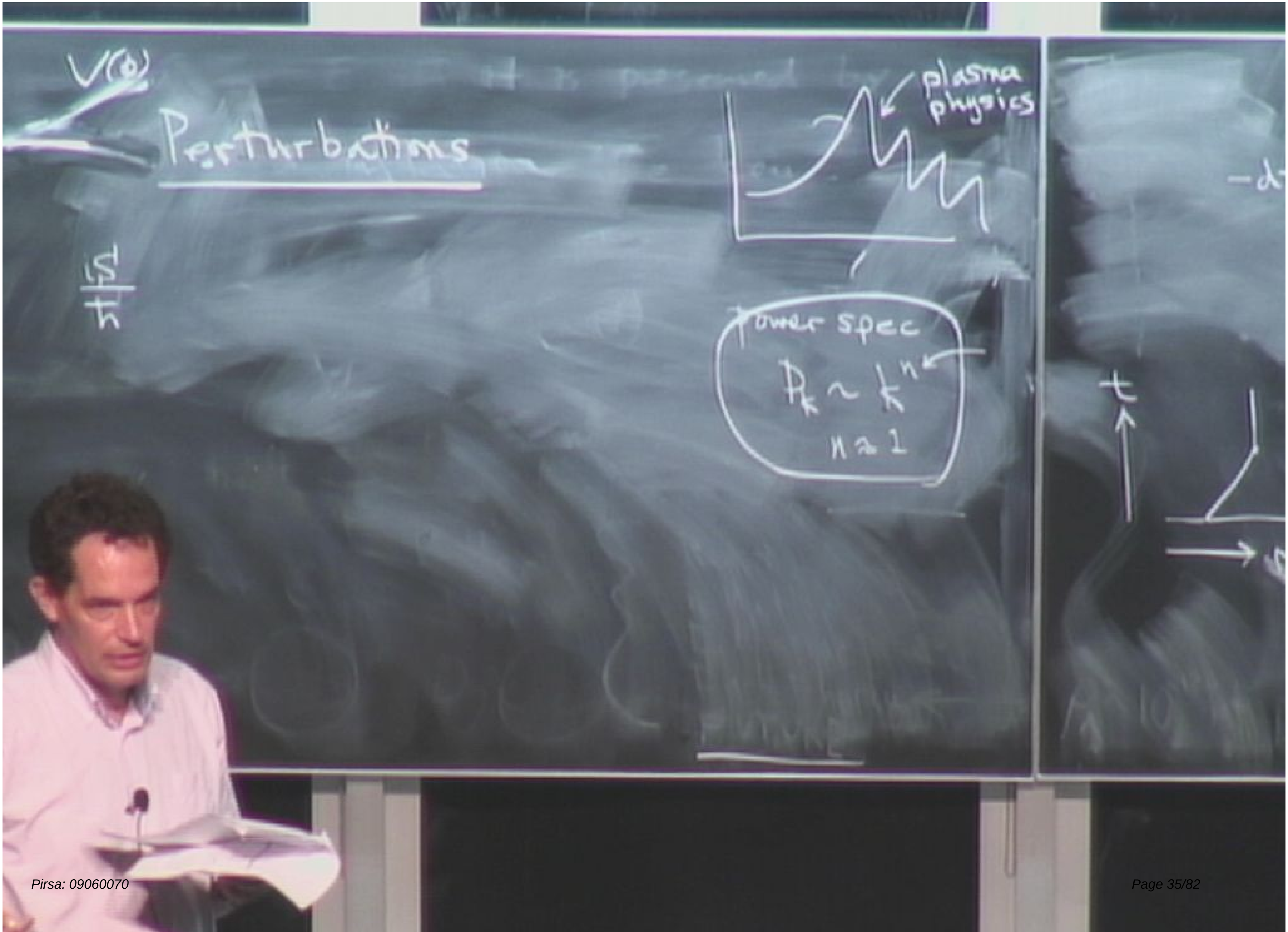
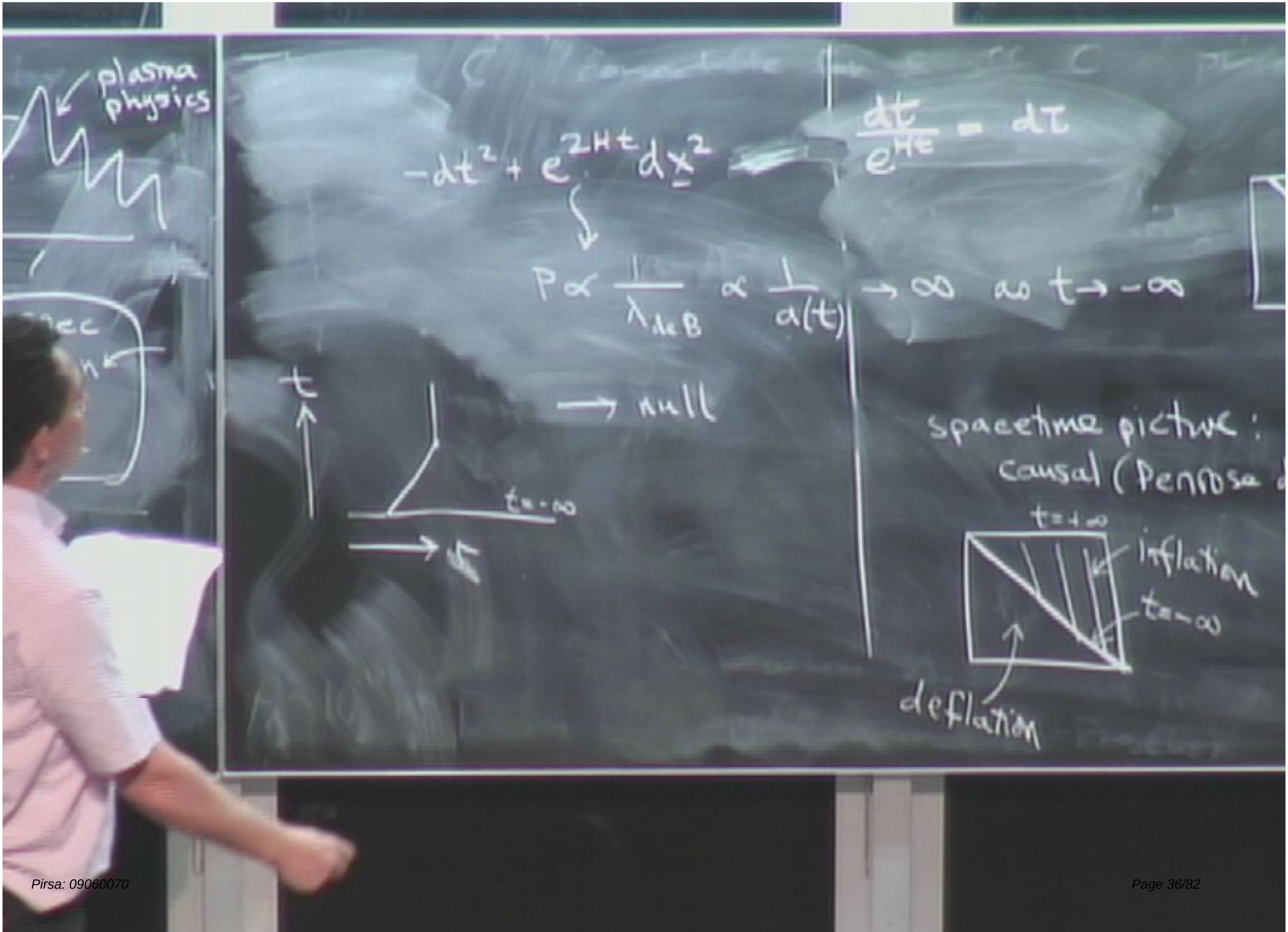
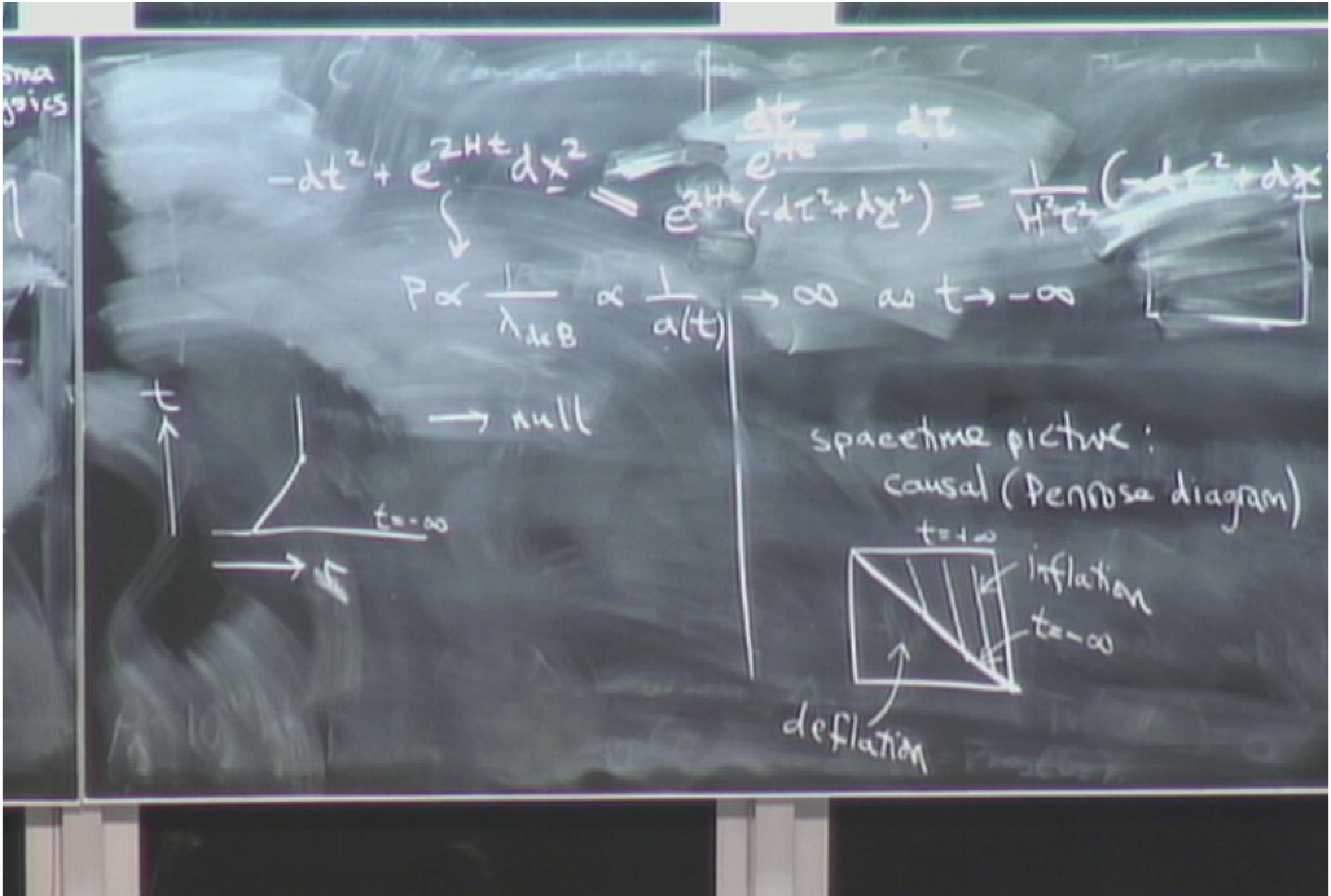

V(ϕ)
Perturbations
plasma physics
Power spec
P_k ~ k^n
n ≈ 1
t


plasma physics
$-dt^2 + e^{2Ht} d\underline{x}^2$
$\frac{dt}{e^{Ht}} = d\tau$
$p \propto \frac{1}{\lambda_{deB}} \propto \frac{1}{a(t)} \to \infty$ as $t \to -\infty$
t
$\to$ null
$t=-\infty$
$\underline{x}$
spacetime picture:
causal (Penrose
$t=+\infty$
inflation
$t=-\infty$
deflation


$-dt^2 + e^{2Ht} d\underline{x}^2 = e^{2Ht}(-d\tau^2 + d\underline{x}^2) = \frac{1}{H^2\tau^2}(-d\tau^2 + d\underline{x}^2)$
$\frac{dt}{e^{Ht}} = d\tau$
$p \propto \frac{1}{\lambda_{deB}} \propto \frac{1}{a(t)} \to \infty$ as $t \to -\infty$
t
$\longrightarrow$ null
$t = -\infty$
spacetime picture:
causal (Penrose diagram)
$t = +\infty$
inflation
$t = -\infty$
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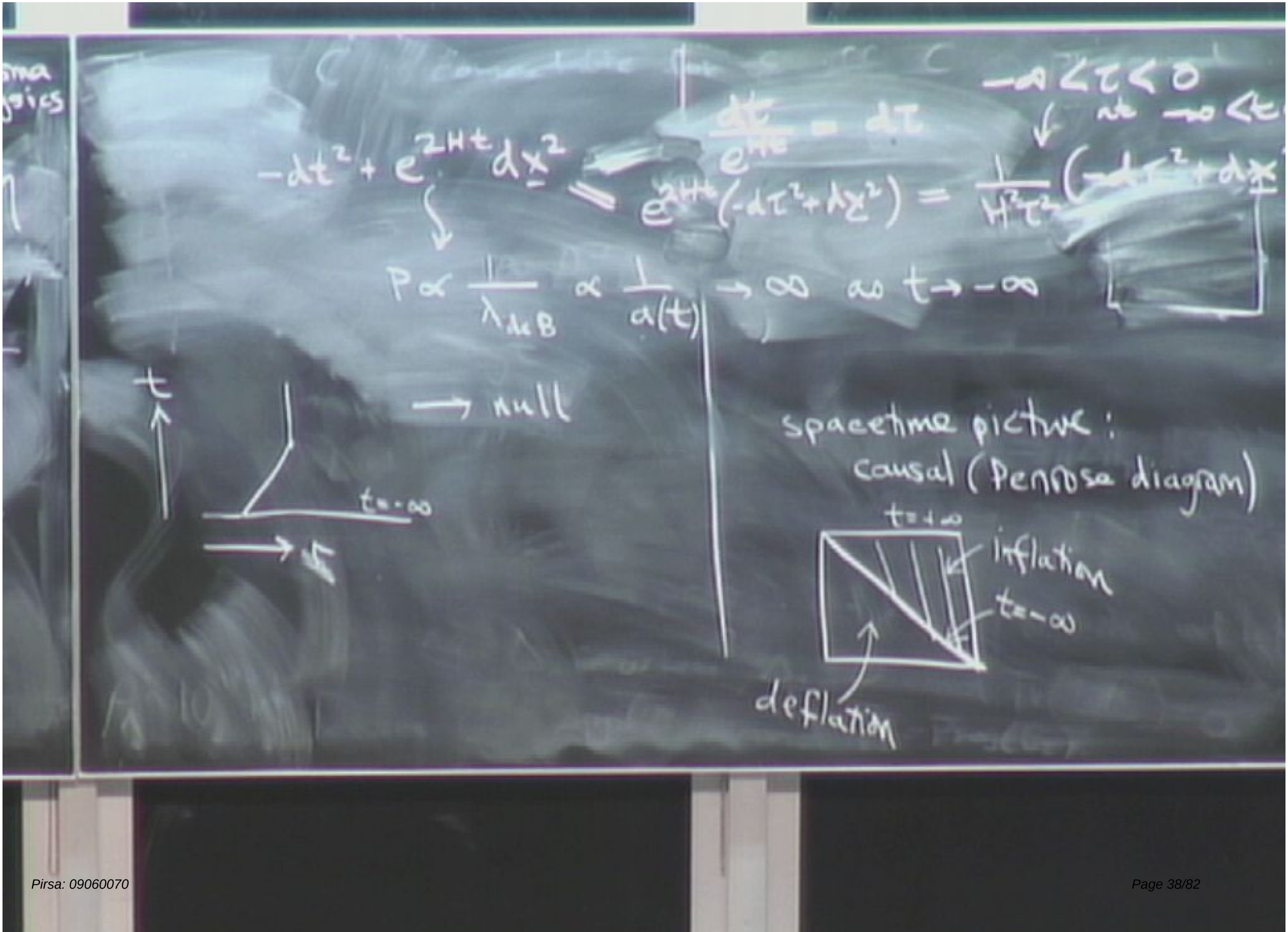
$-\infty < \tau < 0$
$-\infty < t$
$\frac{dt}{e^{Ht}} = d\tau$
$-dt^2 + e^{2Ht} d\underline{x}^2 = e^{2Ht}(-d\tau^2 + d\underline{x}^2) = \frac{1}{H^2\tau^2}(-d\tau^2 + d\underline{x}^2)$
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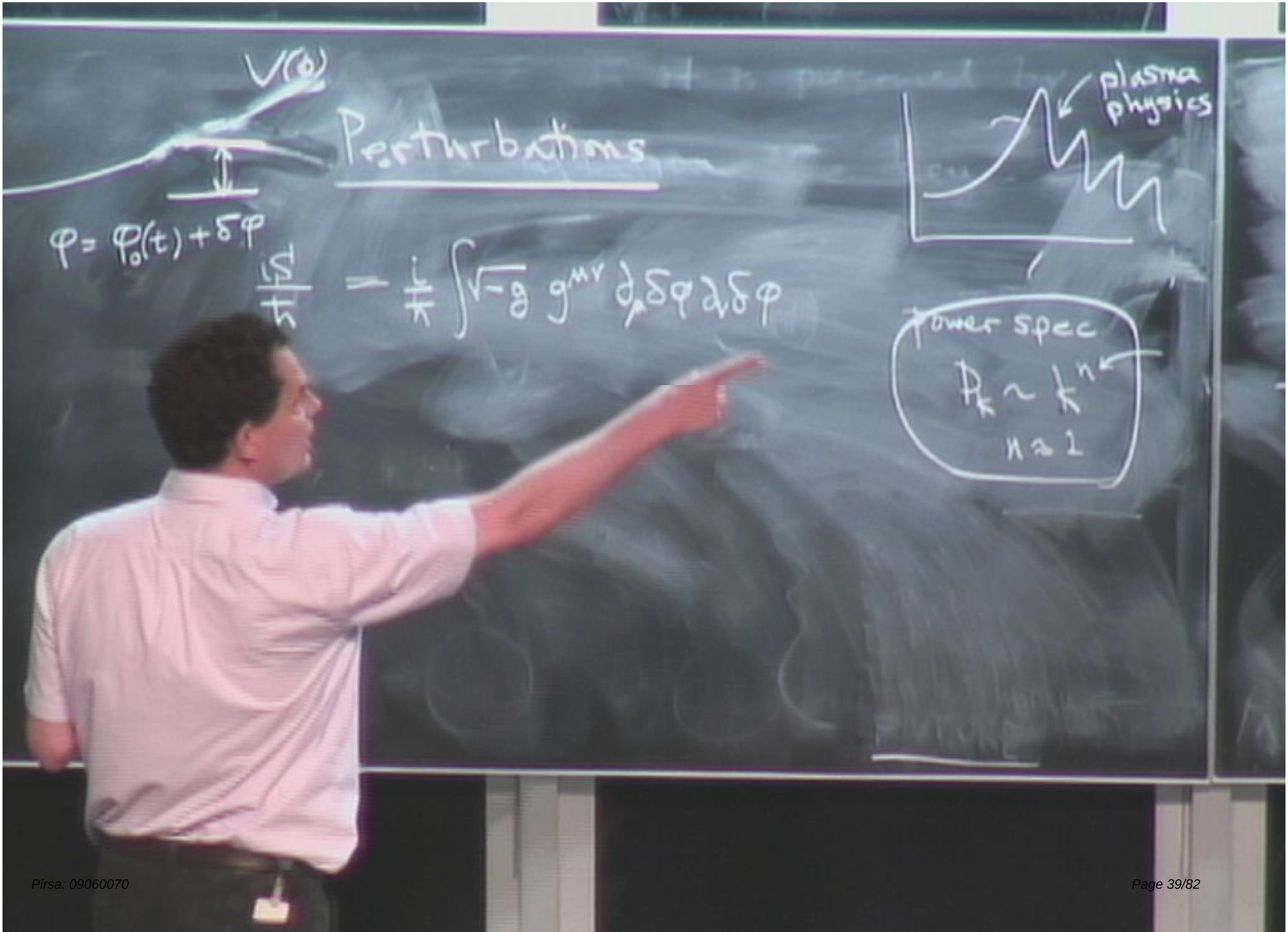
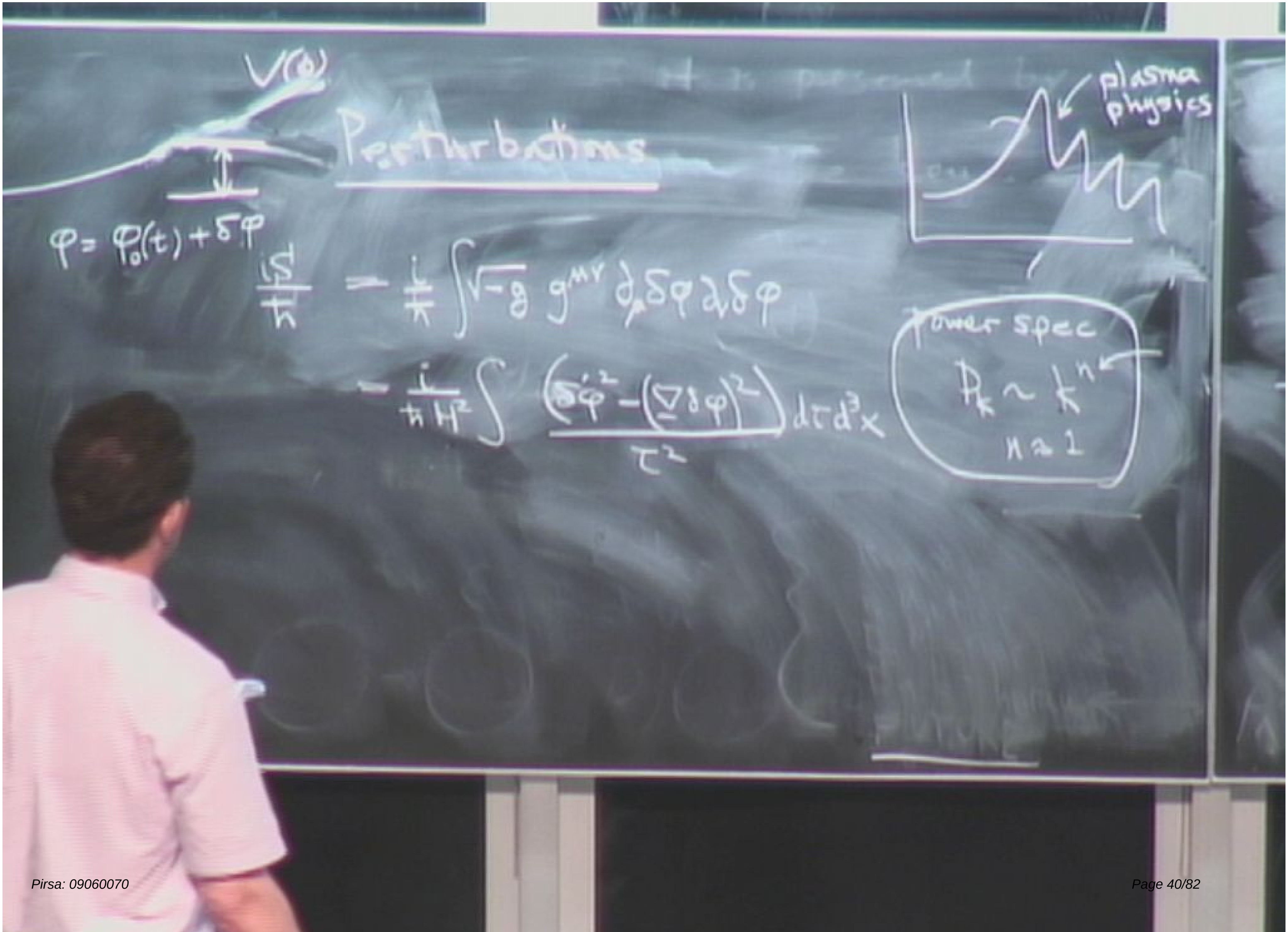
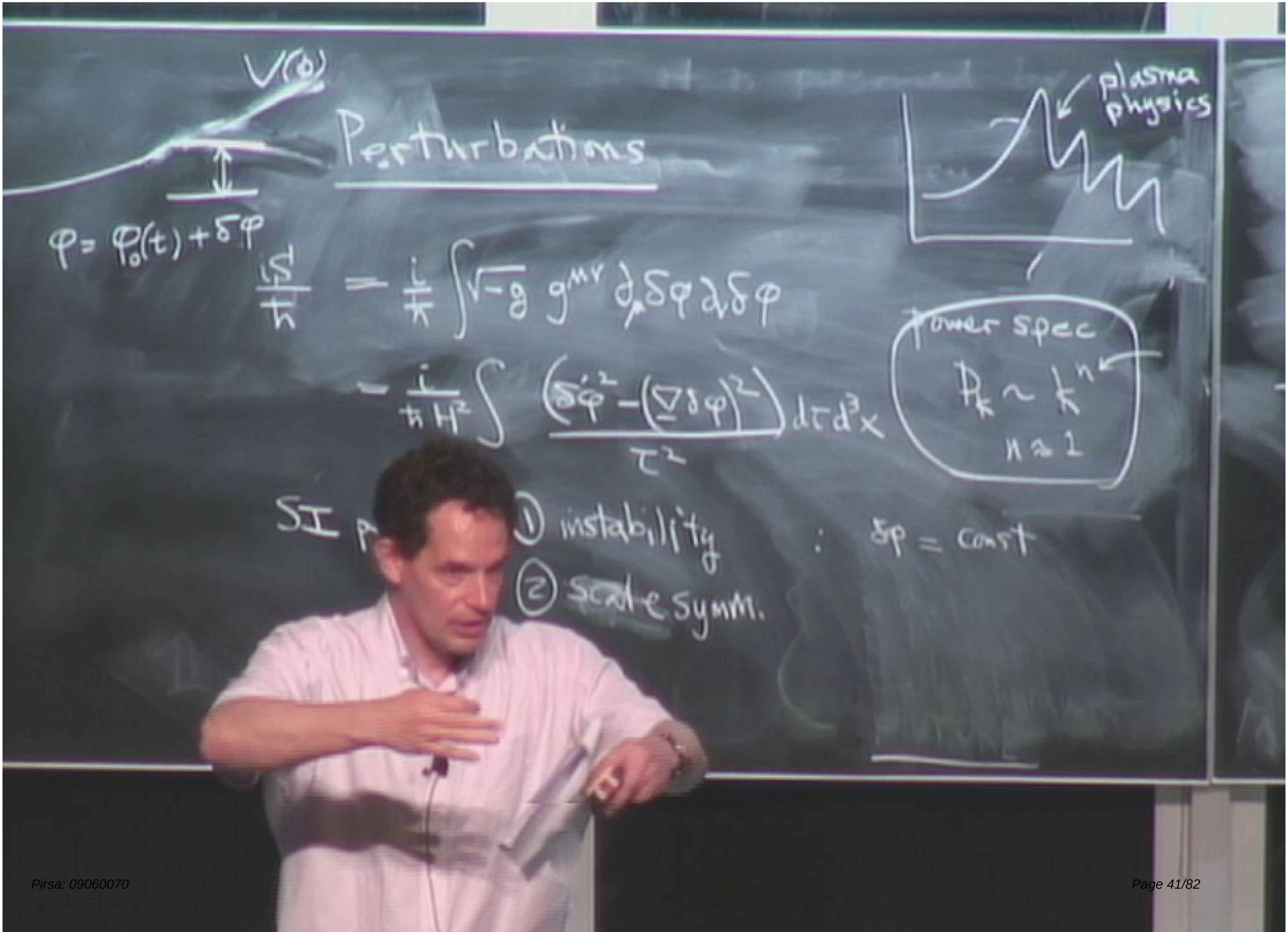
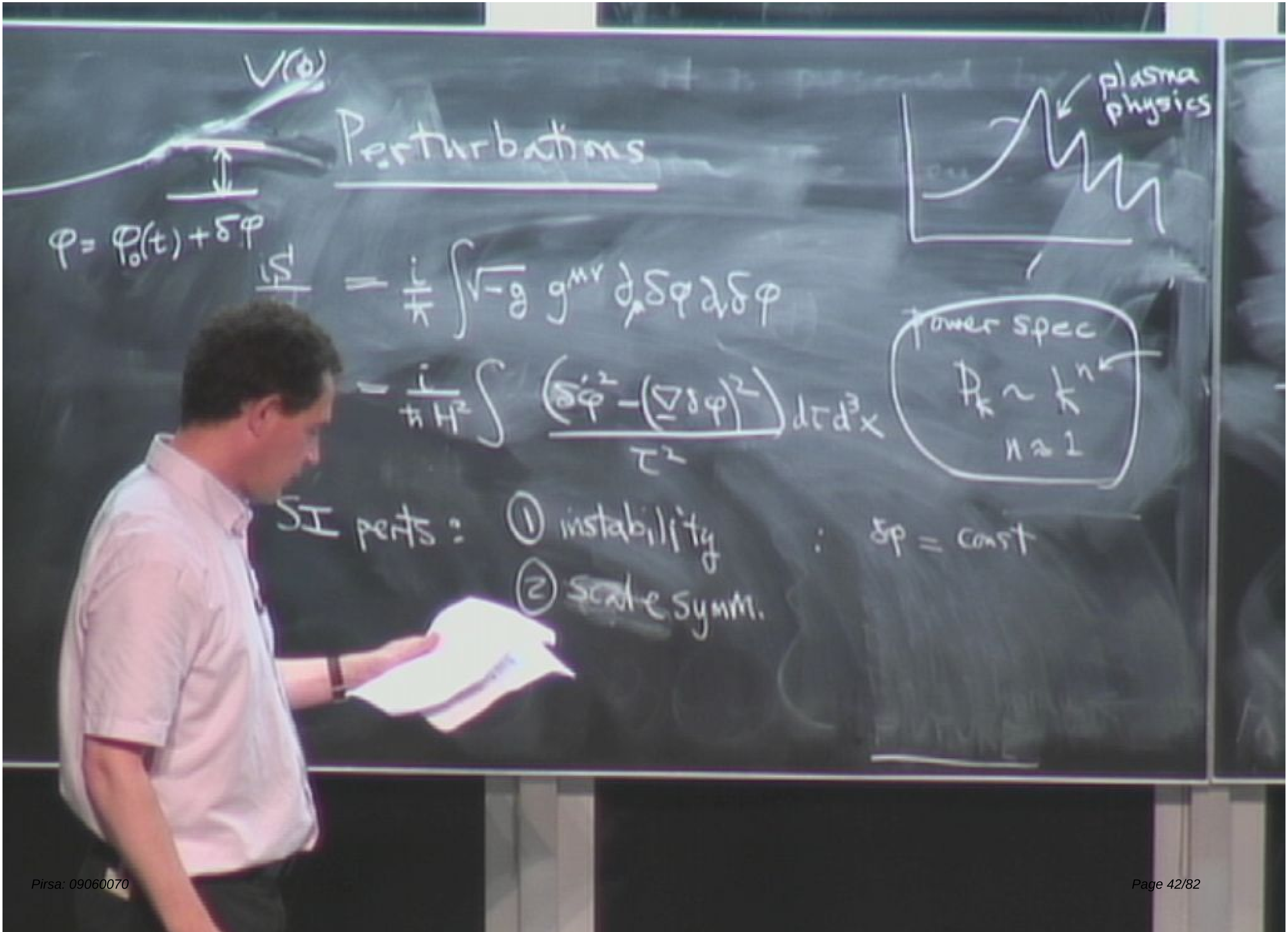
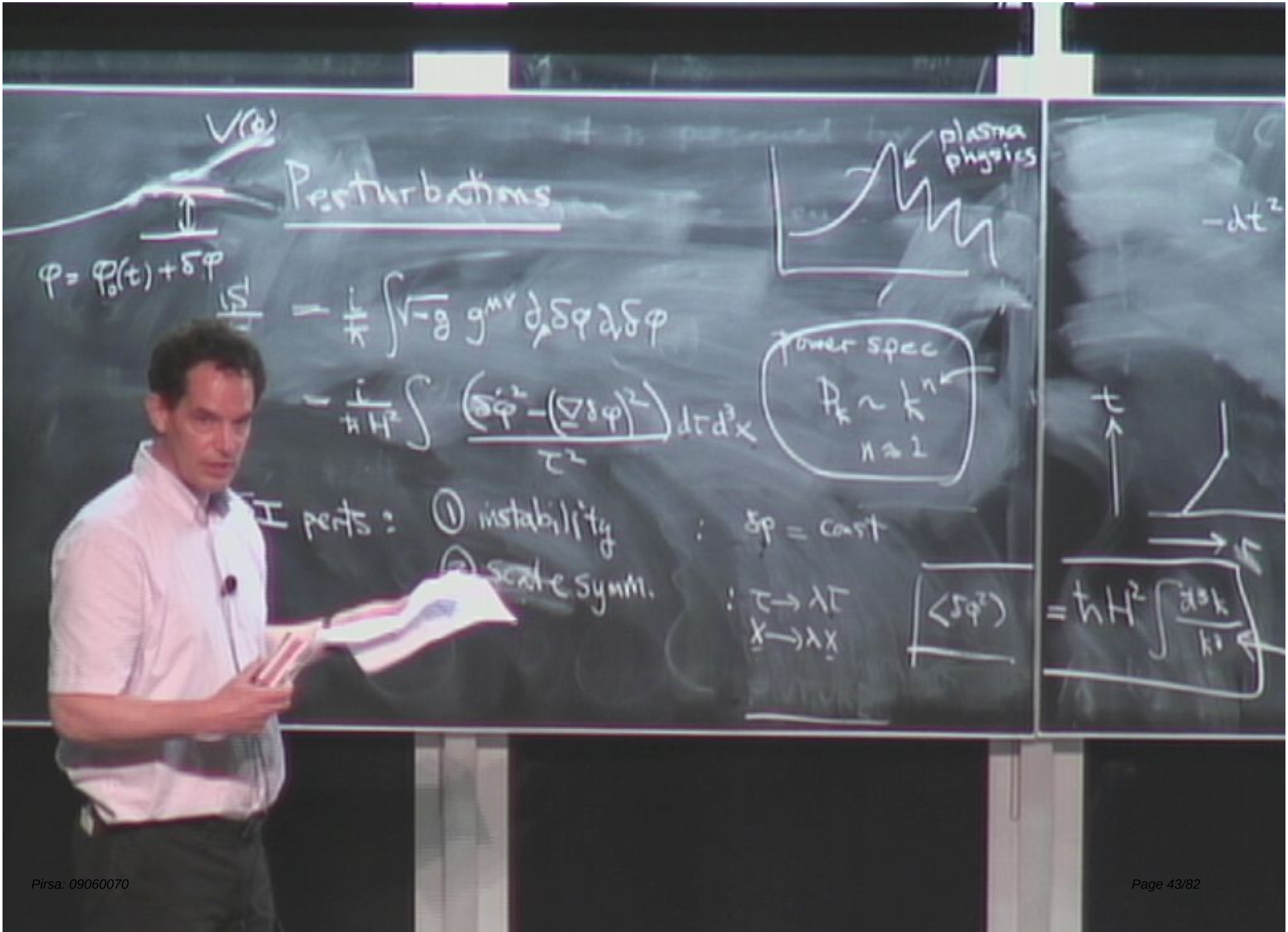

V(φ)
Perturbations
φ = φ₀(t) + δφ
iS/ħ = i/ħ ∫√-g g^μν ∂_μ δφ ∂_ν δφ
plasma physics
Power spec
P_k ~ k^n
n ≈ 1



$V(\phi)$
Perturbations
$\varphi = \varphi_0(t) + \delta\varphi$
$\frac{iS}{\hbar} = \frac{i}{\hbar}\int \sqrt{-g}\, g^{\mu\nu} \partial_\mu \delta\varphi \partial_\nu \delta\varphi$
$= \frac{i}{\hbar H^2}\int \frac{\left(\delta\varphi'^2 - (\nabla\delta\varphi)^2\right)}{\tau^2} d\tau d^3x$
plasma physics
Power spec
$P_k \sim k^n$
$n \approx 1$


V(ϕ)
Perturbations
plasma physics
φ = φ_0(t) + δφ
iS/ħ = i/ħ ∫ √-g g^{μν} ∂_μ δφ ∂_ν δφ
= i/(ħH^2) ∫ (δφ'^2 − (∇δφ)^2)/τ^2 dτ d^3x
Power spec
P_k ~ k^n
n ≈ 1
SI
1 instability : δφ = const
2 scale symm.


V(φ)
Perturbations
φ = φ₀(t) + δφ
plasma physics
Power spec
n ≈ 1
SI perts :
① instability : δφ = const
② scale symm.


V(φ)
Perturbations
φ = φ0(t) + δφ
plasma physics
Power spec
n ≈ 1
pents :
instability
scale symm.
δφ = const
τ → λτ
x → λx
⟨δφ²⟩
−dt²

Perturbations

$\varphi = \varphi_0(t) + \delta\varphi$

$$\frac{iS}{\hbar} = \frac{i}{\hbar}\int \sqrt{-g}\, g^{\mu\nu}\,\partial_\mu\delta\varphi\,\partial_\nu\delta\varphi$$

$$= \frac{i}{\hbar H^2}\int \frac{\left(\delta\varphi'^2 - (\nabla\delta\varphi)^2\right)}{\tau^2}\, d\tau\, d^3x$$

Power spec

$$\boxed{P_k \sim k^n \quad n \approx 1}$$

SI perts: (1) instability : $\delta\varphi = \text{const}$

(2) scale symm. : $\tau \to \lambda\tau$, $\underline{x} \to \lambda\underline{x}$

$$\boxed{\langle\delta\varphi^2\rangle = \hbar H^2 \int \frac{d^3k}{k^3}}$$

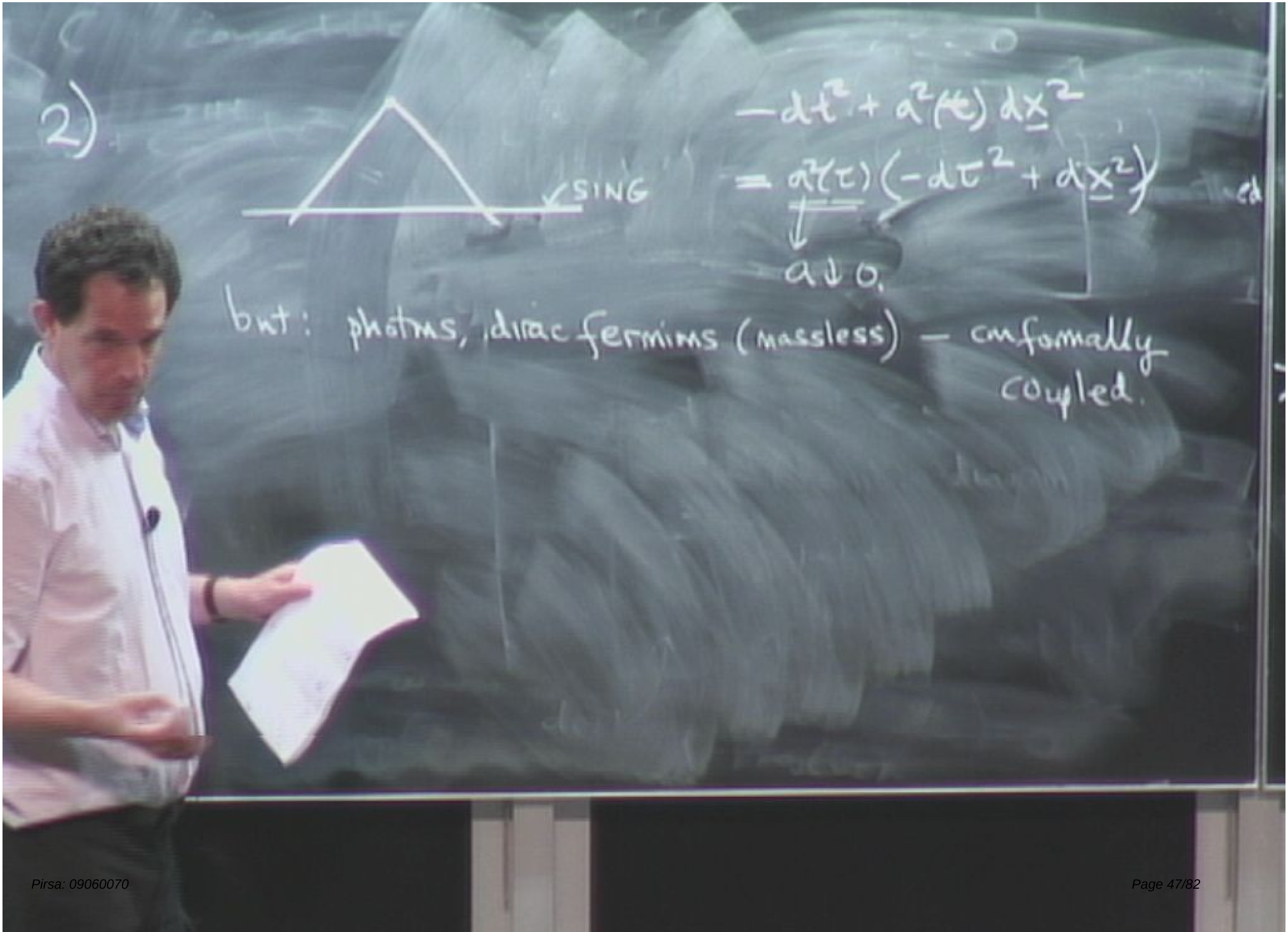
2)

SING

$$-dt^2 + a^2(t)\, d\underline{x}^2$$
$$= a^2(\tau)\left(-d\tau^2 + d\underline{x}^2\right)$$

2)

$$-dt^2 + a^2(t)\, d\underline{x}^2$$
$$= a^2(\tau)\left(-d\tau^2 + d\underline{x}^2\right)$$


2)
SING
−dt² + a²(t) dx²
= a²(τ) (−dτ² + dx²)
a ↓ 0.
but: photons, dirac fermions (massless) – conformally coupled.

2)

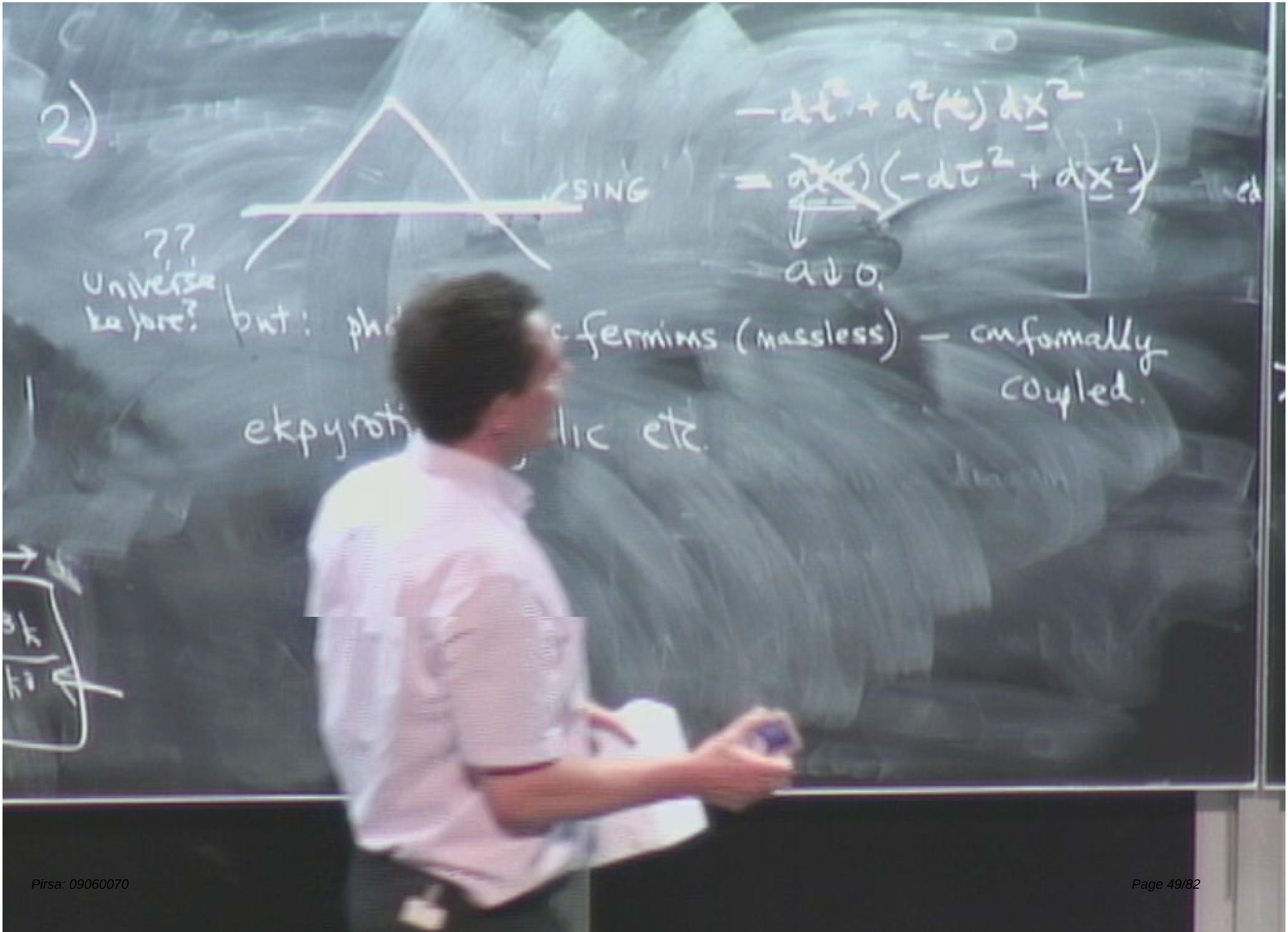
SING

$$-dt^2 + a^2(t)\, d\underline{x}^2$$

$$= \cancel{a^2(\tau)}\,(-d\tau^2 + d\underline{x}^2)$$

$a \downarrow 0.$

but: photons, dirac fermions (massless) — conformally coupled.


2)
SING
??
universe
before?
but:
fermions (massless) — conformally
coupled.
ekpyroti
lic etc.
$-dt^2 + a^2(t)\,d\underline{x}^2$
$= a^2(\tau)(-d\tau^2 + d\underline{x}^2)$
$a \downarrow 0.$

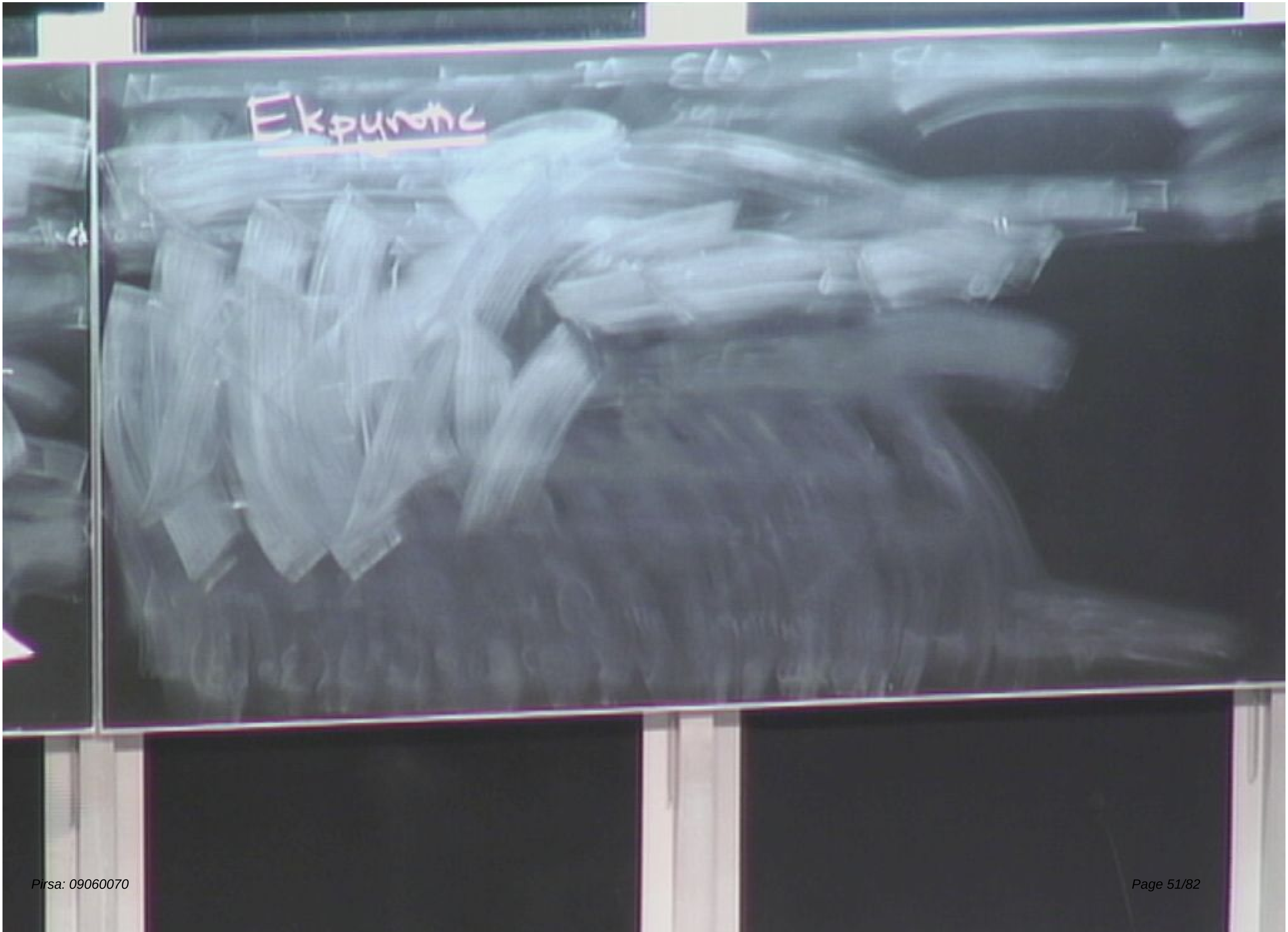
2)

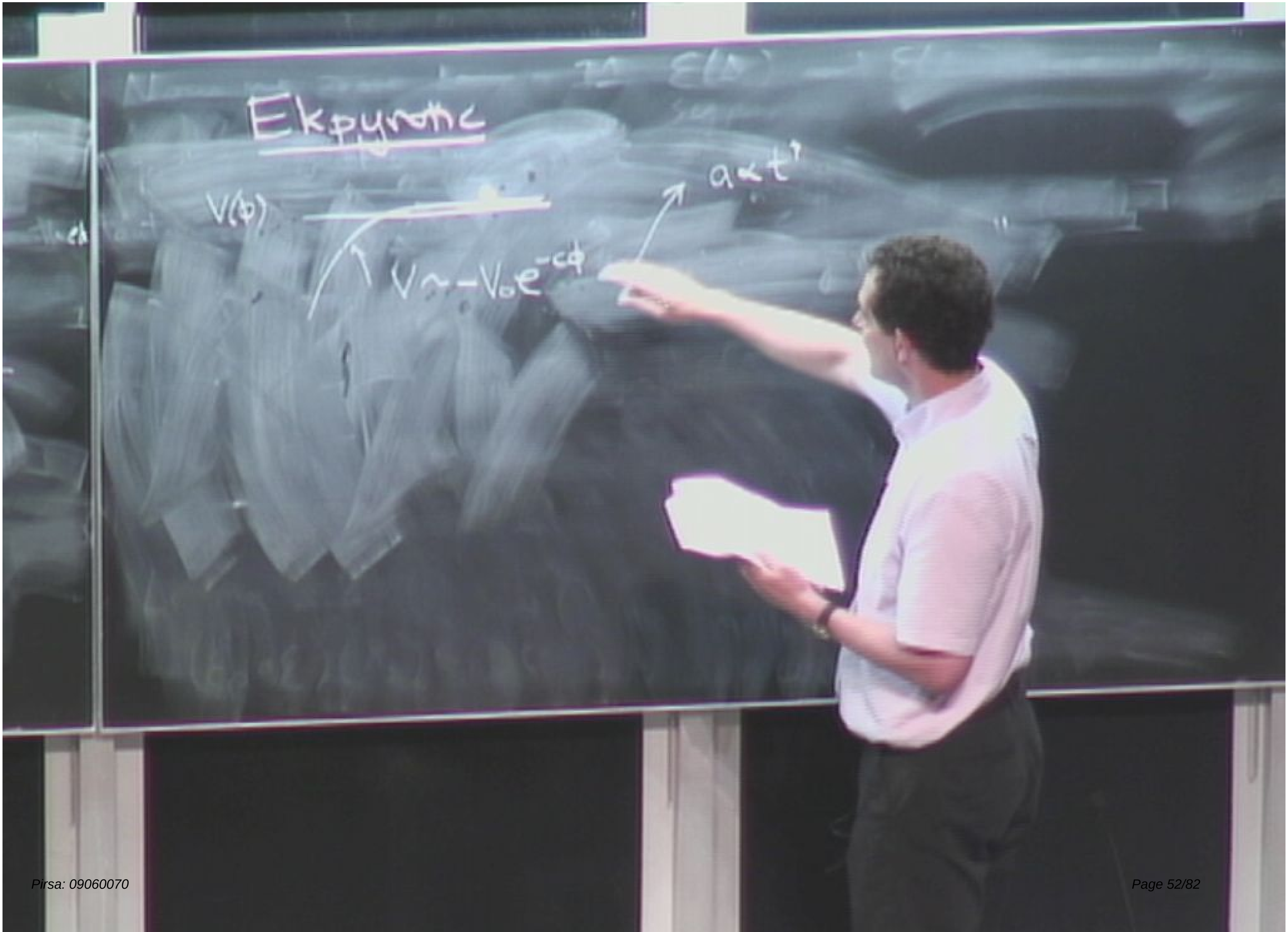
$$-dt^2 + a^2(t)\,d\underline{x}^2 = \cancel{a^2(\tau)}\left(-d\tau^2 + d\underline{x}^2\right)$$

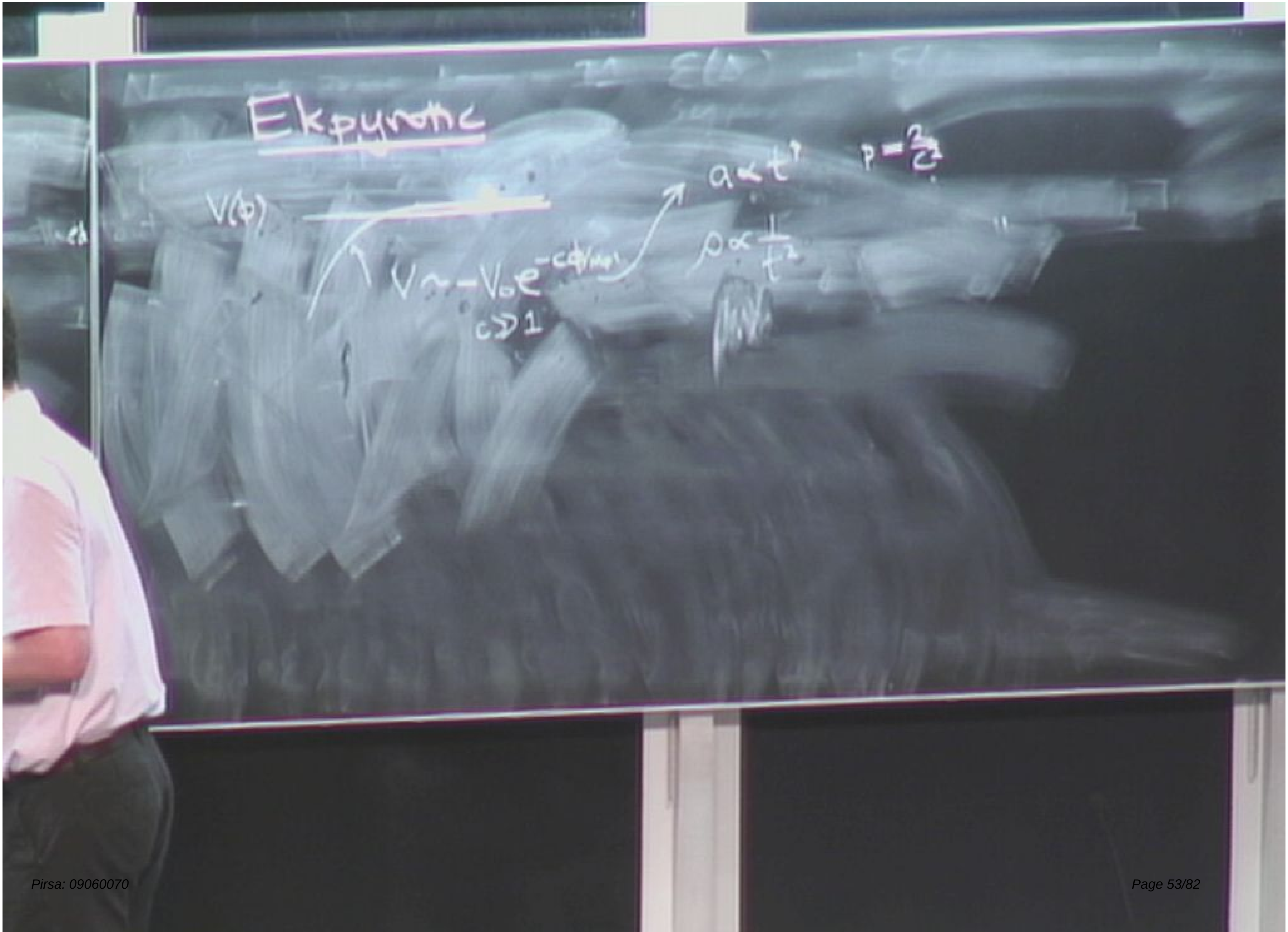
$a \downarrow 0.$

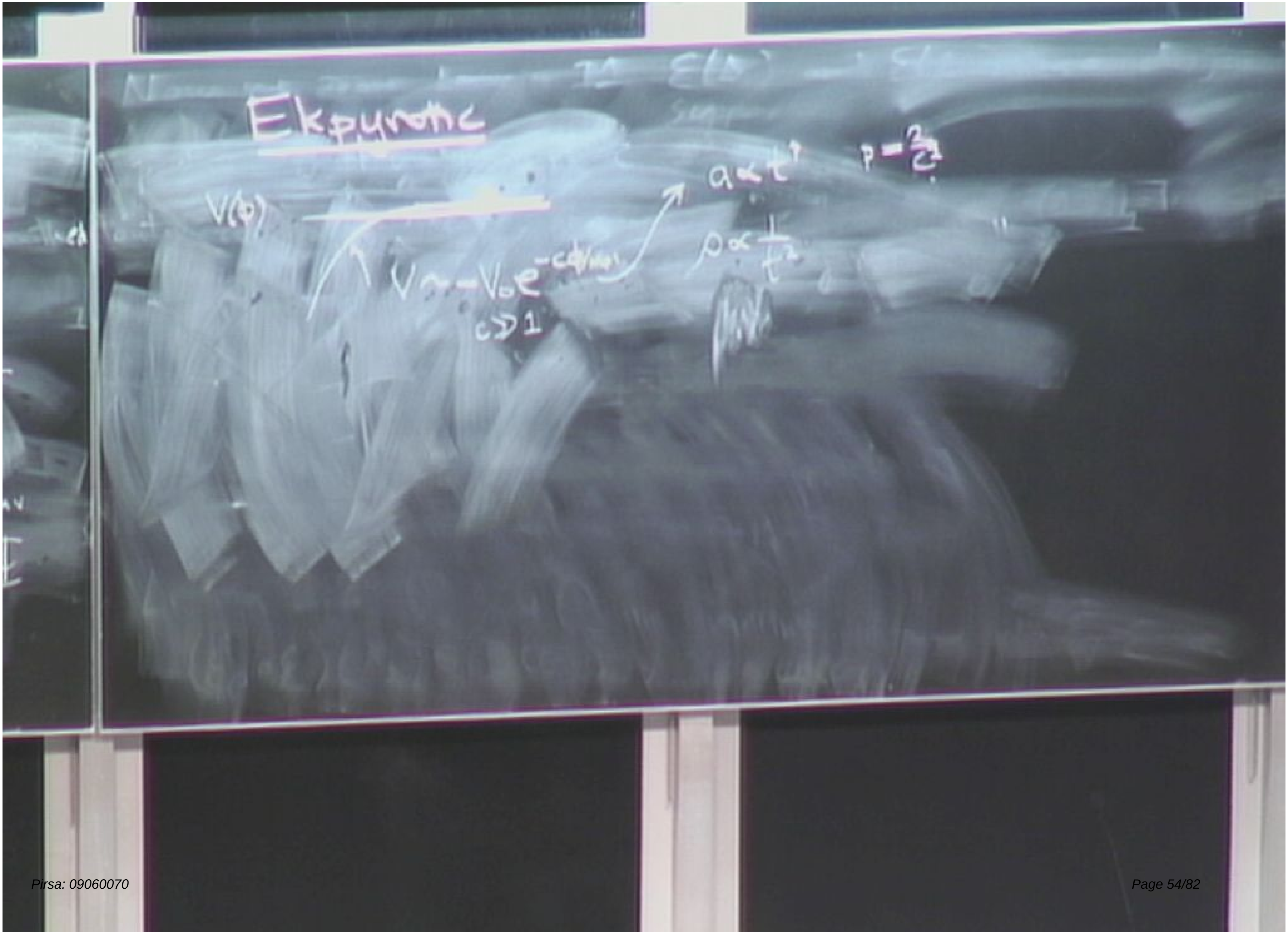
but: photons, dirac fermions (massless) — conformally coupled.

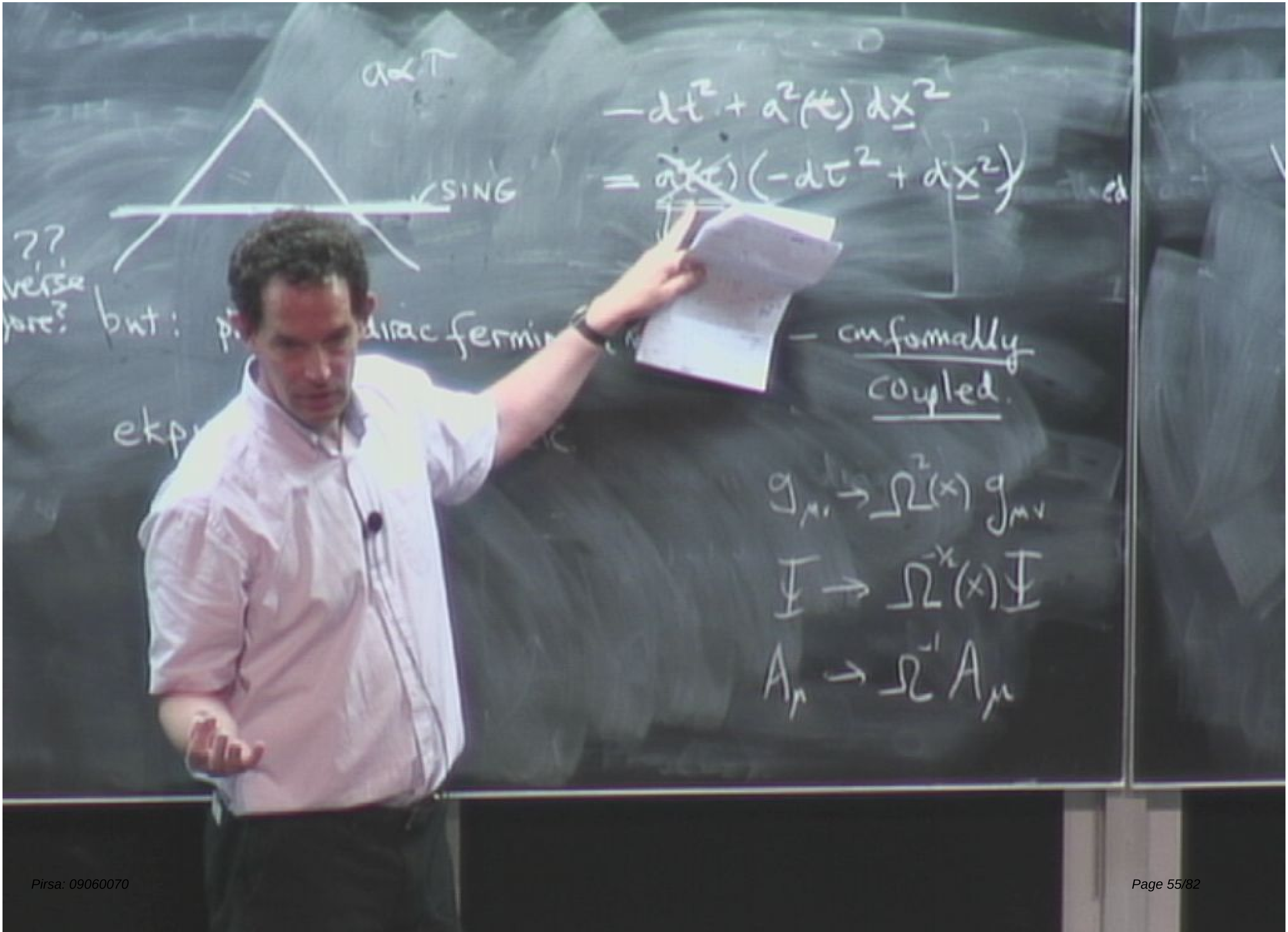
ekpyrotic, cyclic etc.


Ekpyrotic

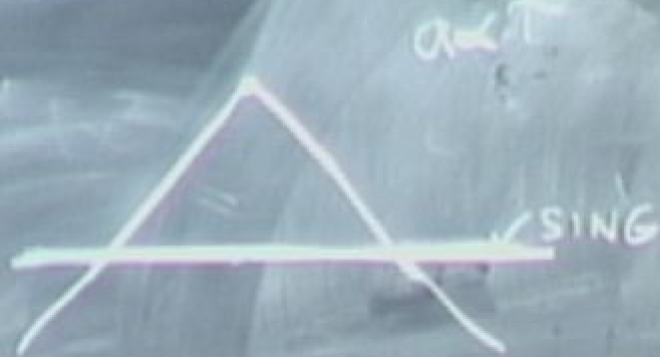

Ekpyrotic
V(φ)
V ~ -V₀e^-cφ
a ∝ t^p


Ekpyrotic
V(φ)
$V \sim -V_0 e^{-c\phi/M_{pl}}$
$c \gg 1$
$a \propto t^p$
$p = \frac{2}{c^2}$
$\rho \propto \frac{1}{t^2}$


Ekpyrotic
V(φ)
V ≈ −V₀e^{−cφ/M_pl}
c>1
a ∝ t^p
p = 2/c²
ρ ∝ 1/t²



$a \propto \tau$
SING
??
verse
ore?
but:
dirac fermi
conformally
coupled
ekp
$-dt^2 + a^2(t)\, d\underline{x}^2$
$= a^2(\tau)(-d\tau^2 + d\underline{x}^2)$
$g_{\mu\nu} \to \Omega^2(x)\, g_{\mu\nu}$
$\Psi \to \Omega^{-3/2}(x)\, \Psi$
$A_\mu \to \Omega^{-1} A_\mu$



??
...verse
...ore?

$$-dt^2 + a^2(t)\,d\underline{x}^2$$

$$= \cancel{a^2(\tau)}\left(-d\tau^2 + d\underline{x}^2\right)$$

$a \downarrow 0$.

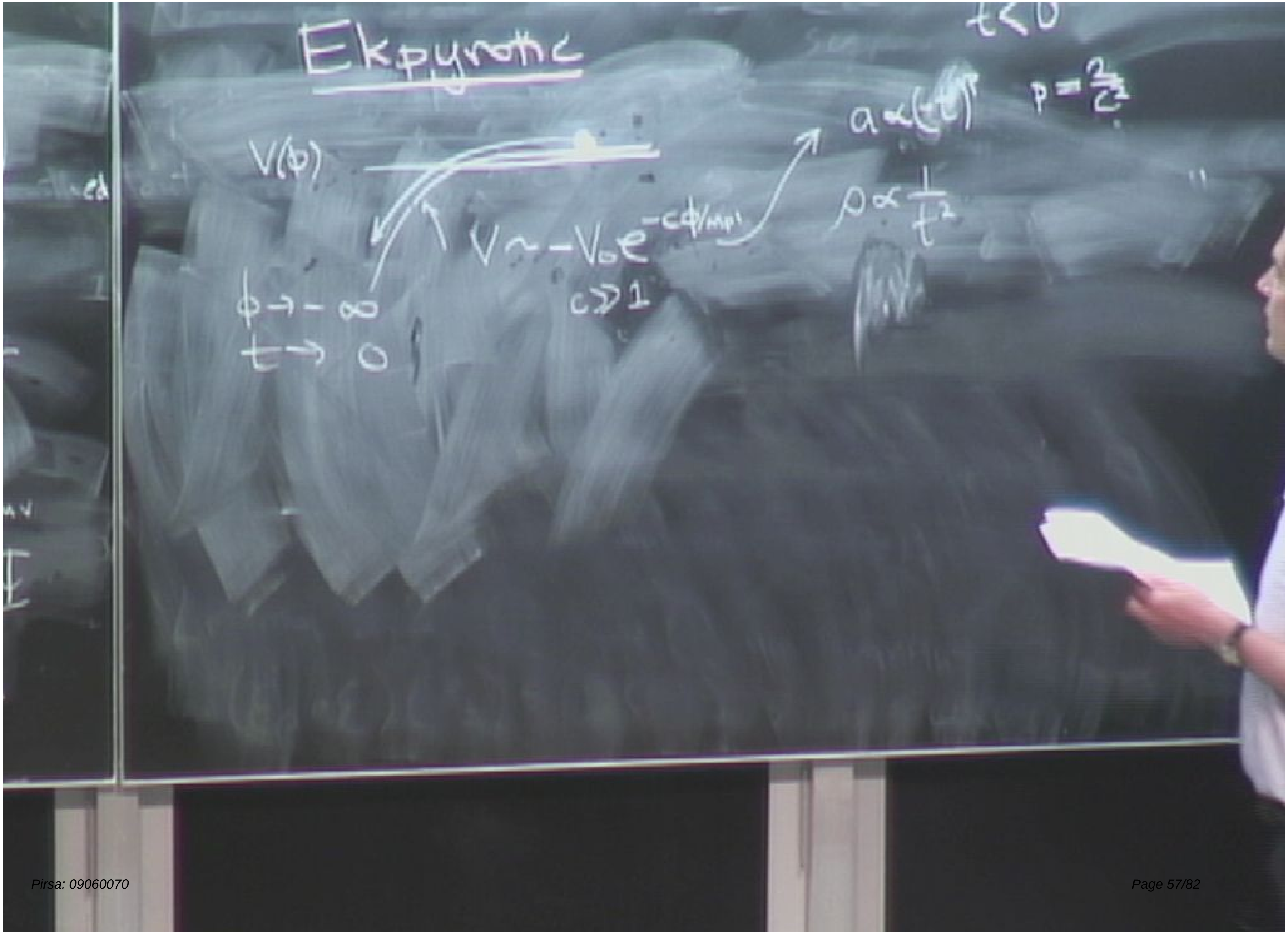
but: photons, dirac fermions (massless) — conformally coupled.

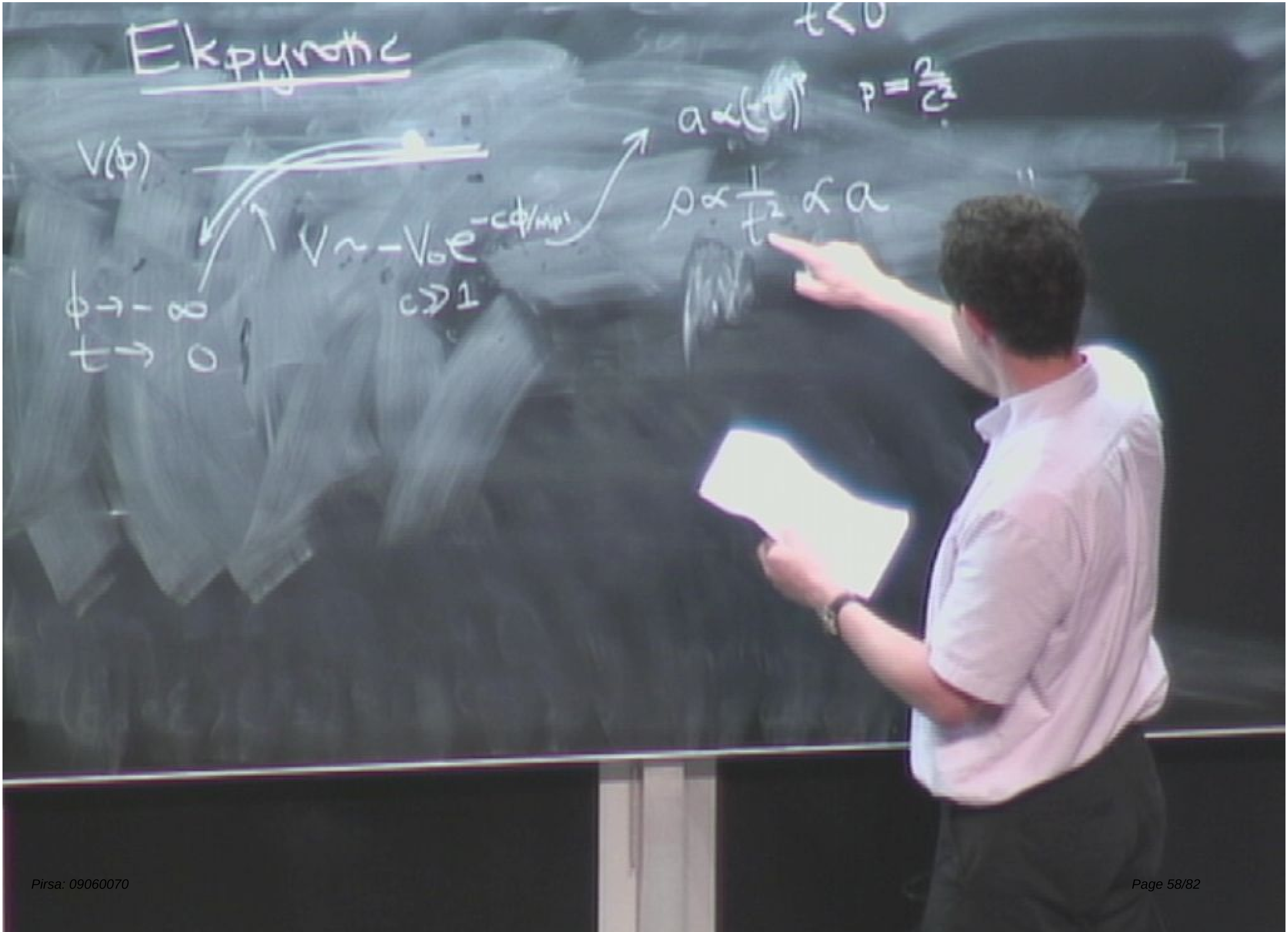
ekpyrotic, cyclic etc.

$$g_{\mu\nu} \to \Omega^2(x)\, g_{\mu\nu}$$

$$\Psi \to \Omega^{-3/2}(x)\, \Psi$$

$$A_\mu \to \Omega^{-1} A_\mu$$


Ekpyrotic
$t<0$
$a \propto (-t)^p$
$p = \frac{2}{c^2}$
$V(\phi)$
$V \sim -V_0 e^{-c\phi/m_{pl}}$
$c \gg 1$
$\phi \to -\infty$
$t \to 0$
$\rho \propto \frac{1}{t^2}$


Ekpyrotic
t<0
V(φ)
V ~ -V₀e^(-cφ/mpl)
c>>1
φ → -∞
t → 0
a ∝ (-t)^p
p = 2/c²
ρ ∝ 1/t² ∝ a

Ekpyrotic

$t<0$

$V(\phi)$

$V \sim -V_0 e^{-c\phi/M_{pl}}$

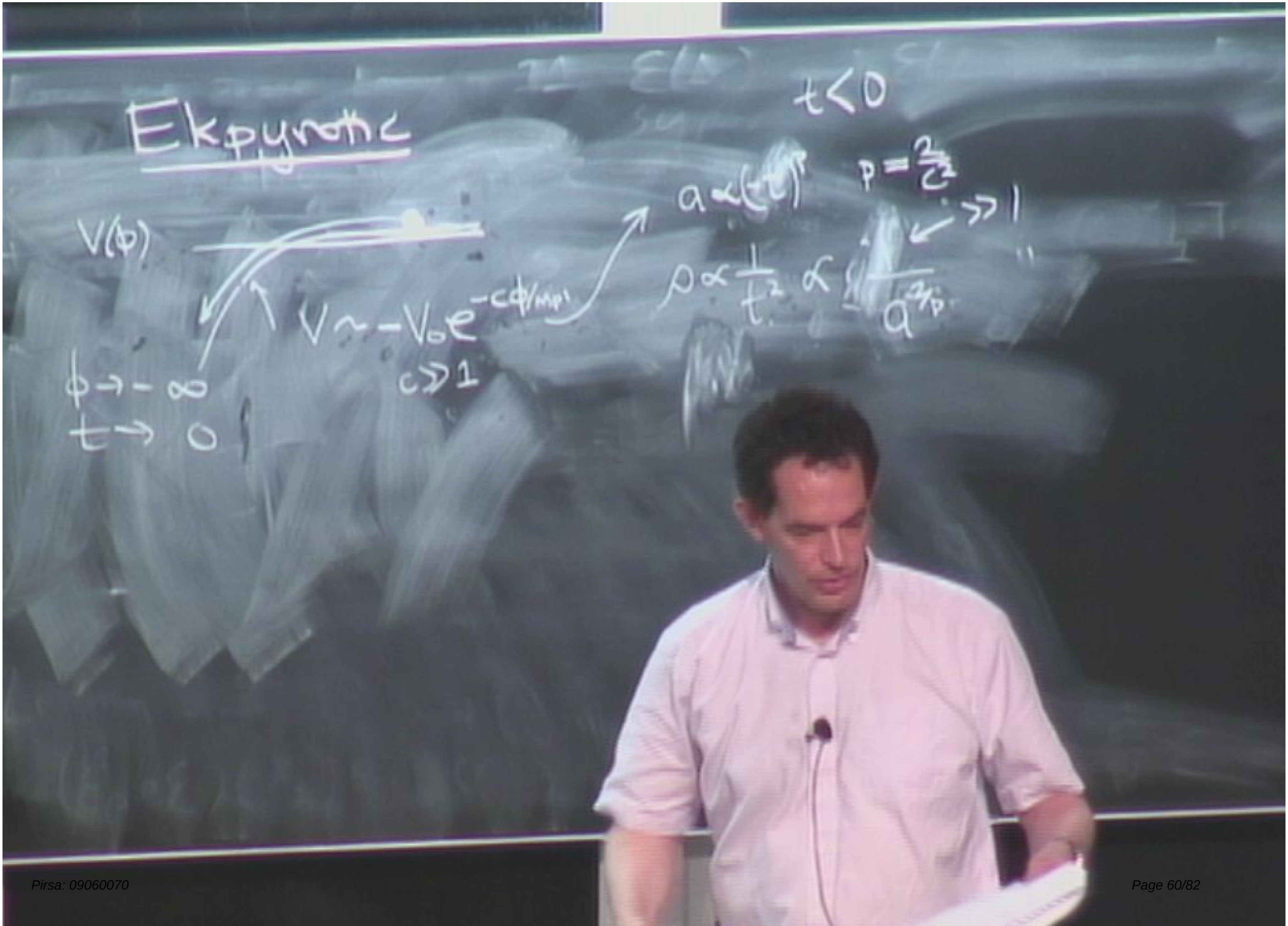
$c \gg 1$

$\phi \to -\infty$

$t \to 0$

$a \propto (-t)^p \qquad p = \frac{2}{c^2}$

$\rho \propto \frac{1}{t^2} \propto a^{-\frac{2}{p}} \quad \frac{2}{p} \gg 1$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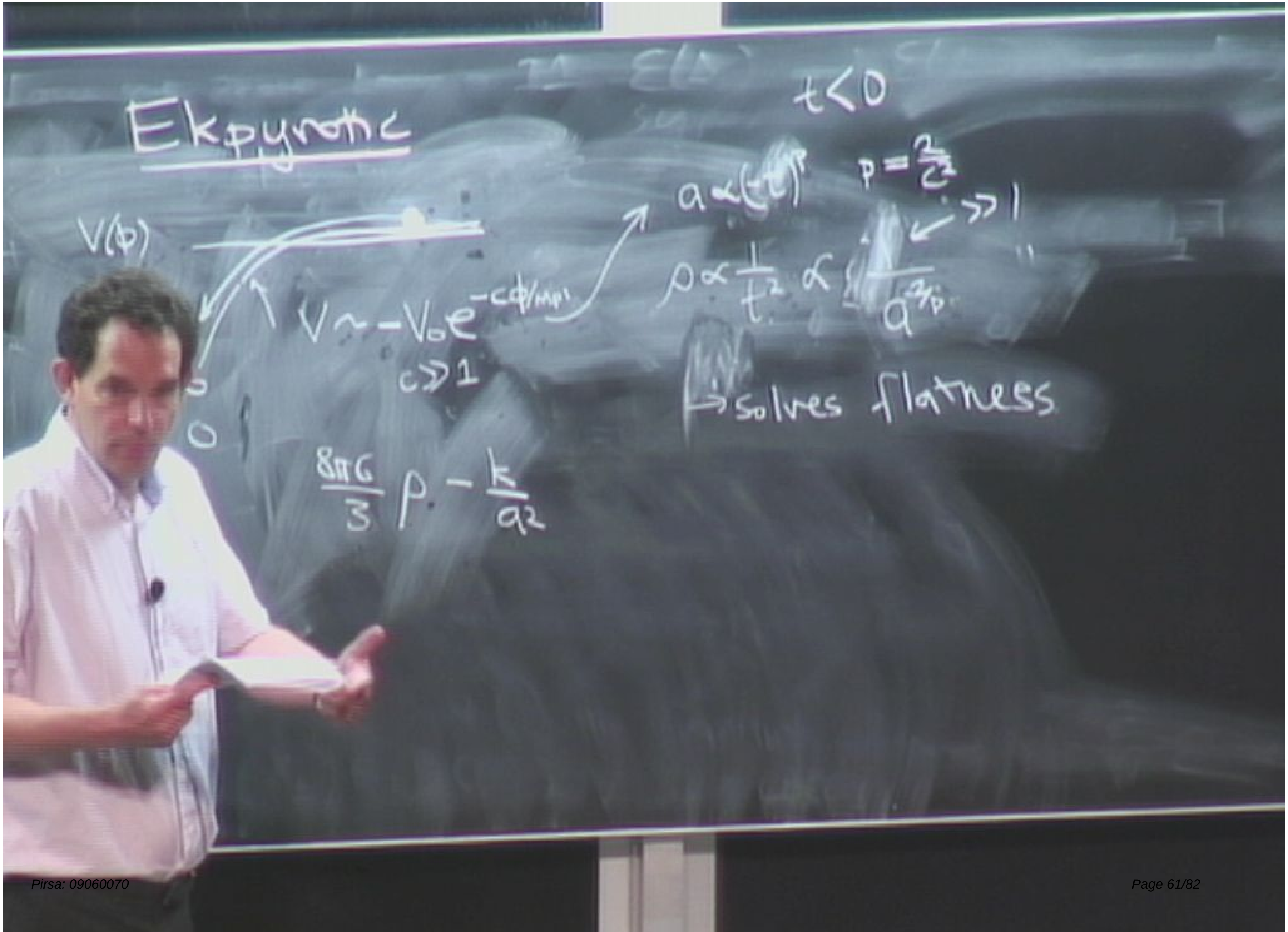
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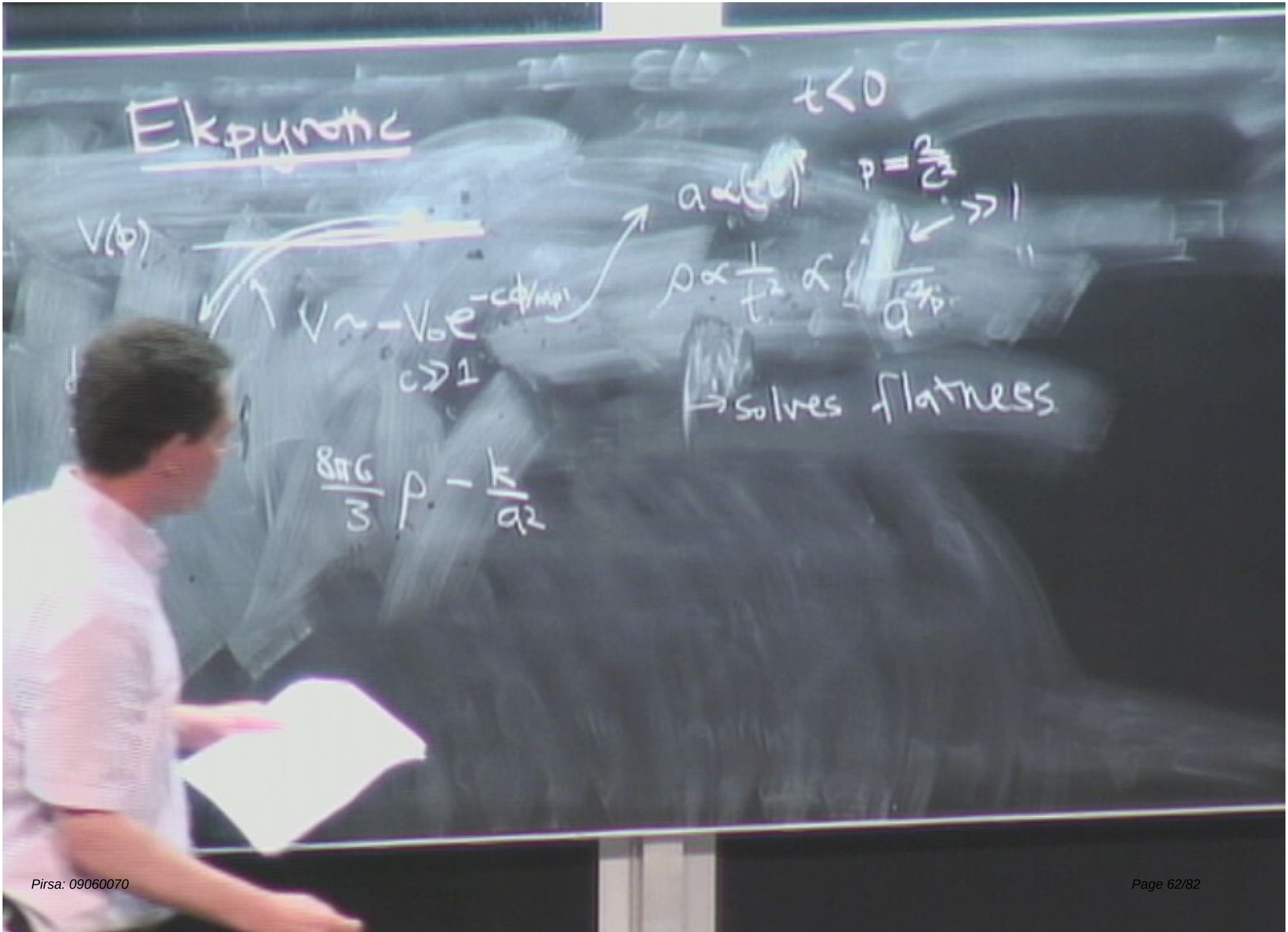
V ~ -V₀e^(-cφ/Mpl)
c>>1
a ∝ (-t)^p
p = 2/c²
>>1
ρ ∝ 1/t² ∝ 1/a^(2/p)
solves flatness
8πG/3 ρ - k/a²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$\rho \propto \frac{1}{t^2} \propto \frac{1}{a^{2/p}}$
solves flatness
$\frac{8\pi G}{3}\rho - \frac{k}{a^2}$

Ekpyrotic

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$a \propto (-t)^p \quad p = \frac{2}{c^2}$

$\ll 1$

$V(\phi)$

$V \sim -V_0 e^{-c\phi/m_{pl}}$

$c \gg 1$

$\phi \to -\infty$

$t \to 0$

$\rho \propto \frac{1}{t^2} \propto \frac{1}{a^{2/p}}$

$\hookrightarrow$ solves flatness
isotropy

$\frac{8\pi G}{3}\rho - \frac{k}{a^2}$

$\to$ SI pert^{n}s [illegible] !

$$\frac{S}{\hbar} = \frac{1}{\hbar}\int d^4x\left(\frac{1}{2}(\partial\phi)^2 + V_0 e^{-c\phi}\right)$$

neglect gravity

$$\boxed{\ldots n H^2 \int \frac{d^3k}{k^3}}$$

$$\frac{iS}{\hbar} = \frac{i}{\hbar}\int d^4x \left(\frac{1}{2}(\partial\phi)^2 + V_0 e^{-c\phi} \right)$$

neglect gravity

Scale symm $x^\mu \to \lambda x^\mu$

$\phi \to \phi + \frac{2}{c}\ln\lambda$

$\hbar \to \hbar\lambda^2$

$$\boxed{\hbar H^2 \int \frac{d^3k}{k^3}}$$

$$\frac{iS}{\hbar} = \frac{i}{\hbar}\int d^4x \left(\tfrac{1}{2}(\partial\phi)^2 + V_0 e^{-c\phi}\right)$$

neglect gravity

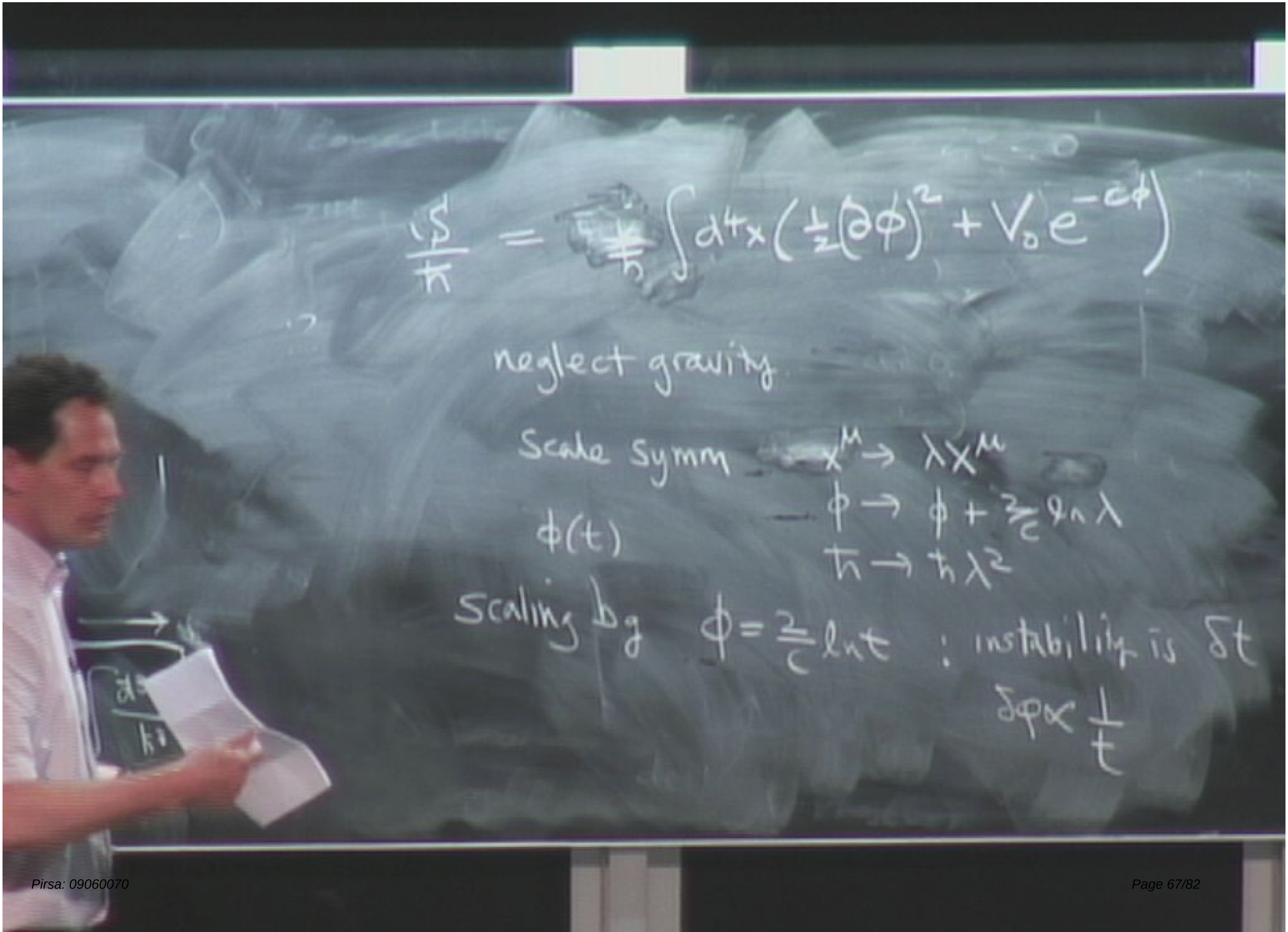
Scale symm $\quad x^\mu \to \lambda x^\mu$

$\phi(t) \qquad \phi \to \phi + \frac{2}{c}\ln\lambda$

$\hbar \to \hbar\lambda^2$

scaling bg $\quad \phi = \frac{2}{c}\ln t \quad :$

$$\boxed{\hbar H^2 \int \frac{d^3k}{k^3}}$$


$\frac{iS}{\hbar} = \frac{i}{\hbar}\int d^4x \left(\frac{1}{2}(\partial\phi)^2 + V_0 e^{-c\phi} \right)$
neglect gravity
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$\phi(t)$
$\hbar \to \hbar \lambda^2$
scaling bg $\phi = \frac{2}{c} \ln t$: instability is δt
$\delta\phi \propto \frac{1}{t}$

$$\frac{iS}{\hbar} = \frac{i}{\hbar}\int d^4x\left(\frac{1}{2}(\partial\phi)^2 + V_0 e^{-c\phi}\right)$$

neglect gravity

Scale symm $x^\mu \to \lambda x^\mu$

$\phi \to \phi + \frac{2}{c}\ln\lambda$

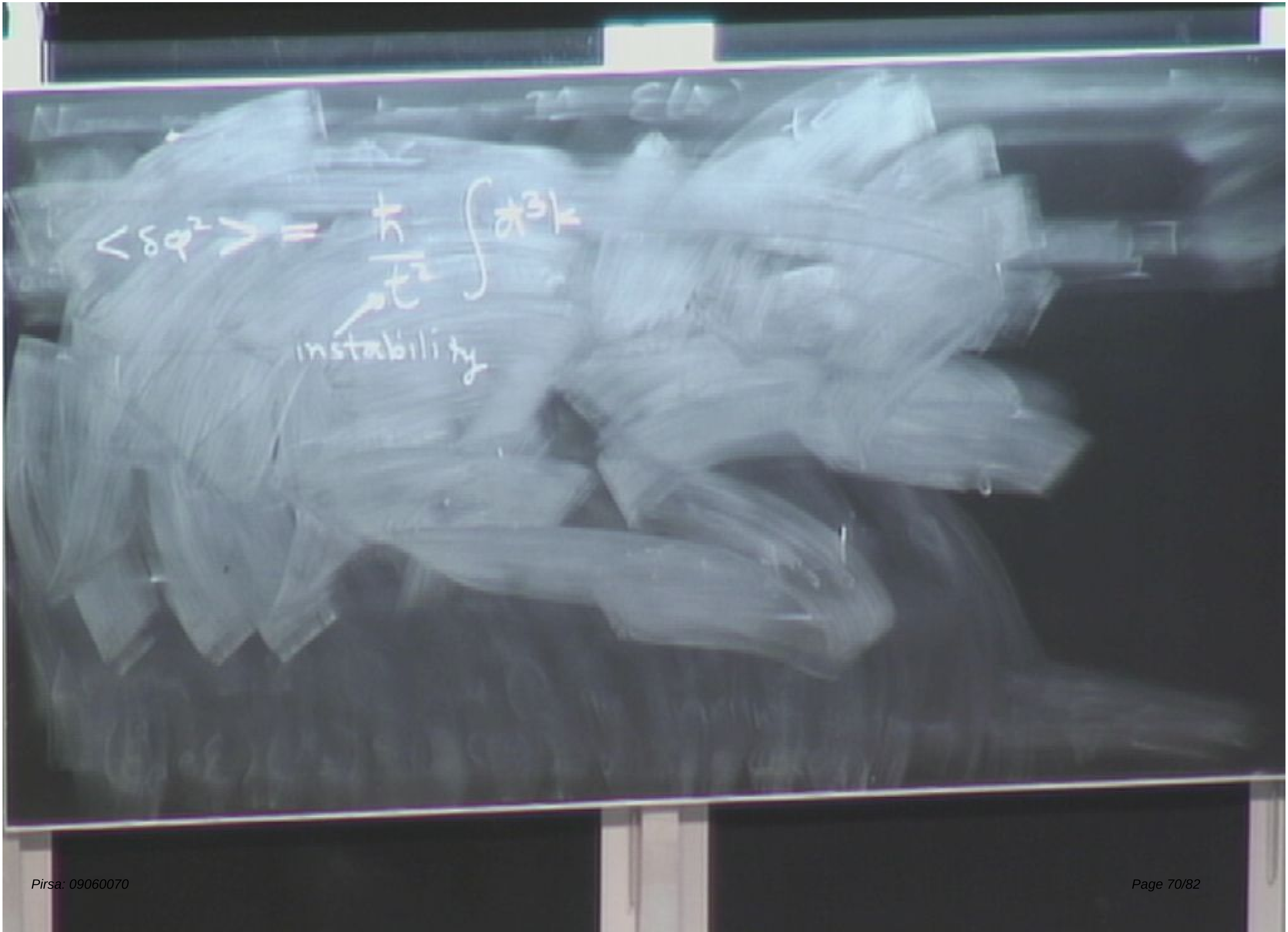
$\phi(t)$

$\hbar \to \hbar\lambda^2$

scaling bg $\phi = \frac{2}{c}\ln t$: instability is δt

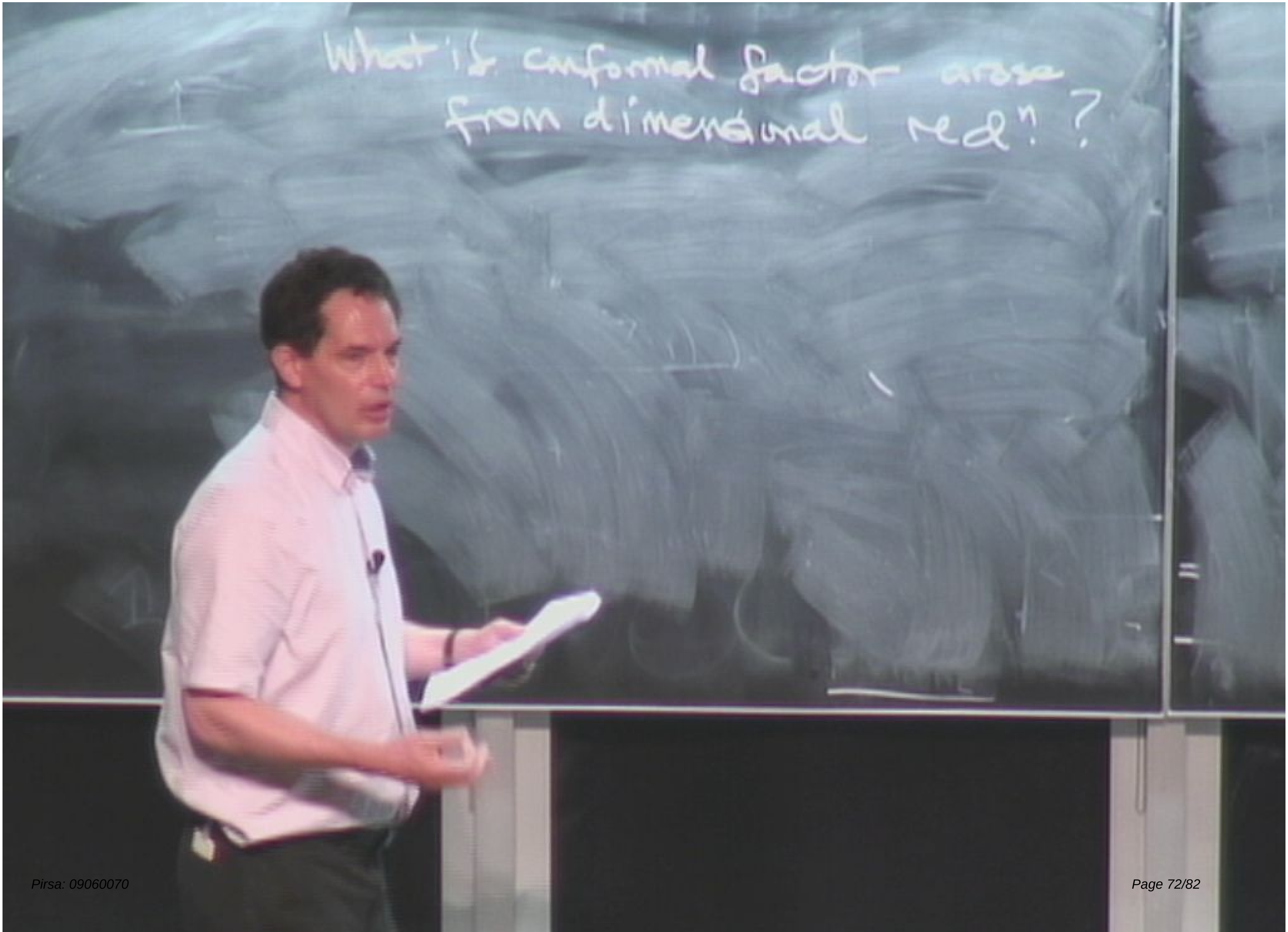
$\delta\phi \propto \frac{1}{t}$

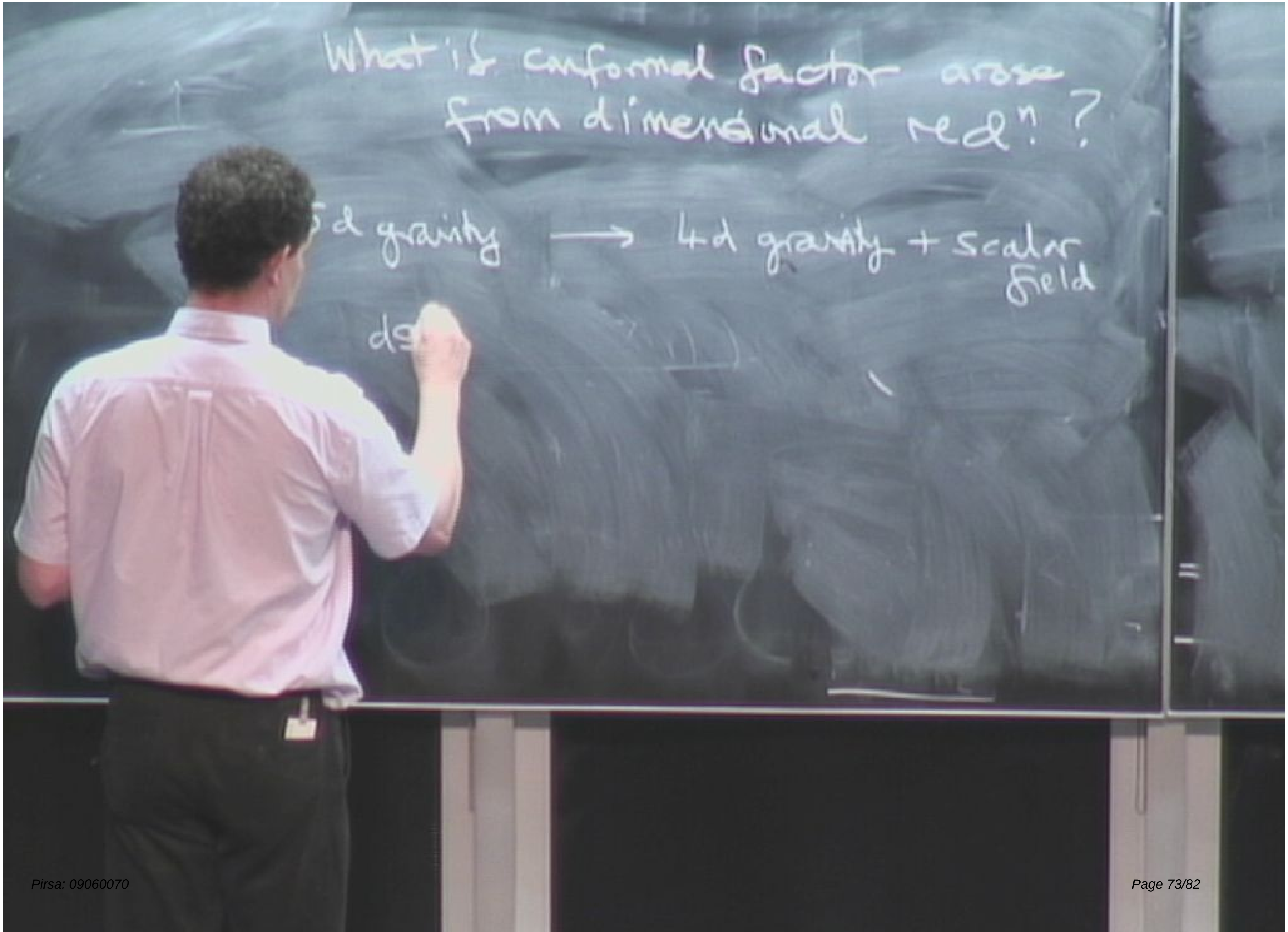
$\langle \delta\varphi^2 \rangle = \hbar$

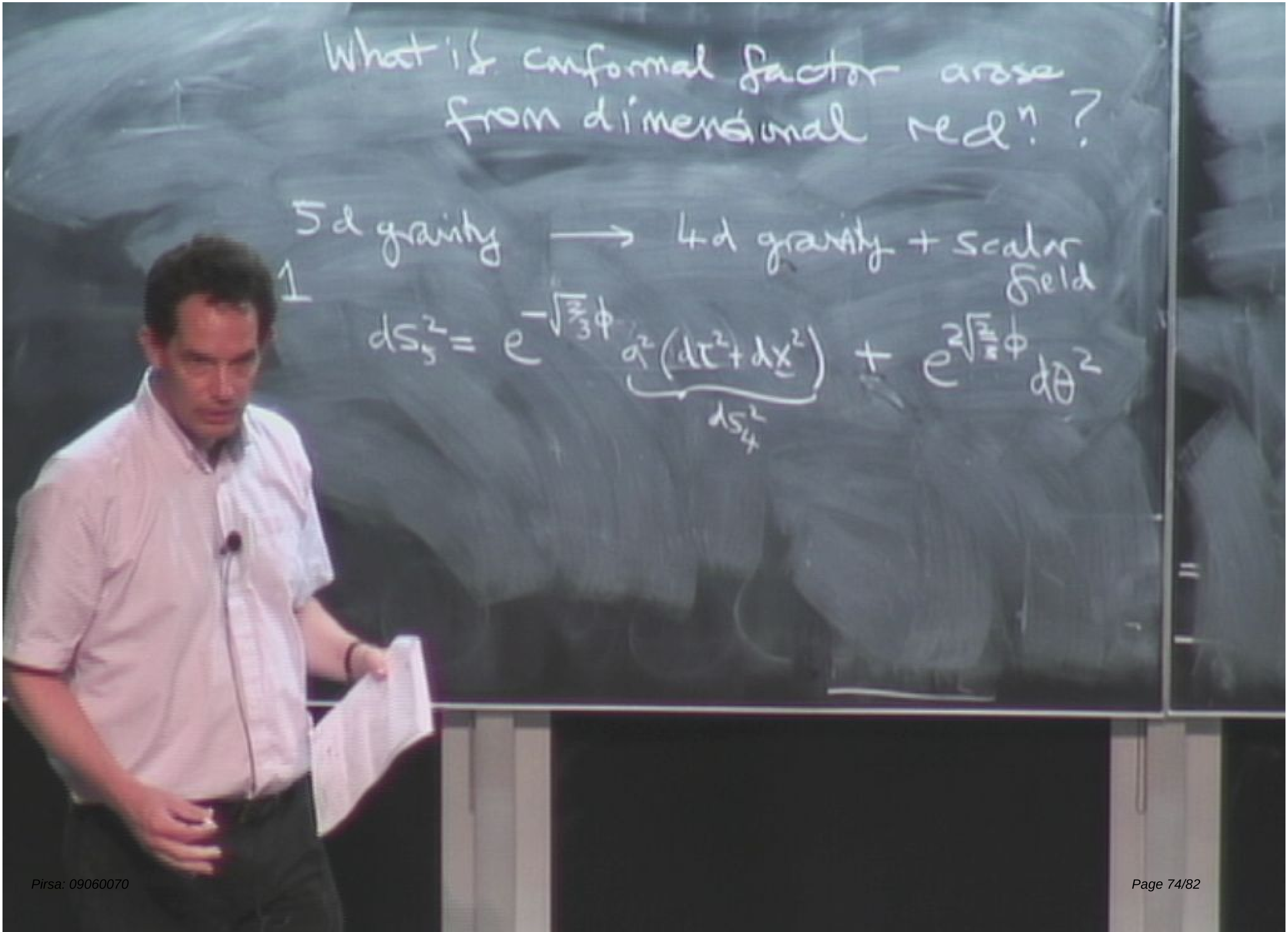

$\langle \delta\varphi^2 \rangle = \frac{\hbar}{t^2} \int d^3k$
instability

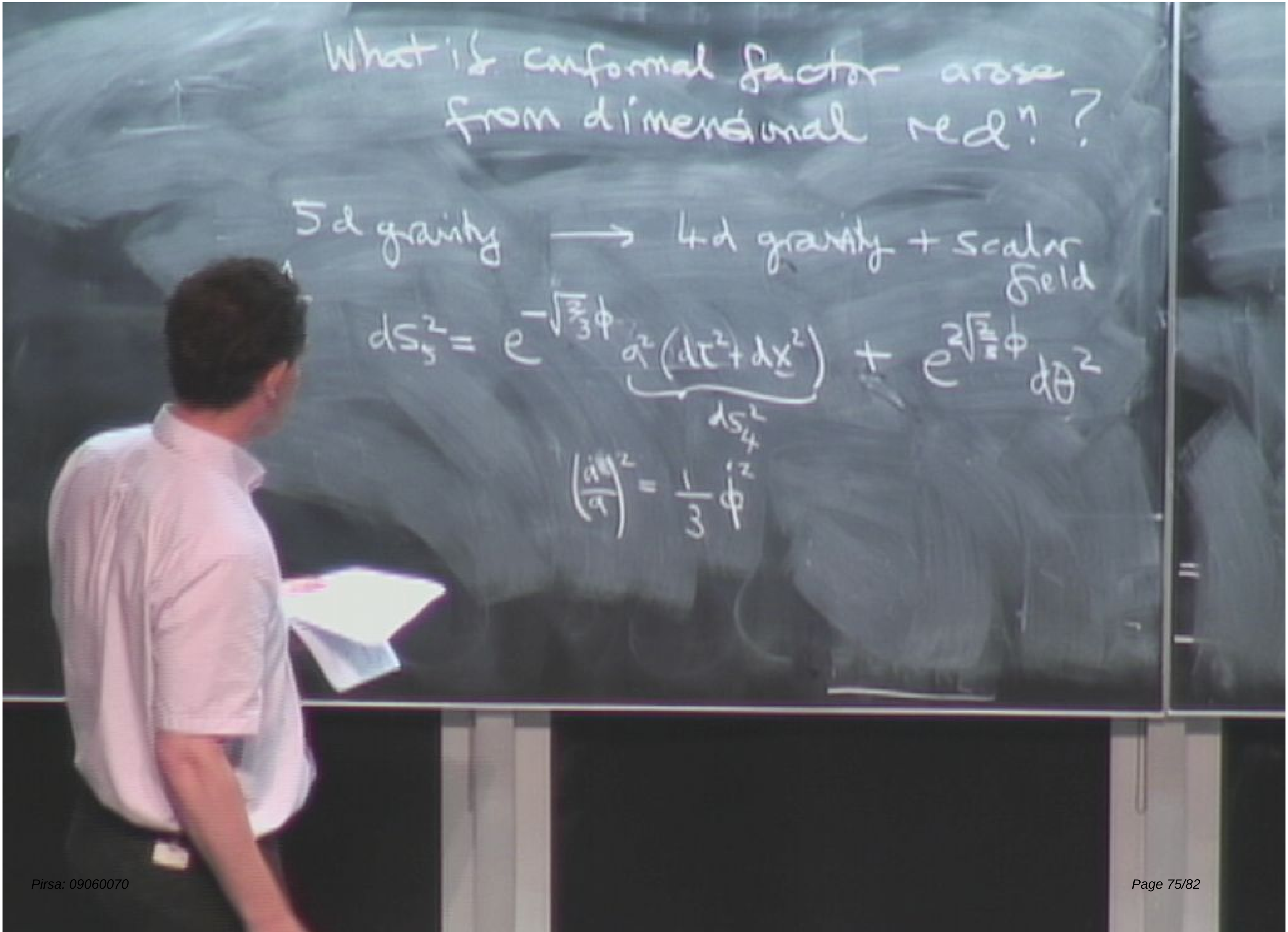
$$\langle \delta\varphi^2 \rangle = \frac{\hbar}{t^2} \int \frac{d^3k}{k^3} \rightarrow \text{SI.}$$

instability


What is conformal factor arose
from dimensional red^{n} ?


What if conformal factor arose
from dimensional red^n ?
5d gravity → 4d gravity + scalar field
ds


What if conformal factor arose from dimensional red^n?
5d gravity $\longrightarrow$ 4d gravity + scalar field
1
$ds_5^2 = e^{-\sqrt{\frac{2}{3}}\phi}\underbrace{a^2(d\tau^2 + d\underline{x}^2)}_{ds_4^2} + e^{2\sqrt{\frac{2}{3}}\phi}d\theta^2$


What is conformal factor arose
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5d gravity $\longrightarrow$ 4d gravity + scalar field
$ds_5^2 = e^{-\sqrt{\frac{2}{3}}\phi} \underbrace{a^2(d\tau^2 + d\underline{x}^2)}_{ds_4^2} + e^{2\sqrt{\frac{2}{3}}\phi} d\theta^2$
$\left(\frac{a'}{a}\right)^2 = \frac{1}{3}\phi'^2$

What if conformal factor arose from dimensional red^n?

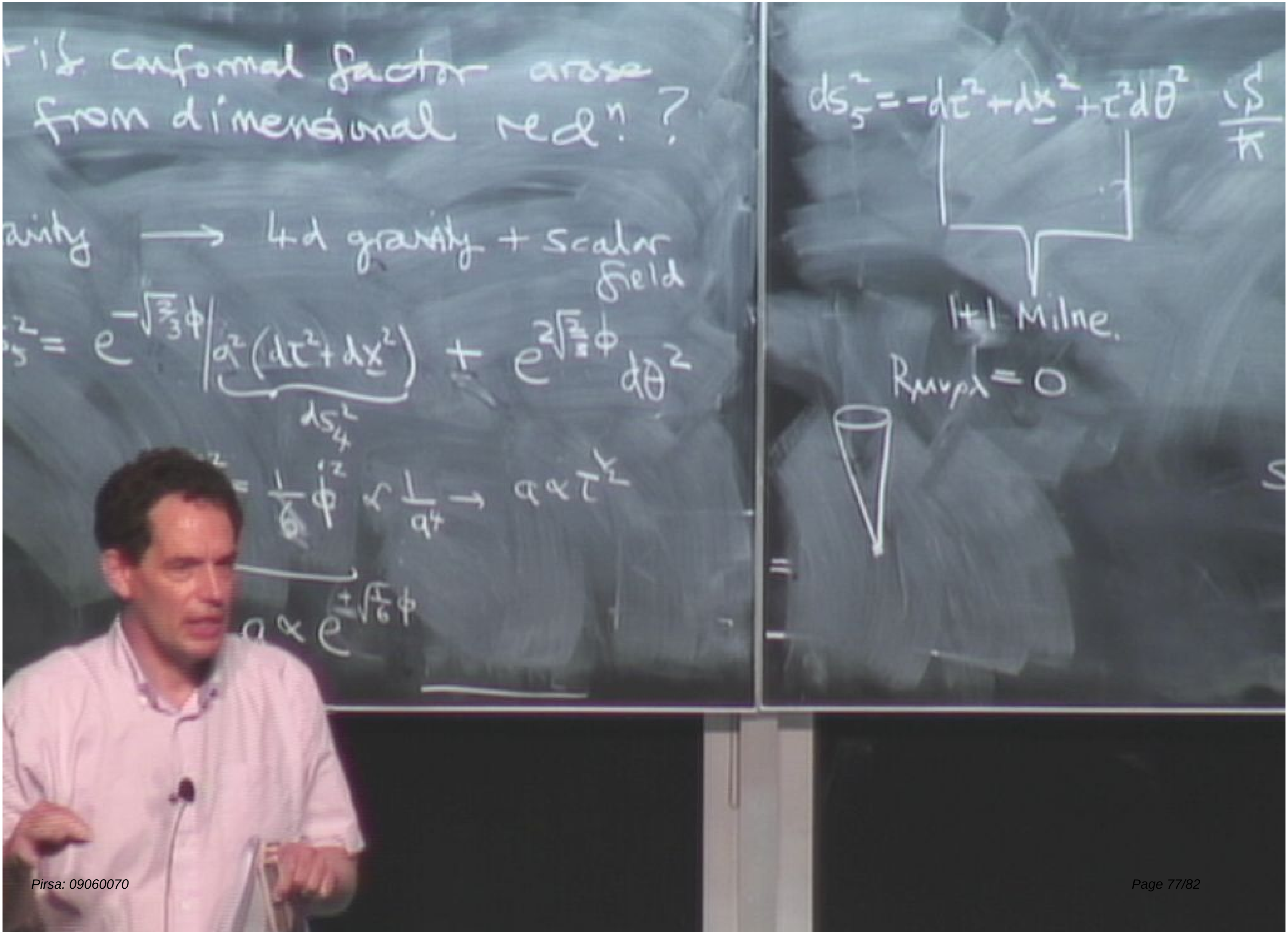
5d gravity $\longrightarrow$ 4d gravity + scalar field

$8\pi G = 1$

$$ds_5^2 = e^{-\sqrt{\frac{2}{3}}\phi}\underbrace{a^2(d\tau^2 + dx^2)}_{ds_4^2} + e^{2\sqrt{\frac{2}{3}}\phi}$$

$$\underbrace{\left(\frac{a'}{a}\right)^2 = \frac{1}{6}\dot{\phi}^2}_{a \propto e^{\pm\sqrt{\frac{1}{6}}\phi}} \propto \frac{1}{a^4} \rightarrow a$$

ds_5^2


is conformal factor arose
from dimensional red^n ?
4d gravity + scalar field
$e^{-\sqrt{\frac{2}{3}}\phi} \underbrace{a^2(d\tau^2 + dx^2)}_{ds_4^2} + e^{2\sqrt{\frac{2}{3}}\phi} d\theta^2$
$\frac{1}{6}\dot{\phi}^2 \propto \frac{1}{a^4} \rightarrow a \propto \tau^{1/2}$
$a \propto e^{\pm\sqrt{\frac{1}{6}}\phi}$
$ds_5^2 = -d\tau^2 + dx^2 + \tau^2 d\theta^2$
1+1 Milne.
$R_{\mu\nu\rho\lambda} = 0$

...is conformal factor arose from dimensional red^n?

...avity $\longrightarrow$ 4d gravity + scalar field

$$ds_5^2 = e^{-\sqrt{\frac{2}{3}}\phi} \underbrace{a^2(d\tau^2 + dx^2)}_{ds_4^2} + e^{2\sqrt{\frac{2}{3}}\phi} d\theta^2$$

$$\underbrace{\left(\frac{\dot a}{a}\right)^2 = \frac{1}{6}\dot\phi^2}_{a \propto e^{\pm\sqrt{\frac{2}{6}}\phi}} \propto \frac{1}{a^4} \to a \propto \tau^{1/2}$$

$$ds_5^2 = -d\tau^2 + dx^2 + \tau^2 d\theta^2 \quad \text{is} \quad \frac{S}{\kappa}$$

1+1 Milne.

$R_{\mu\nu\rho\lambda} = 0$

$$-d\tau^2 + \tau^2 d\theta^2$$

r is conformal factor arose from dimensional red^n ?

avity $\longrightarrow$ 4d gravity + scalar field

$$ds_5^2 = e^{-\sqrt{\frac{2}{3}}\phi}\, \underbrace{a^2(d\tau^2 + dx^2)}_{ds_4^2} + e^{2\sqrt{\frac{2}{3}}\phi}\, d\theta^2$$

$$\underbrace{\left(\frac{\dot a}{a}\right)^2 = \frac{1}{6}\dot\phi^2}_{a \propto e^{\pm\sqrt{\frac{1}{6}}\phi}} \propto \frac{1}{a^4} \to a \propto \tau^{\frac{1}{2}}$$

$$\underbrace{ds_5^2 = -d\tau^2 + dx^2 + \tau^2 d\theta^2}_{1+1 \text{ Milne.}} \qquad \frac{iS}{\hbar}$$

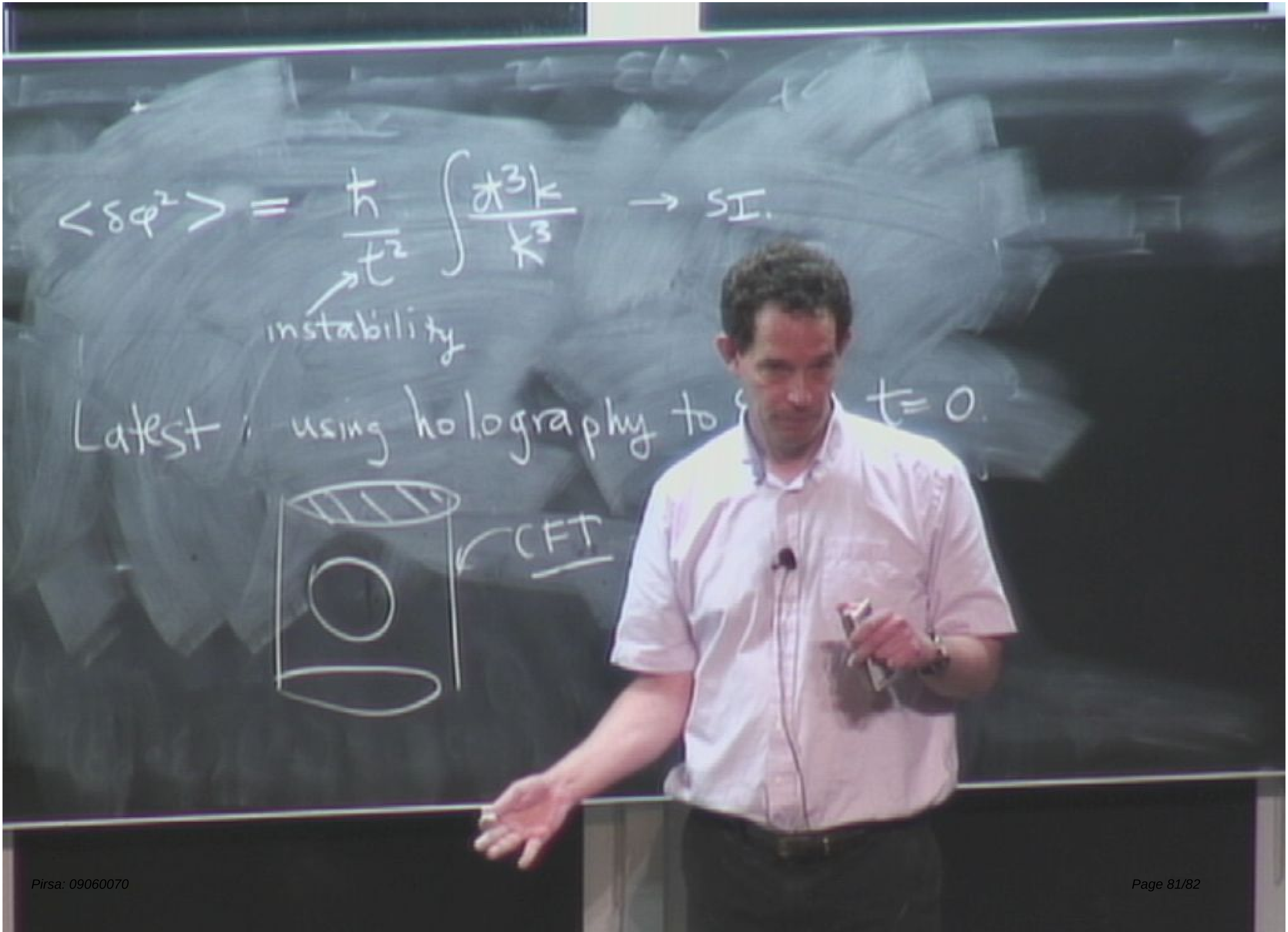
$R_{\mu\nu\rho\lambda} = 0$

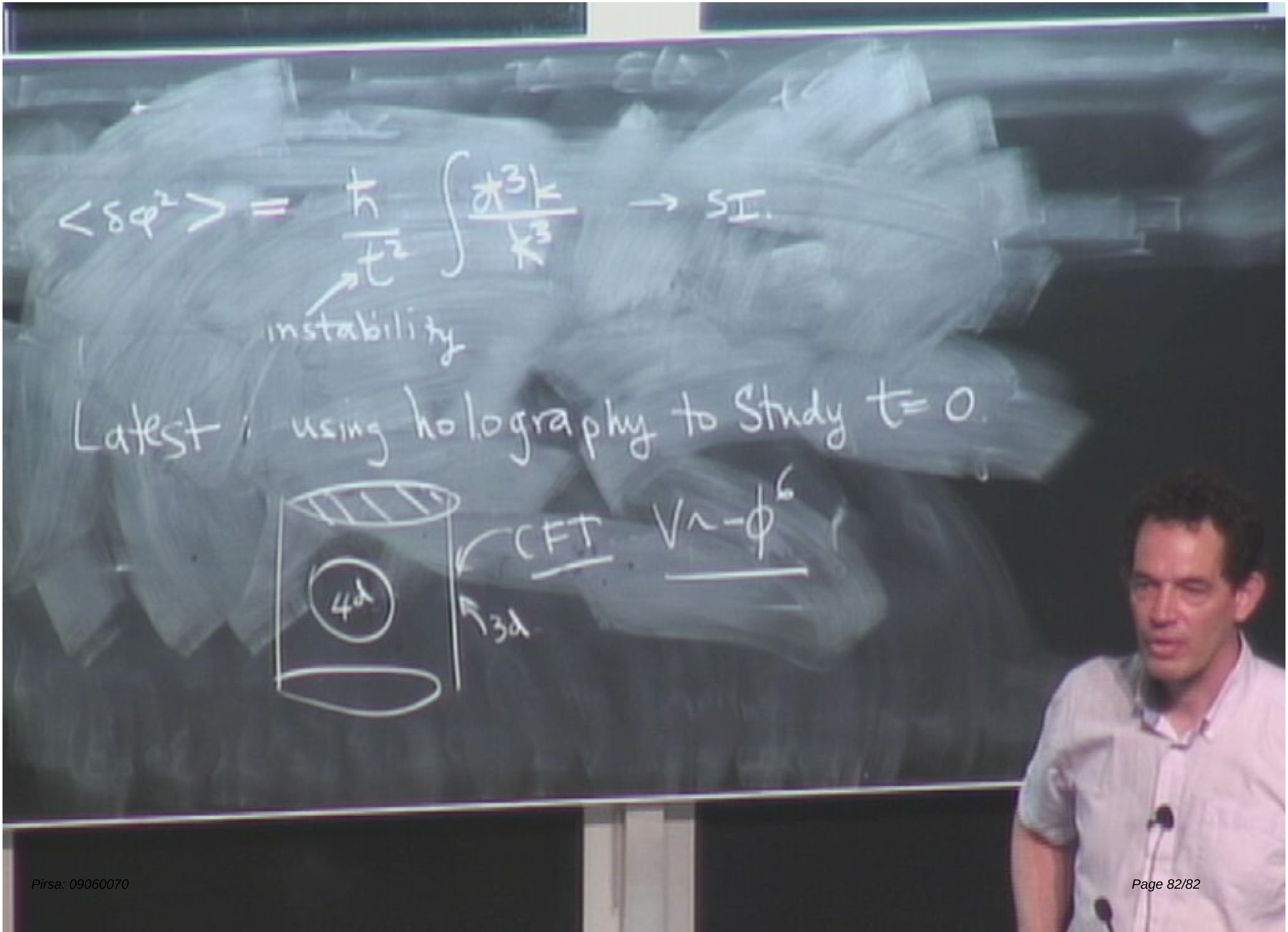
$-d\tau^2 + \tau^2 d\theta^2$

$$\langle \delta\varphi^2 \rangle = \frac{\hbar}{t^2} \int \frac{d^3k}{k^3} \to \text{SI.}$$

instability

Latest: using holography to study $t=0$.


$\langle \delta\varphi^2 \rangle = \frac{\hbar}{t^2} \int \frac{d^3k}{k^3} \to$ SI.
instability
Latest : using holography to t=0.
CFT


$\langle \delta\varphi^2 \rangle = \frac{\hbar}{t^2} \int \frac{d^3k}{k^3} \to$ SI.
instability
Latest : using holography to study t = 0.
CFT
$V \sim -\phi^6$
4d
3d