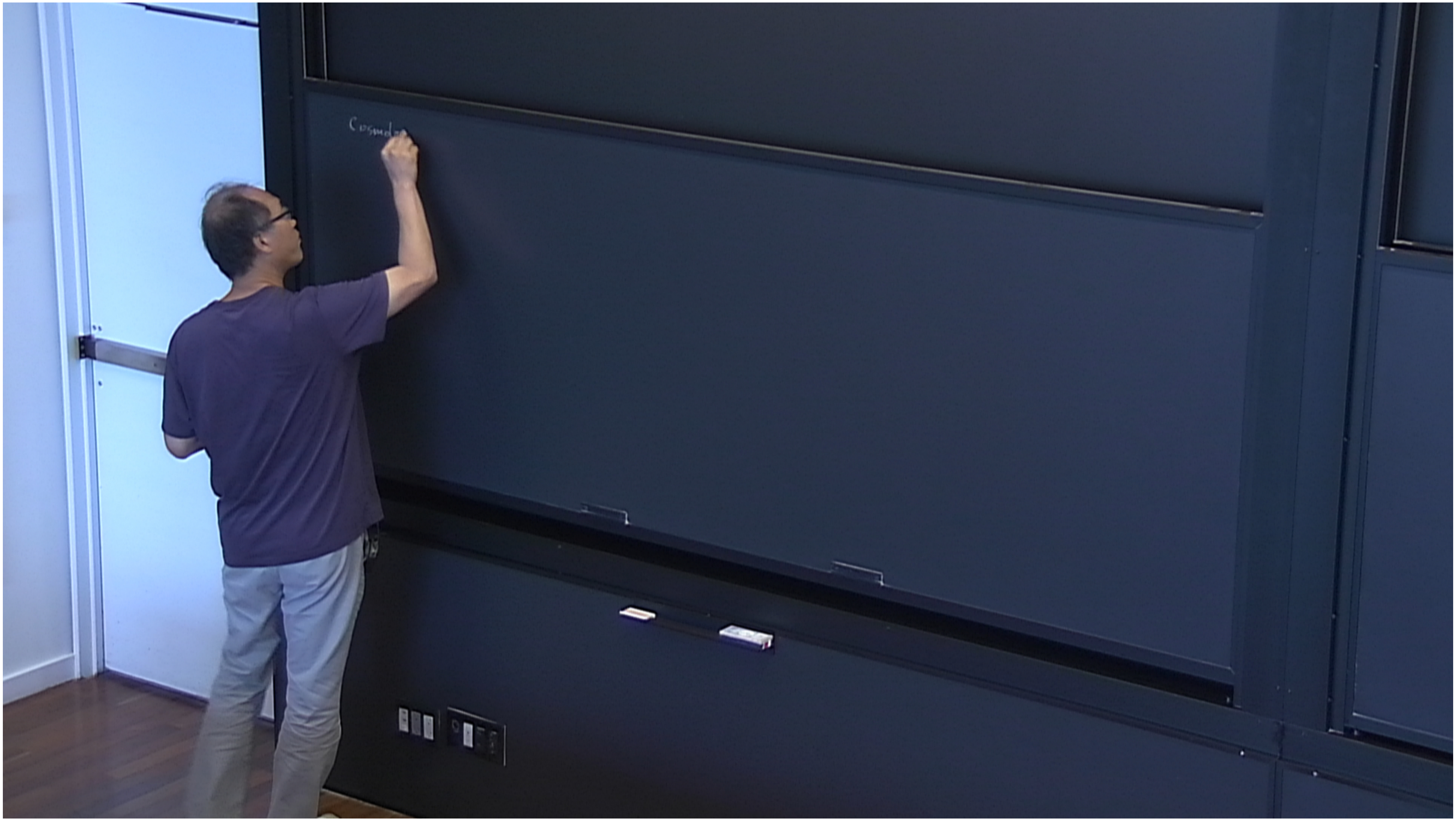
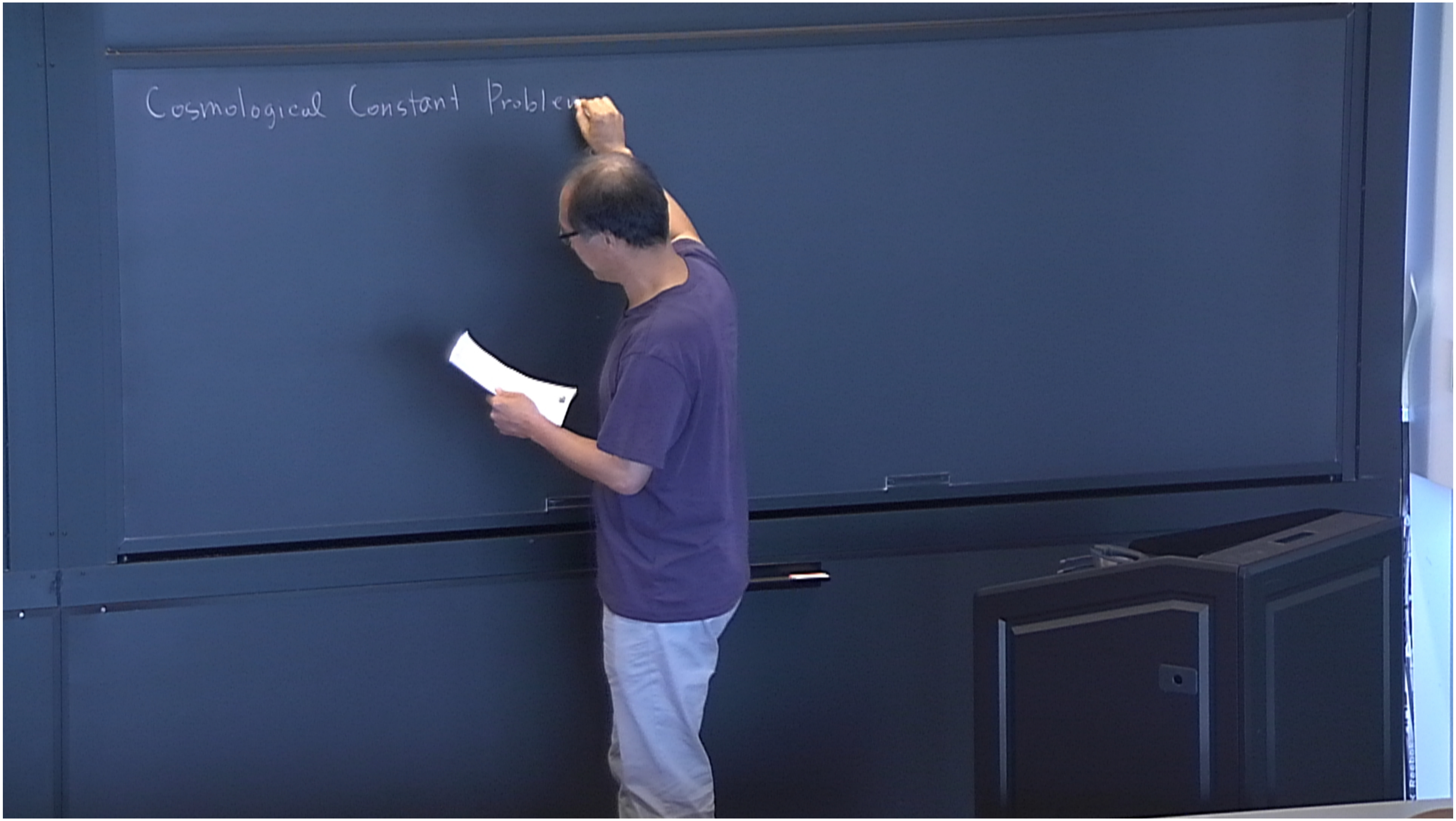
Title: Cosmological Coincidence Problem

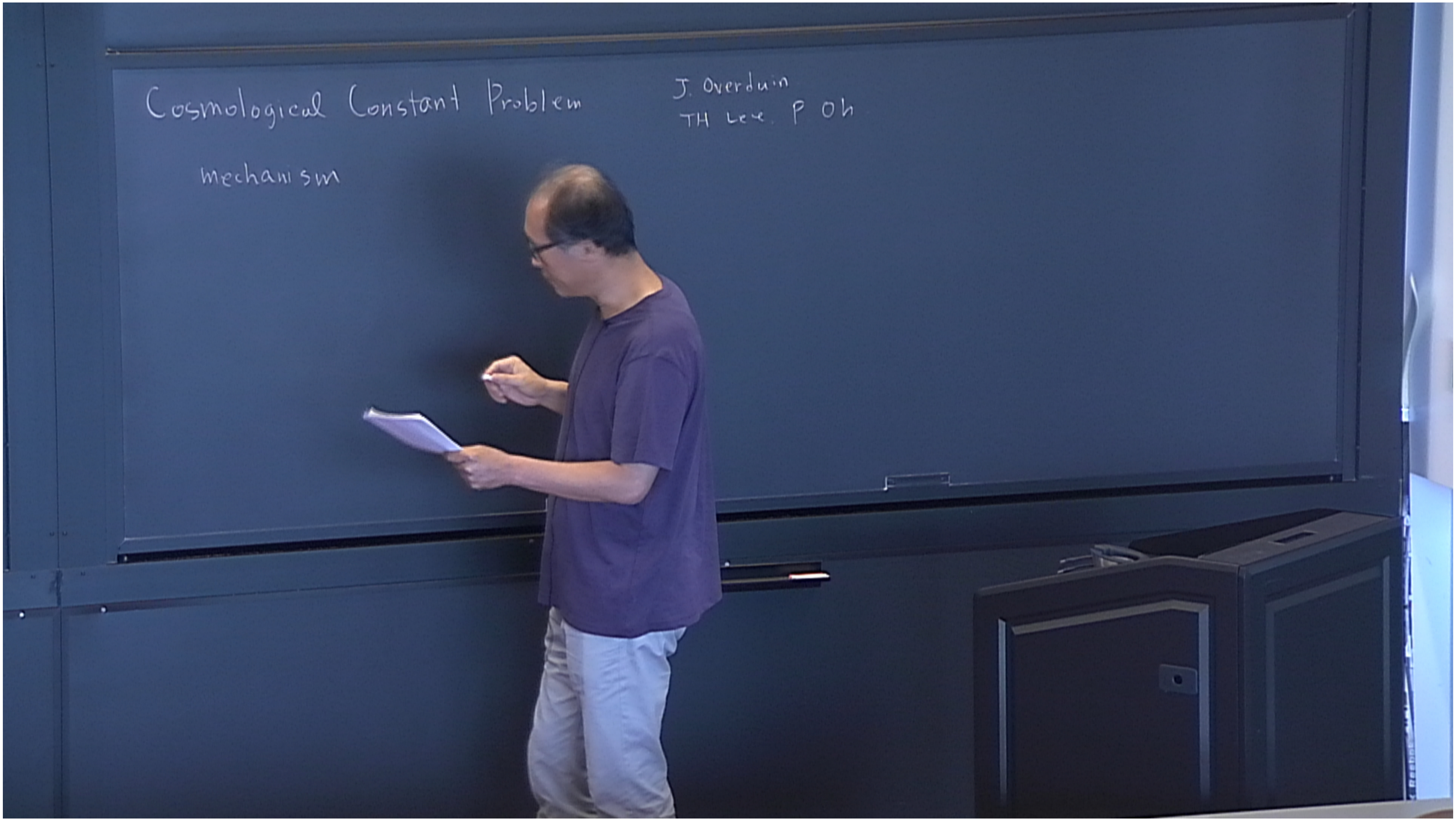
Date: Jul 15, 2014 11:00 AM

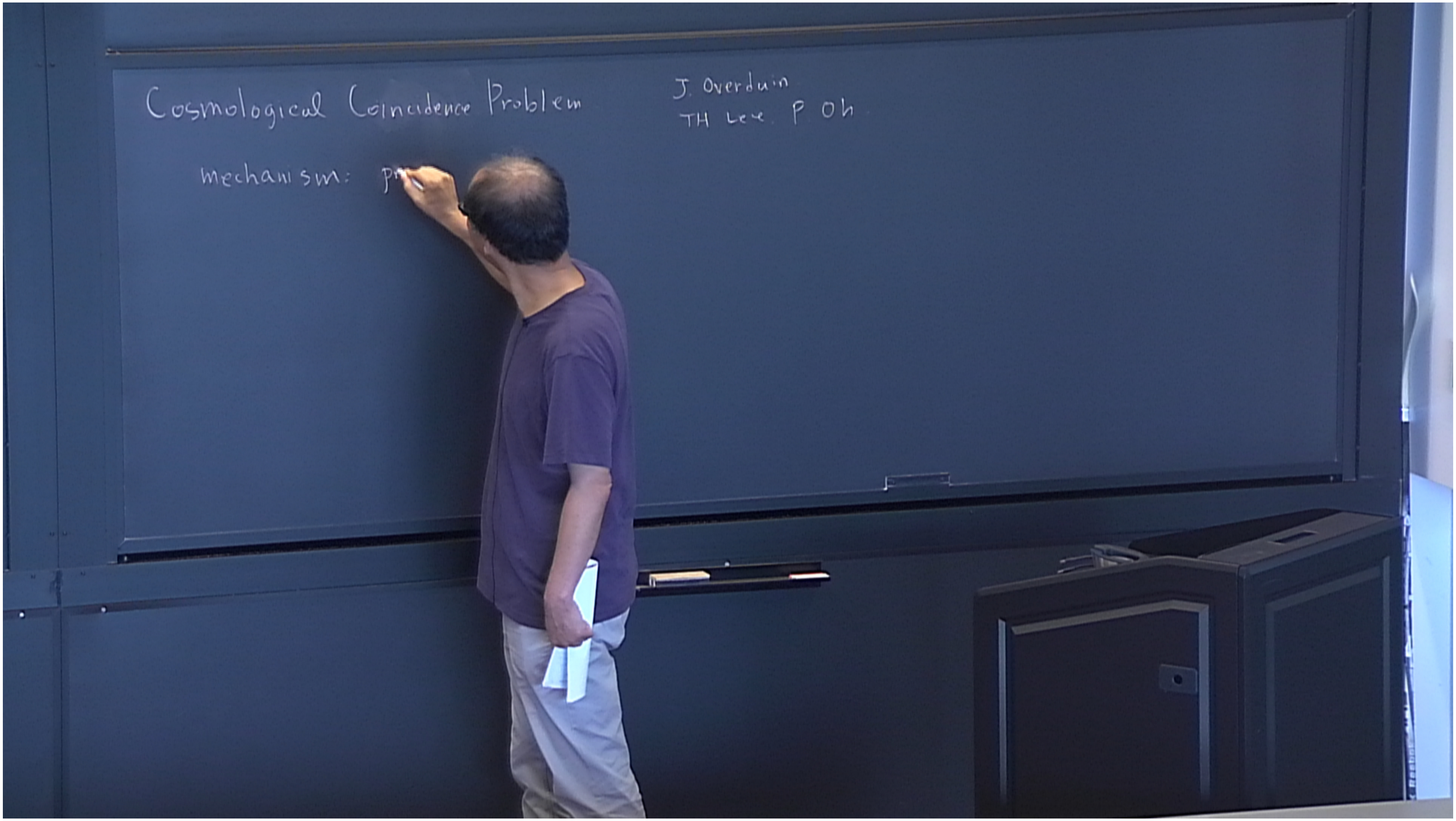
URL: http://pirsa.org/14070030

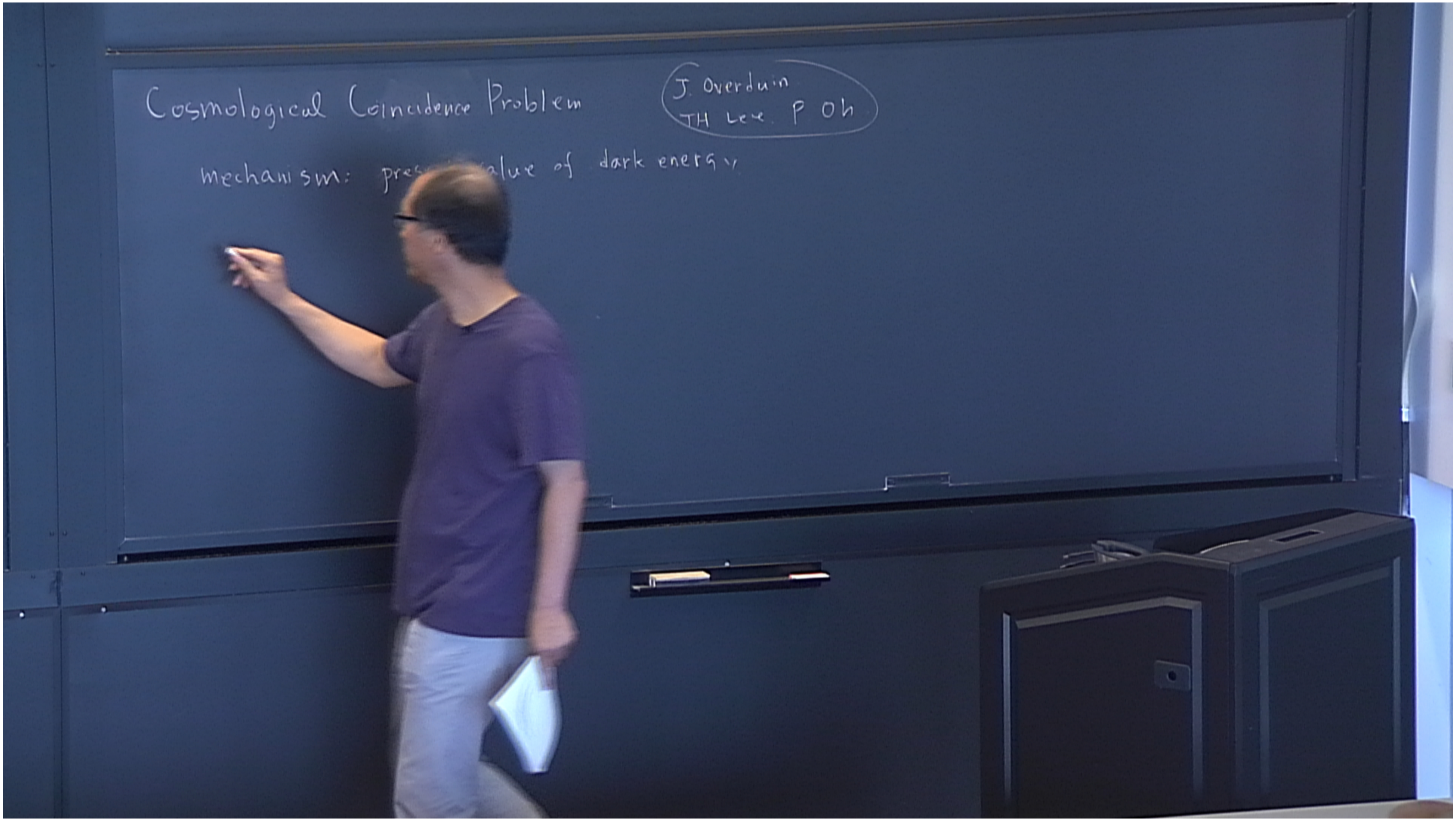
Abstract: I will try to explain how cosmological coincidence of the two values, the matter energy density and the dark energy density, at the present epoch based on a single scalar field model whith a quartic potential, non-mimimally interacting with gravity. Dark energy in this model originates from the potential energy of the scalar field, which is sourced by the appearance of non-relativistic matter at the time z~ 10^10. No fine tuning of parameter are neccessary.

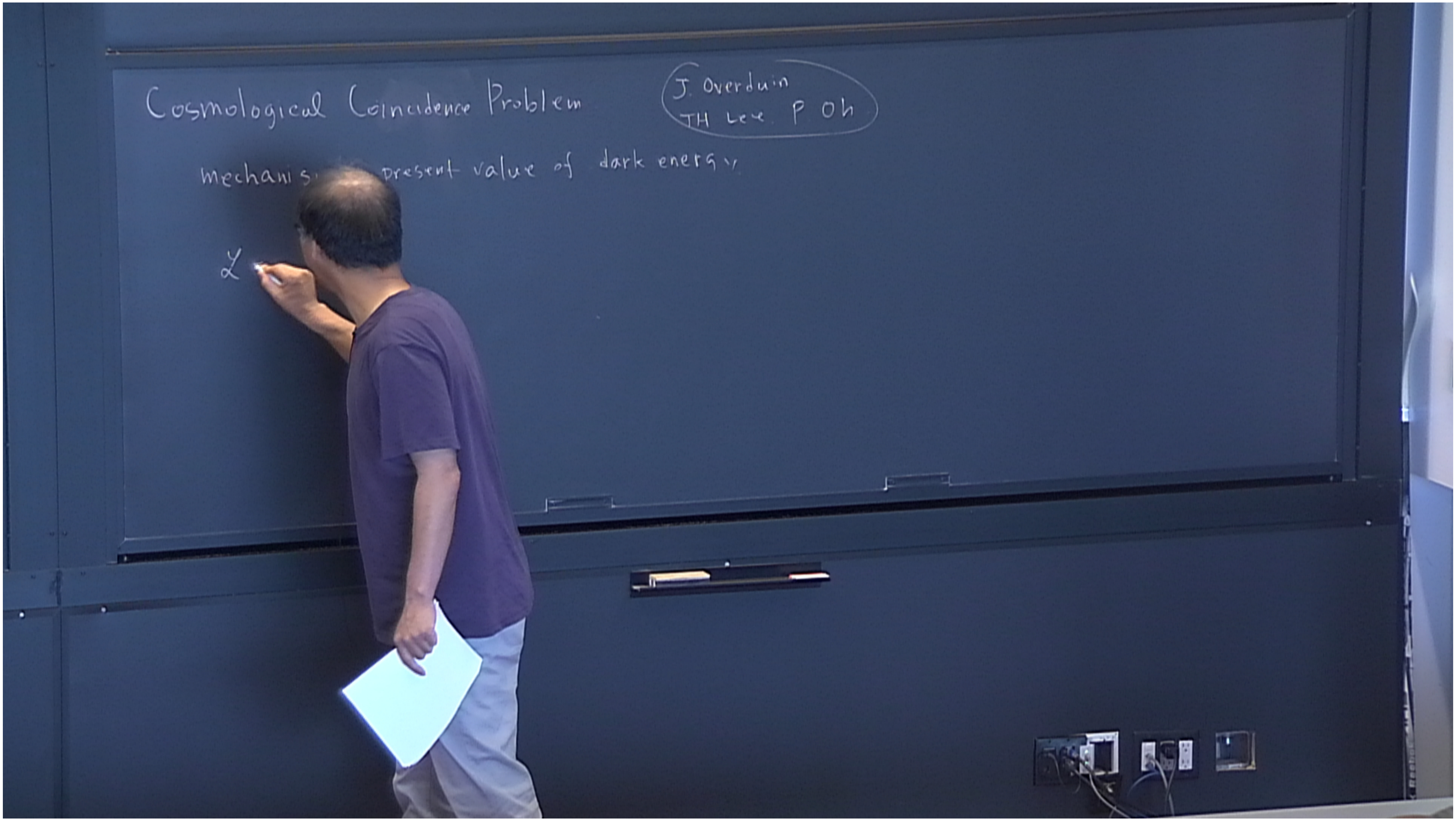


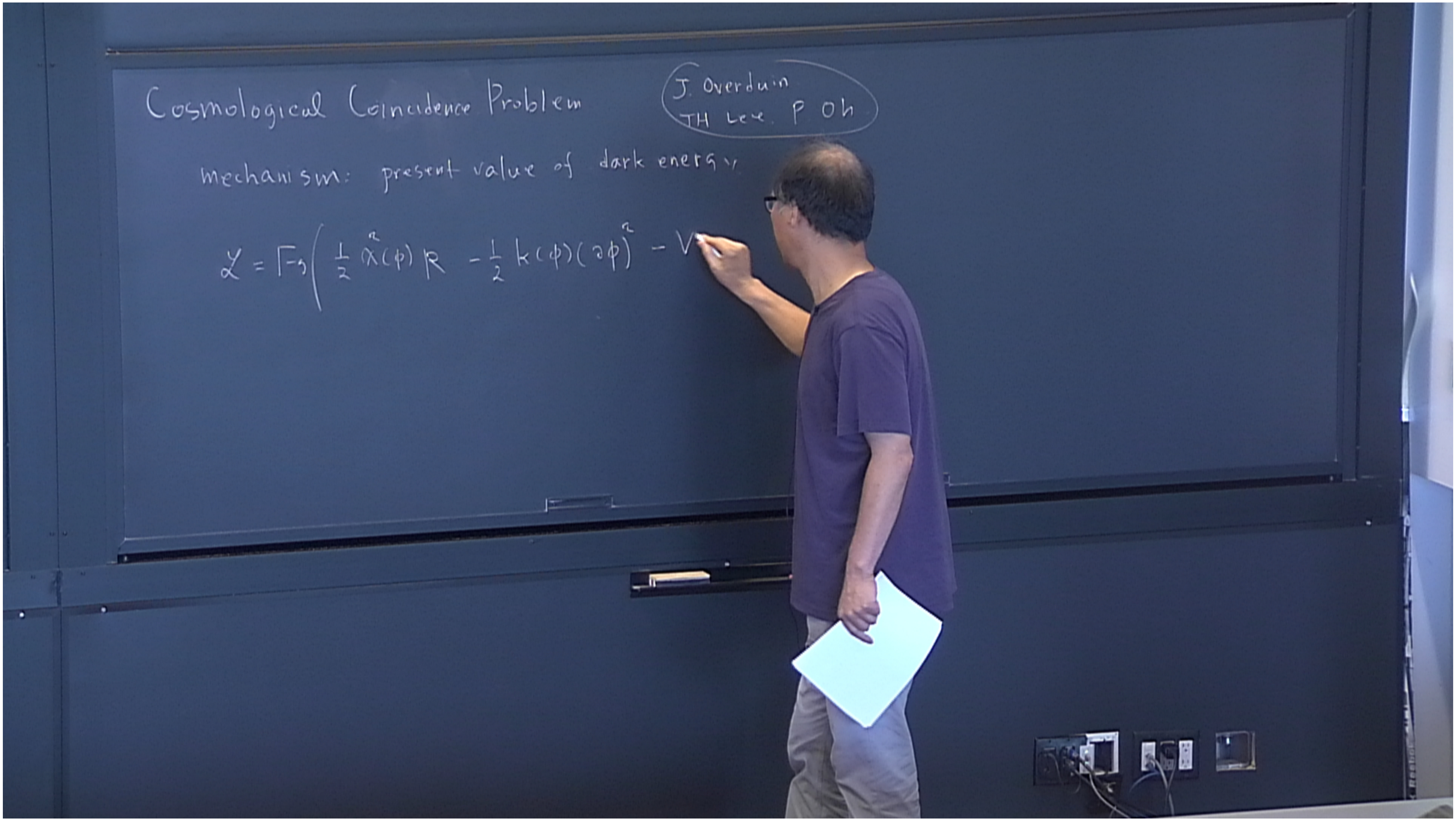

Cosmological Constant Proble

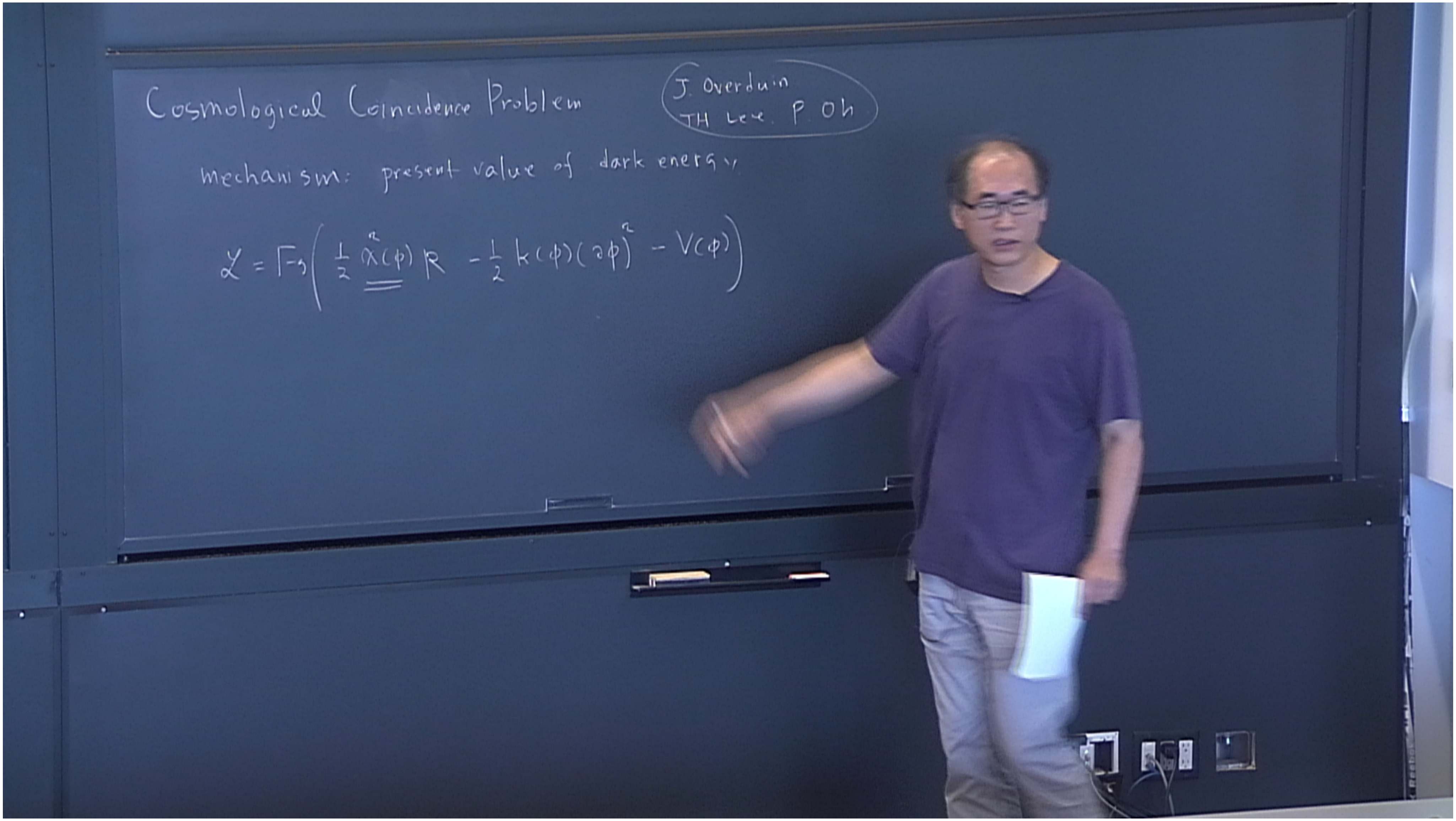

Cosmological Constant Problem
J. Overduin
TH Lee. P Oh
mechanism


Cosmological Coincidence Problem
J. Overduin
TH Lee. P Oh
mechanism:


Cosmological Coincidence Problem
J. Overduin
TH Lee. P Oh
mechanism:
of dark energy


Cosmological Coincidence Problem
J. Overduin
TH Lee P Oh
mechanis
present value of dark energy


Cosmological Coincidence Problem
J. Overduin
TH Lee P Oh
mechanism: present value of dark energy
$\mathcal{L} = \sqrt{-g}\left(\frac{1}{2} \alpha^2(\phi) R - \frac{1}{2} k(\phi)(\partial\phi)^2 - V\right.$


Cosmological Coincidence Problem
J. Overduin
TH Lee. P. Oh
mechanism: present value of dark energy
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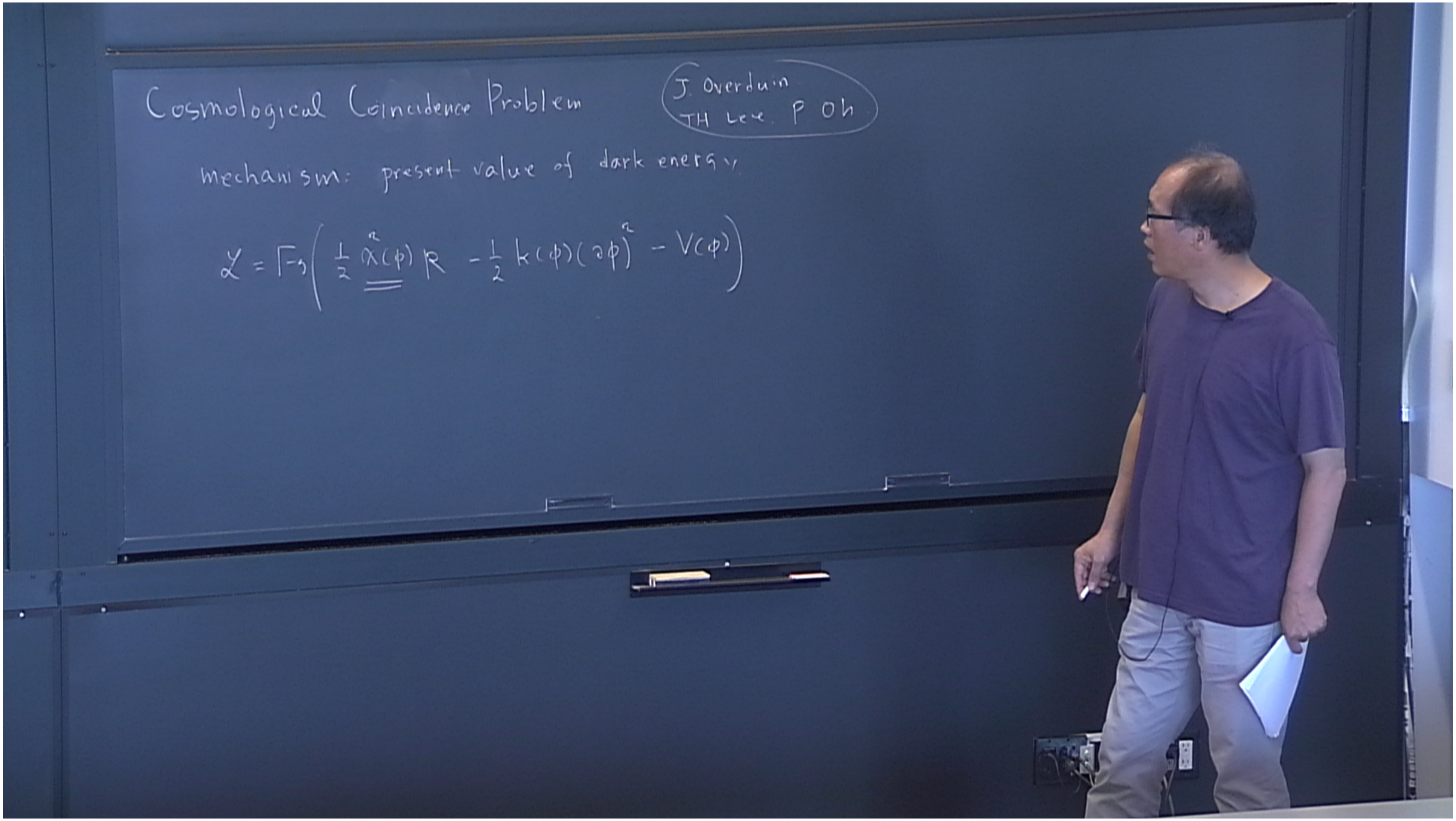
Cosmological Coincidence Problem
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mechanism: present value of dark energy
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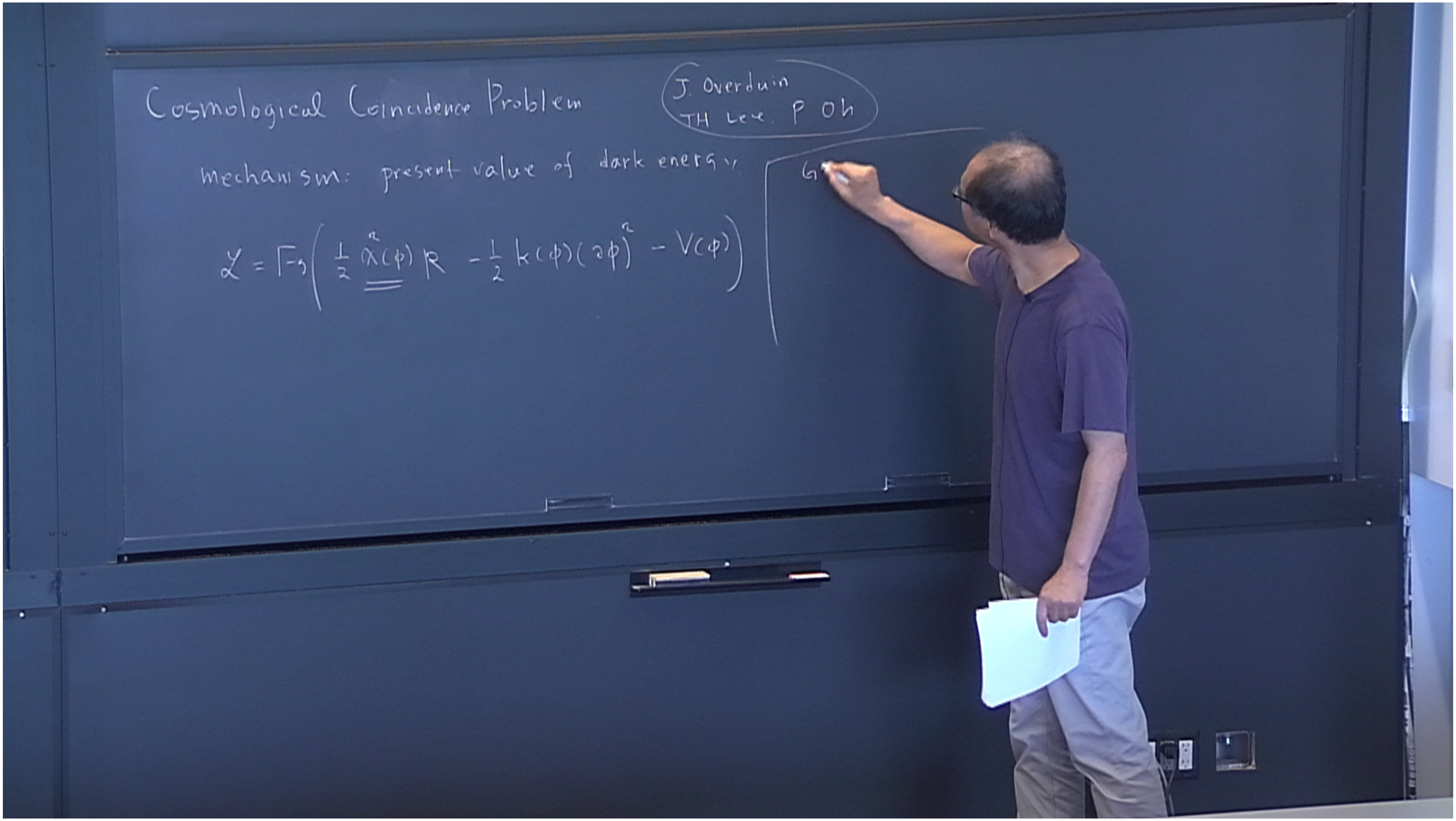
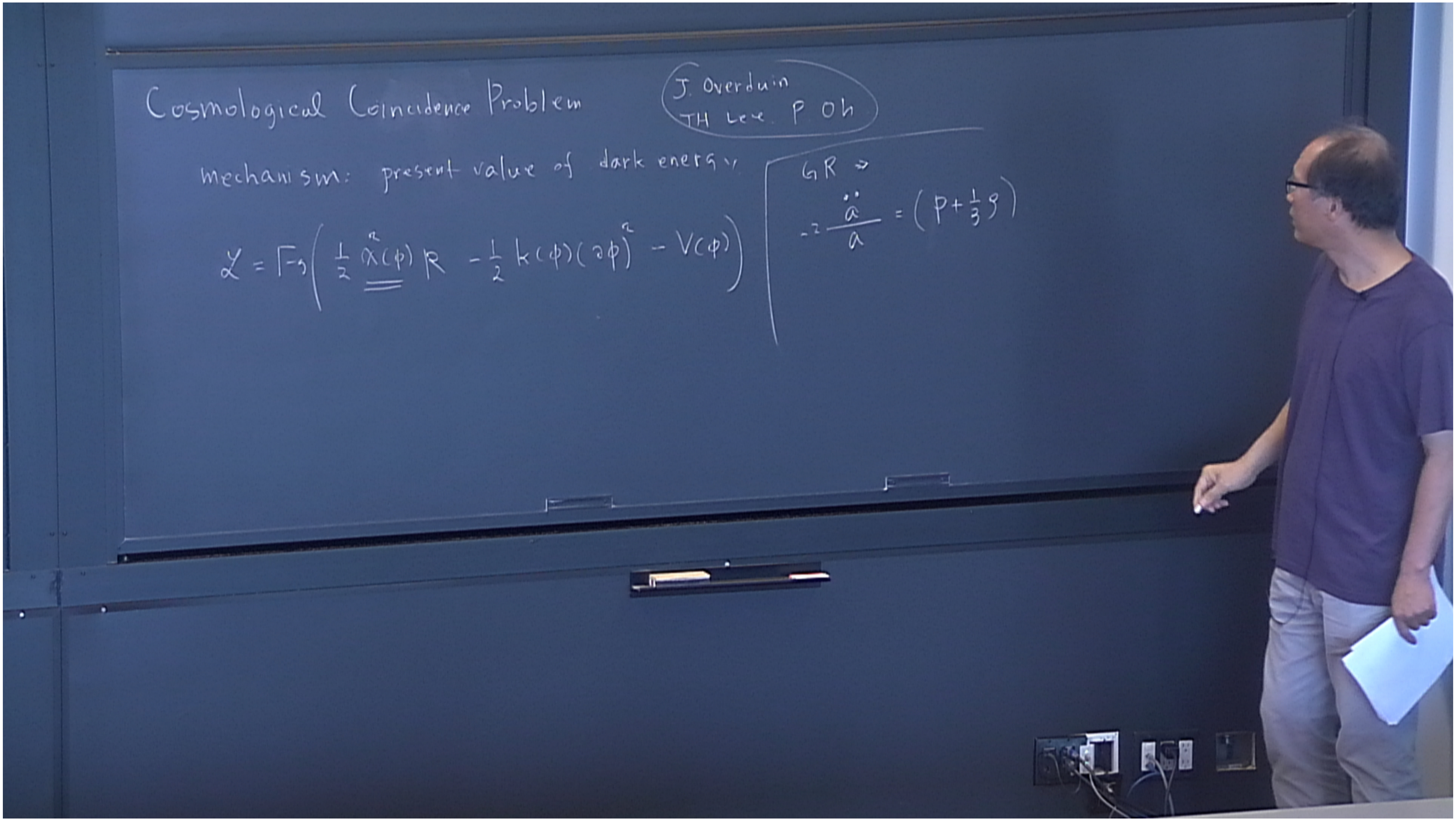
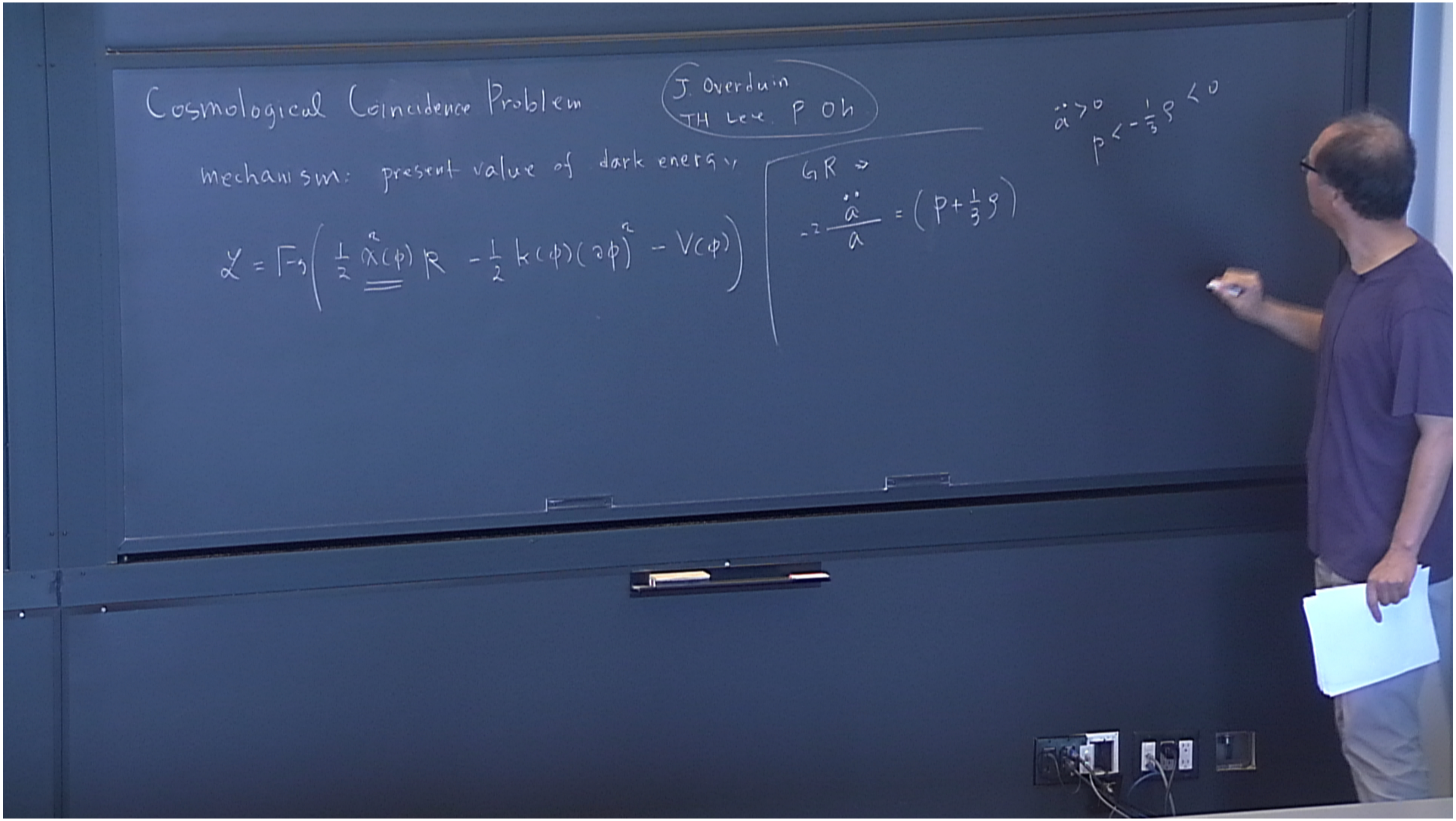

Cosmological Coincidence Problem
J. Overduin
TH Lee. P Oh
mechanism: present value of dark energy
$\mathcal{L} = \sqrt{-g}\left(\frac{1}{2} \alpha^2(\phi) R - \frac{1}{2} k(\phi)(\partial\phi)^2 - V(\phi) \right)$


Cosmological Coincidence Problem
J. Overduin
TH Lee. P. Oh
mechanism: present value of dark energy
GR ⇒



Cosmological Coincidence Problem
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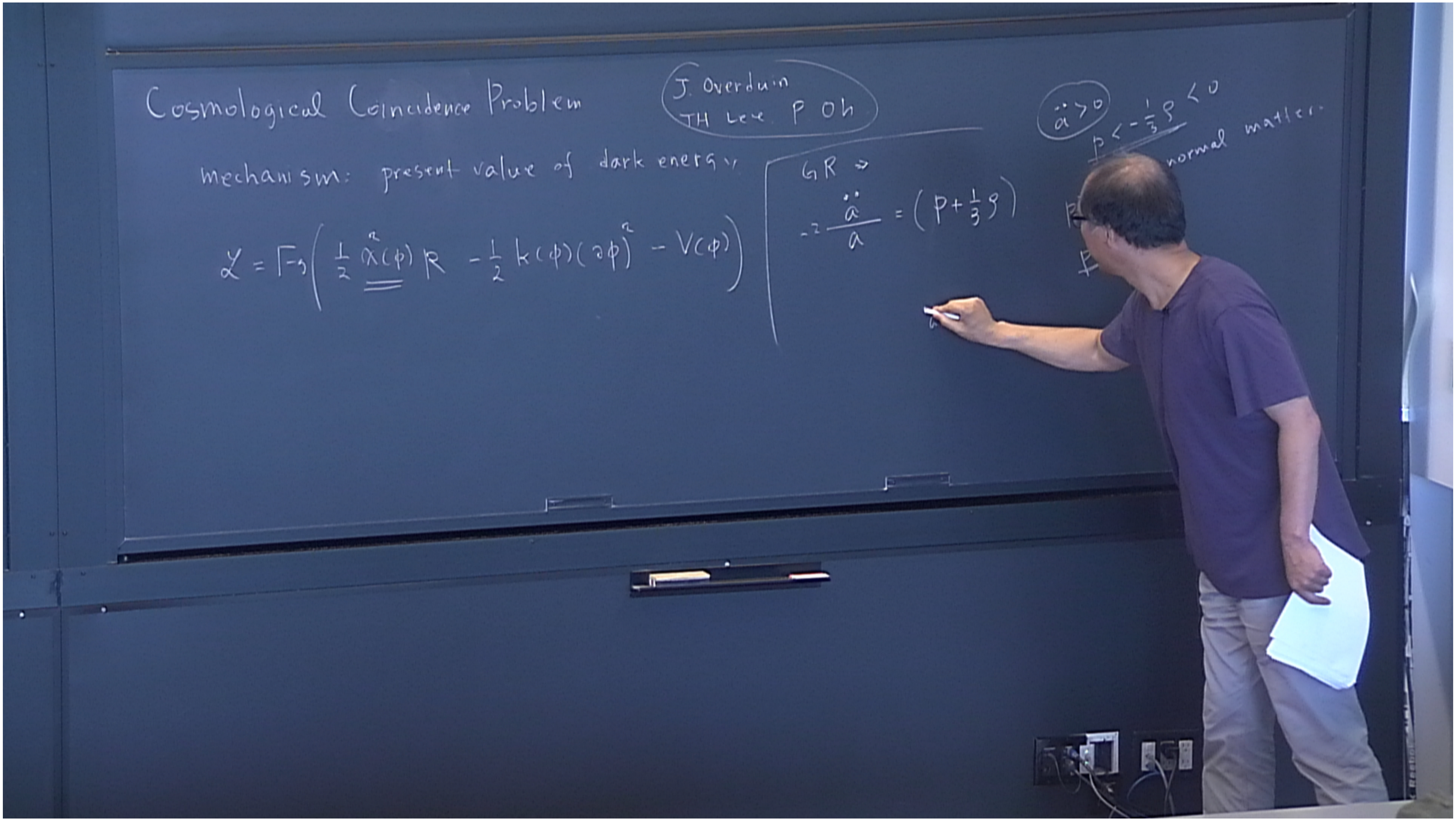
TH Lee. P Oh
mechanism: present value of dark energy
GR ⇒
ä > 0
p < - 1/3 ρ < 0


Cosmological Coincidence Problem
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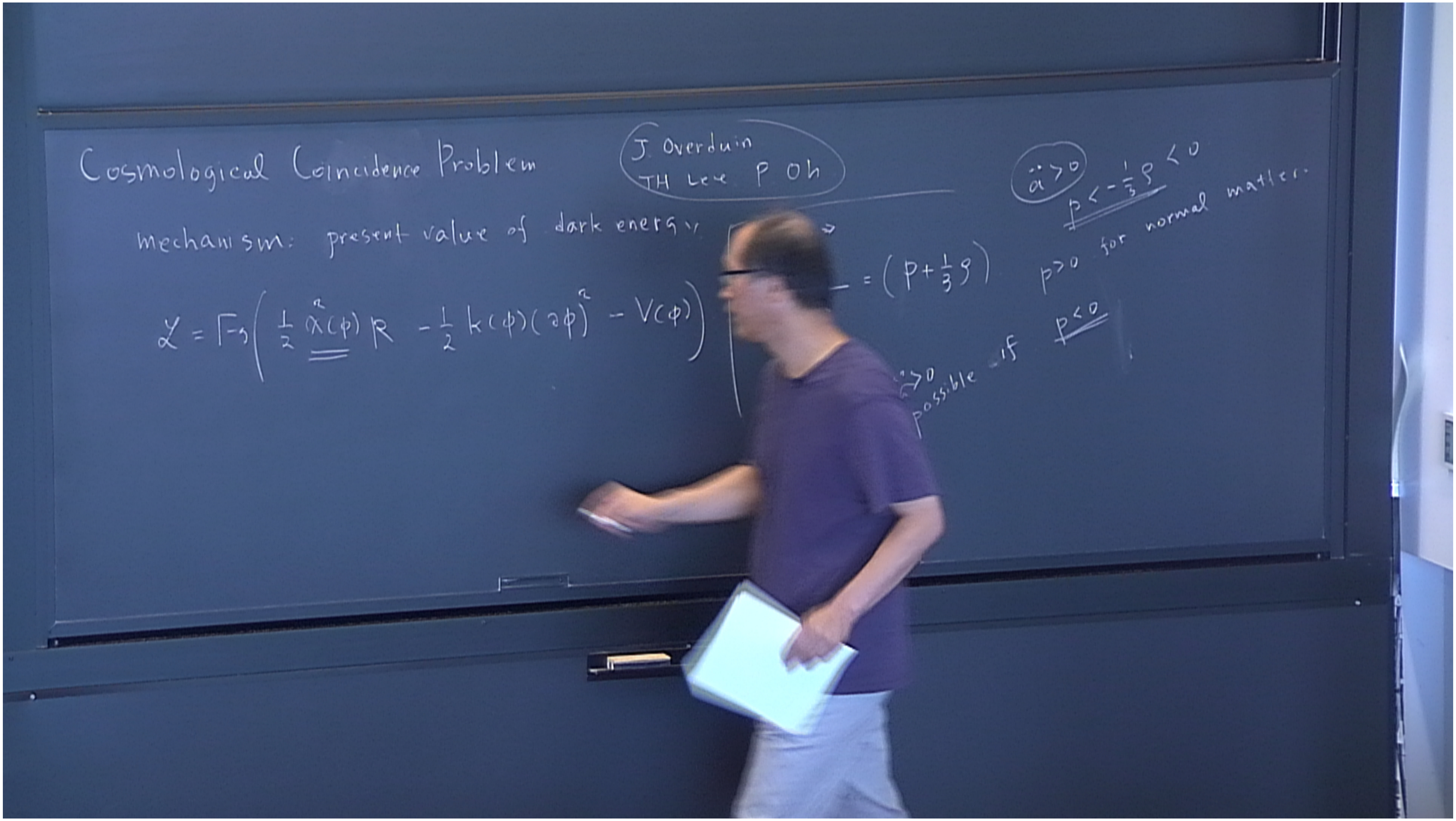
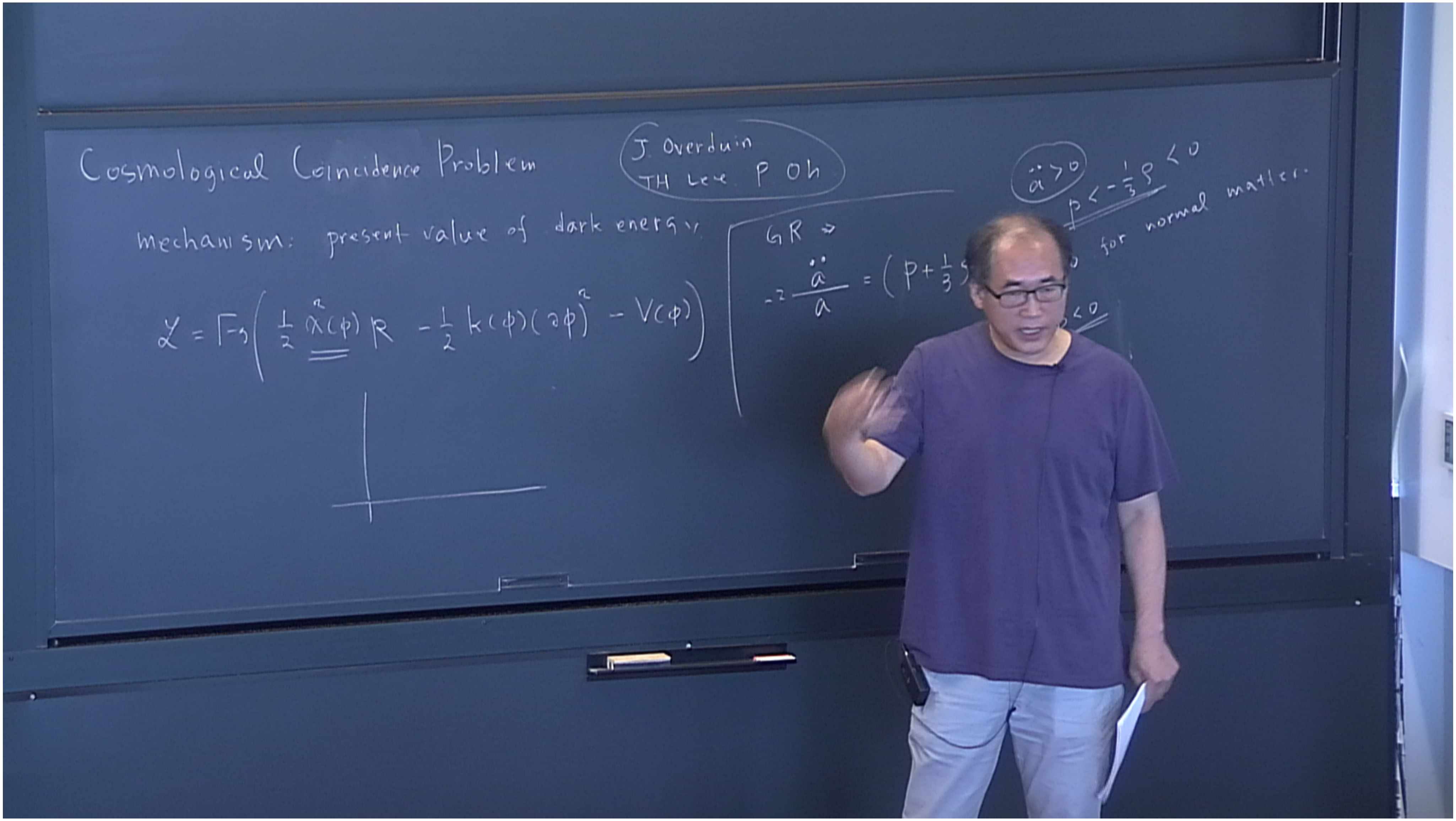
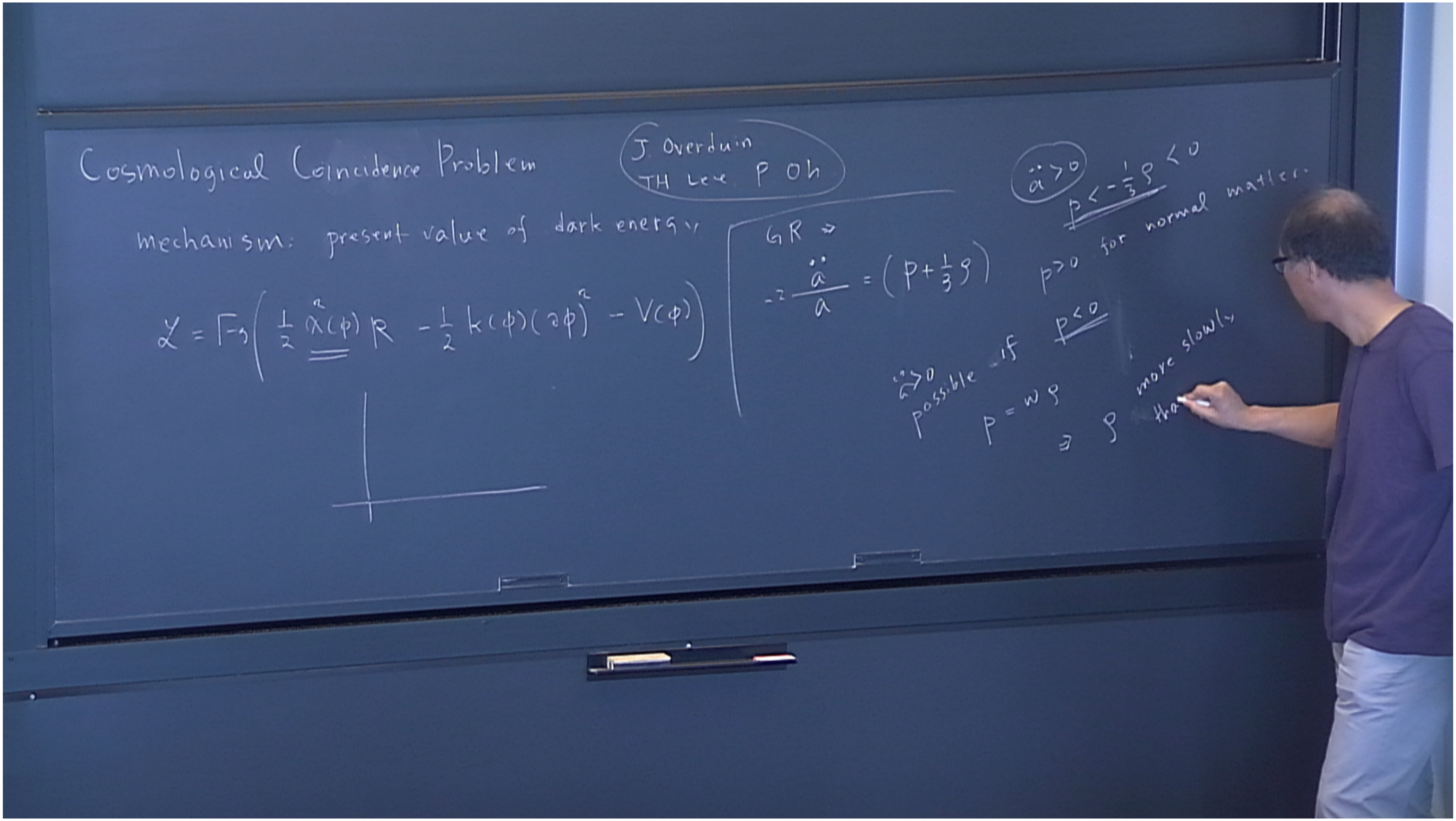
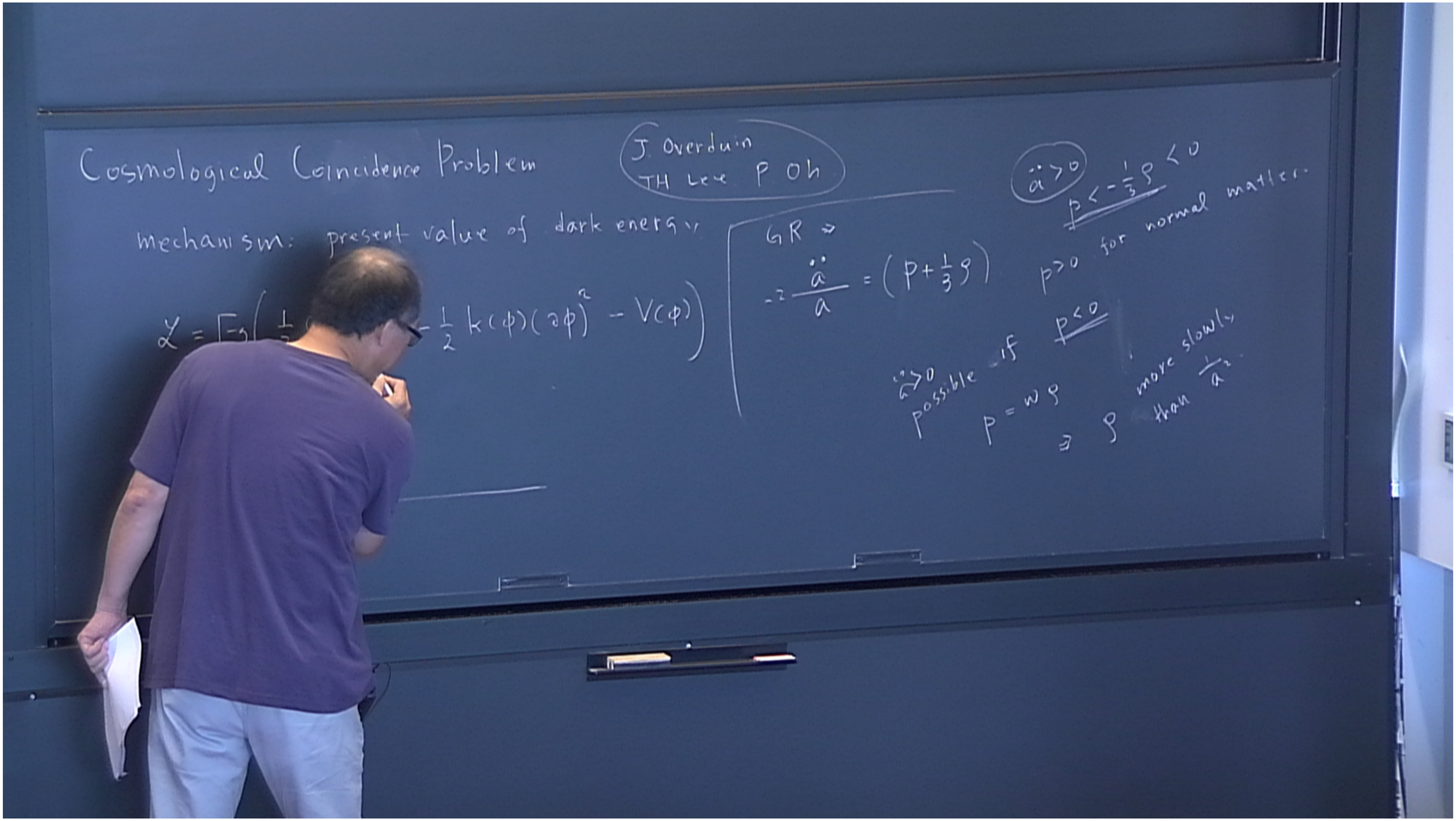
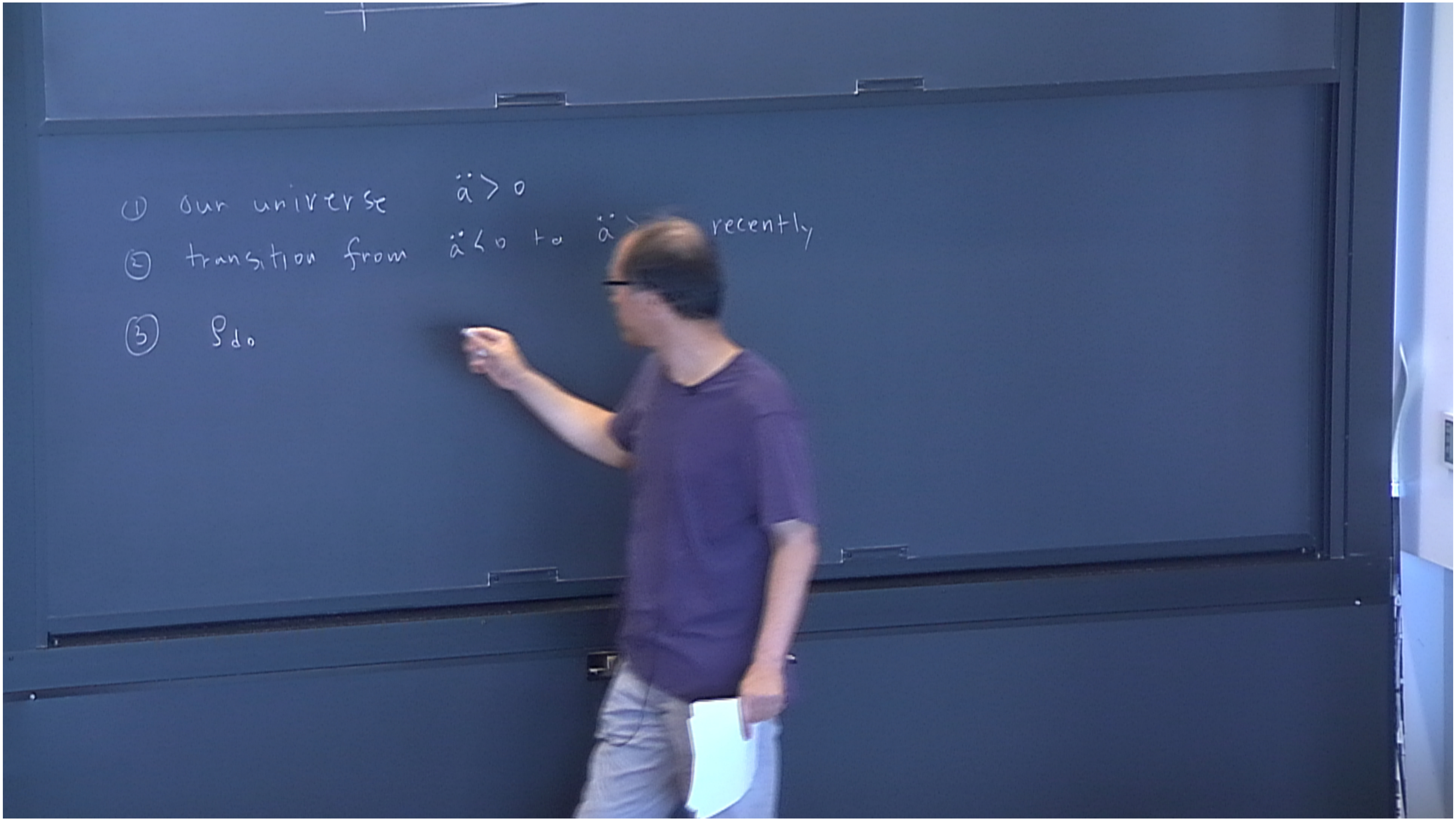
TH Lee P Oh
mechanism: present value of dark energy
GR ⇒
normal matter

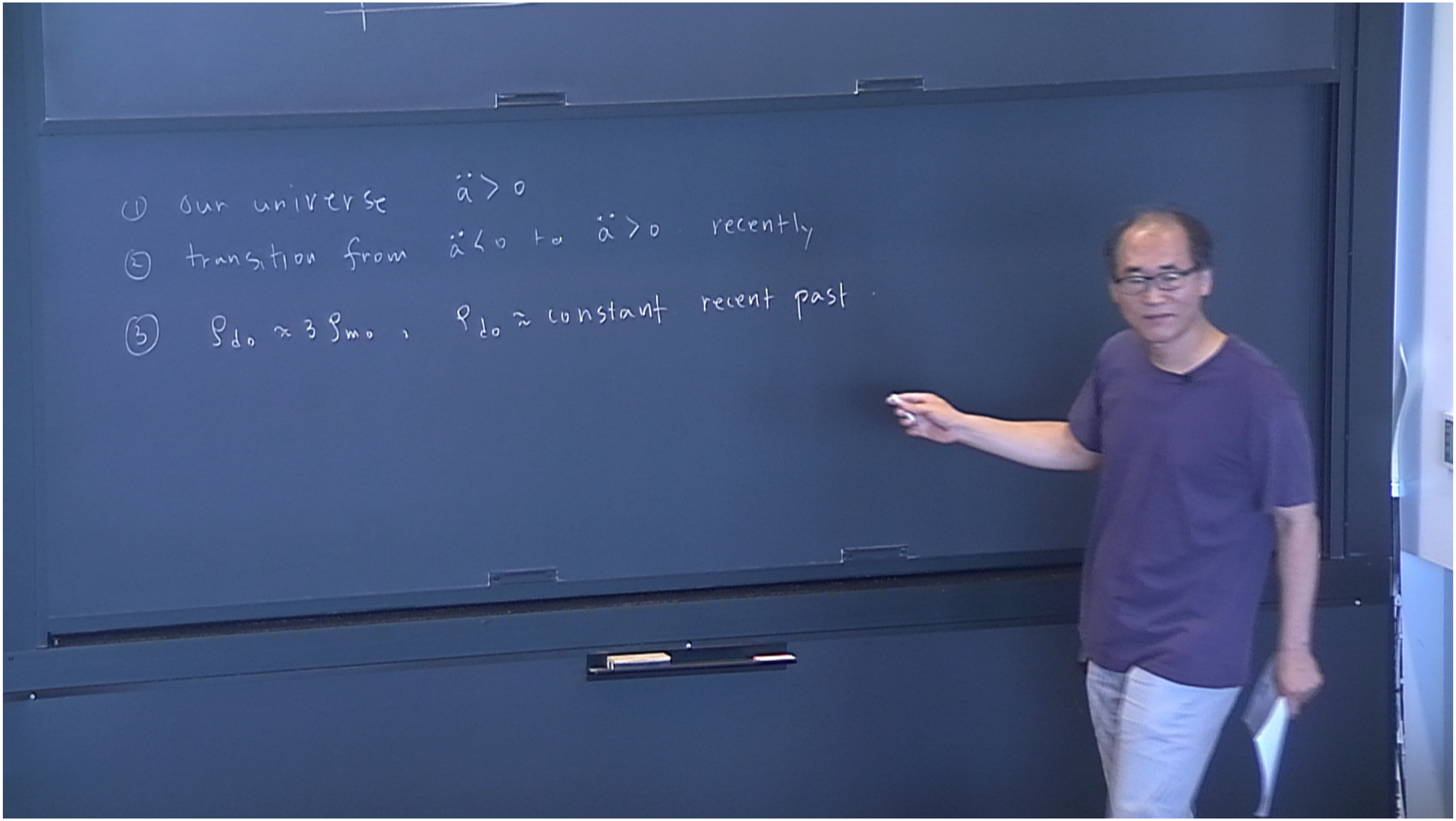

Cosmological Coincidence Problem
J. Overduin
TH Lee P Oh
mechanism: present value of dark energy
= (p + 1/3 ρ)
ä > 0
p < − 1/3 ρ < 0
p > 0 for normal matter
possible if p < 0

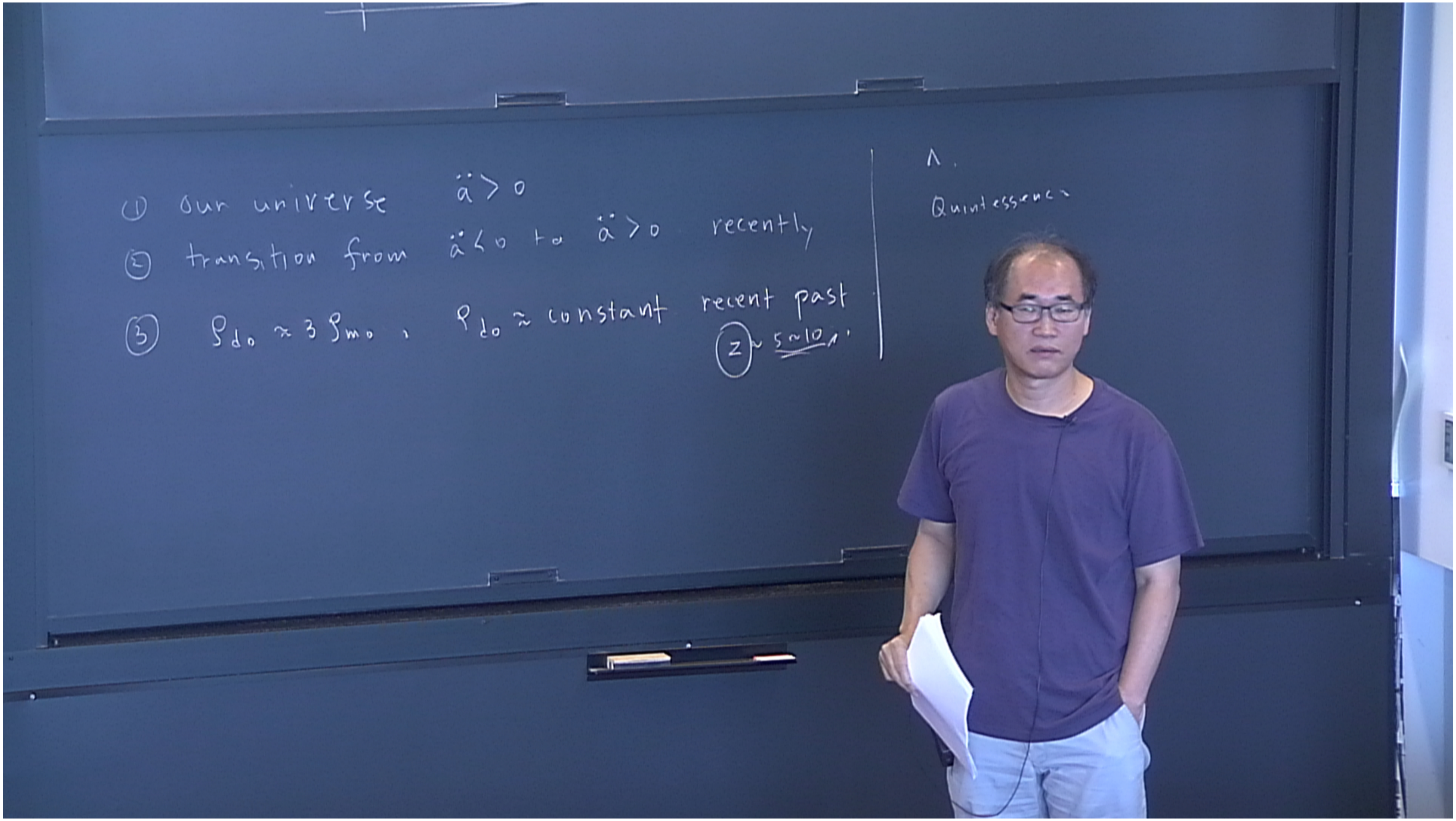

Cosmological Coincidence Problem
J. Overduin
TH Lee P Oh
mechanism: present value of dark energy
GR ⇒
for normal matter

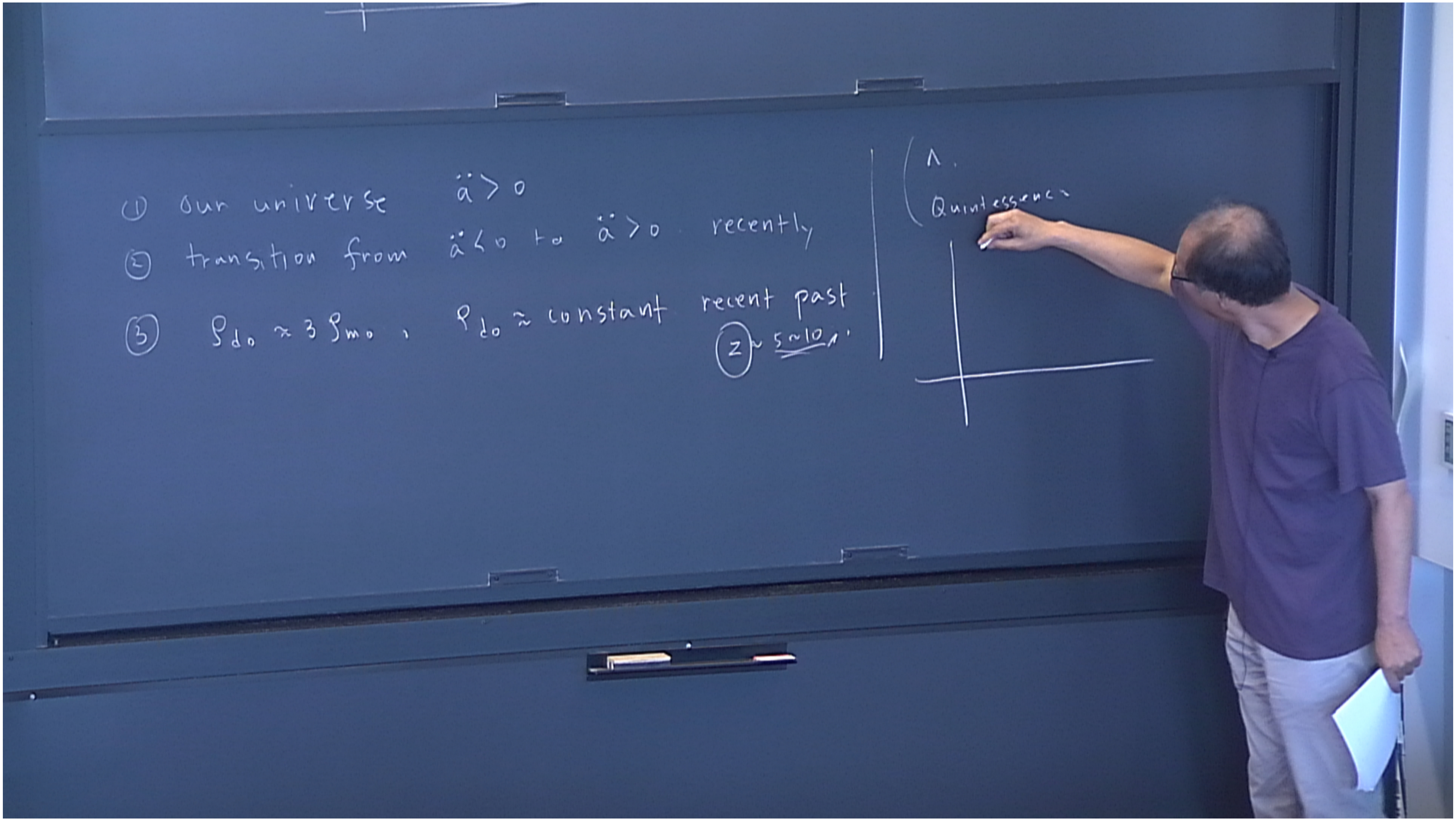

Cosmological Coincidence Problem
J. Overduin
TH Lee P Oh
mechanism: present value of dark energy
GR ⇒
p > 0 for normal matter
possible if p < 0
p = w ρ
more slowly

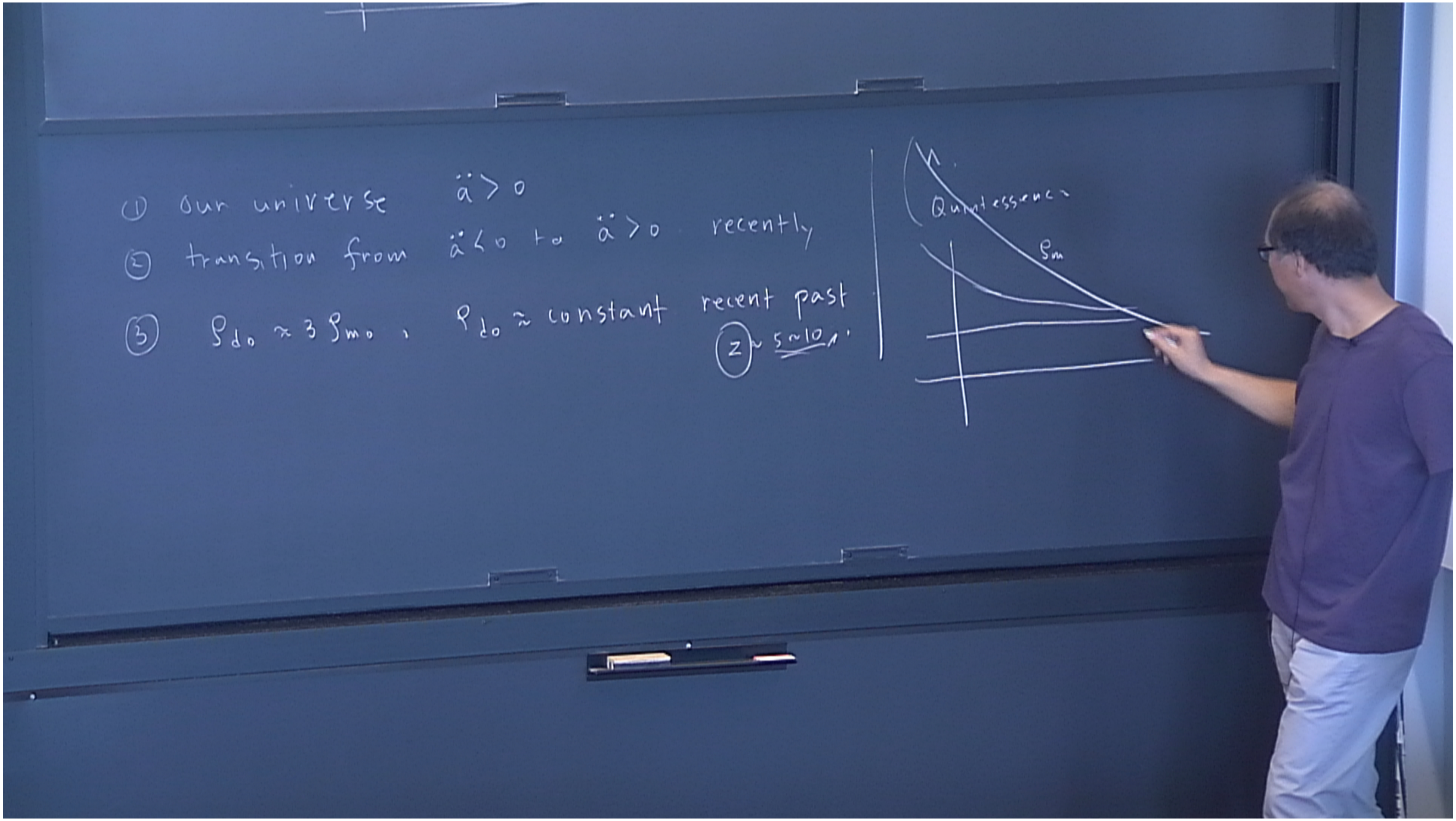

Cosmological Coincidence Problem
J. Overduin
TH Lee P Oh
mechanism: present value of dark energy
GR ⇒
p > 0 for normal matter
p < 0
p = w ρ
possible if
more slowly
than

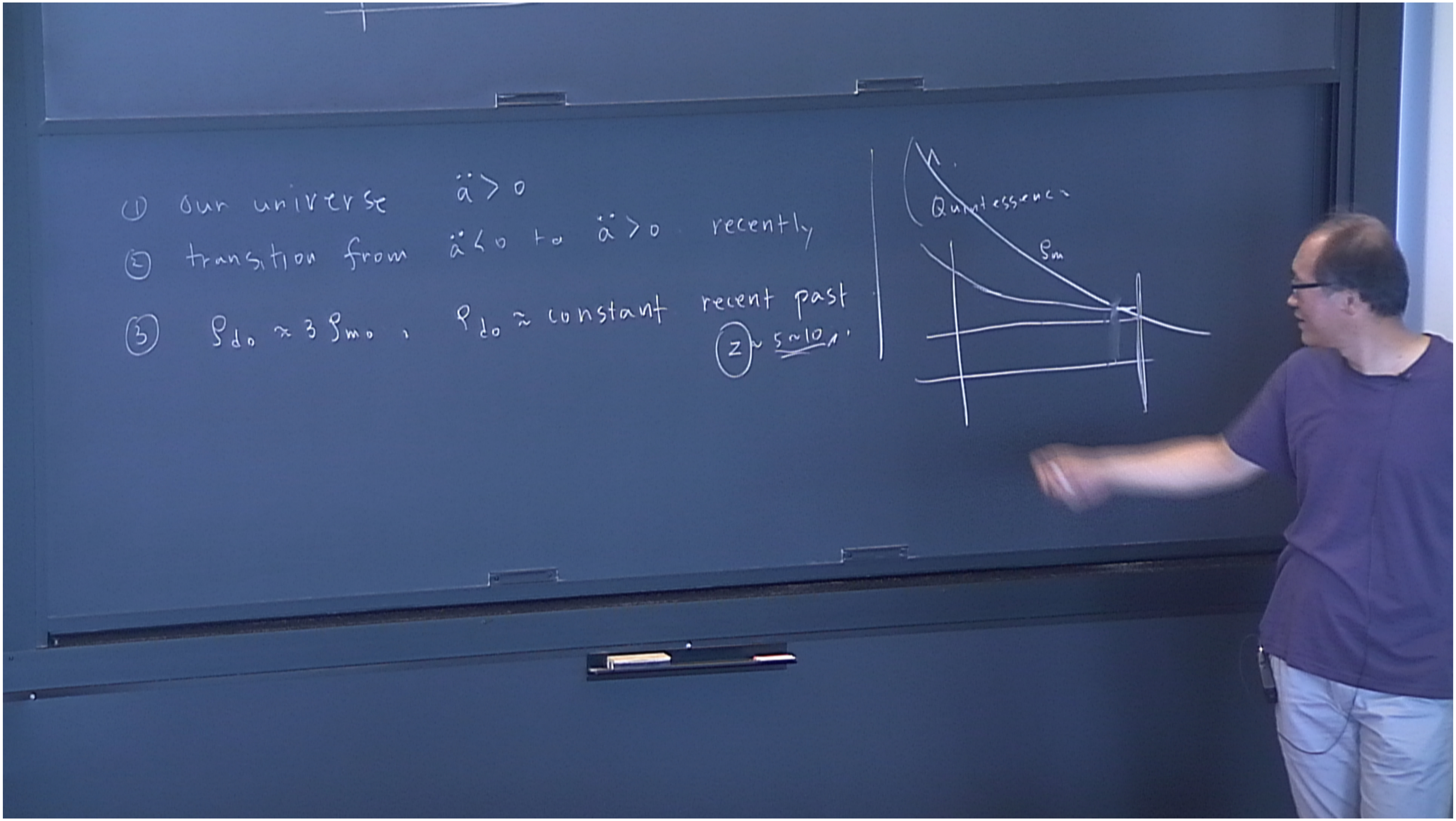

① our universe ä > 0
② transition from ä < 0 to ä
recently
③ ρd0

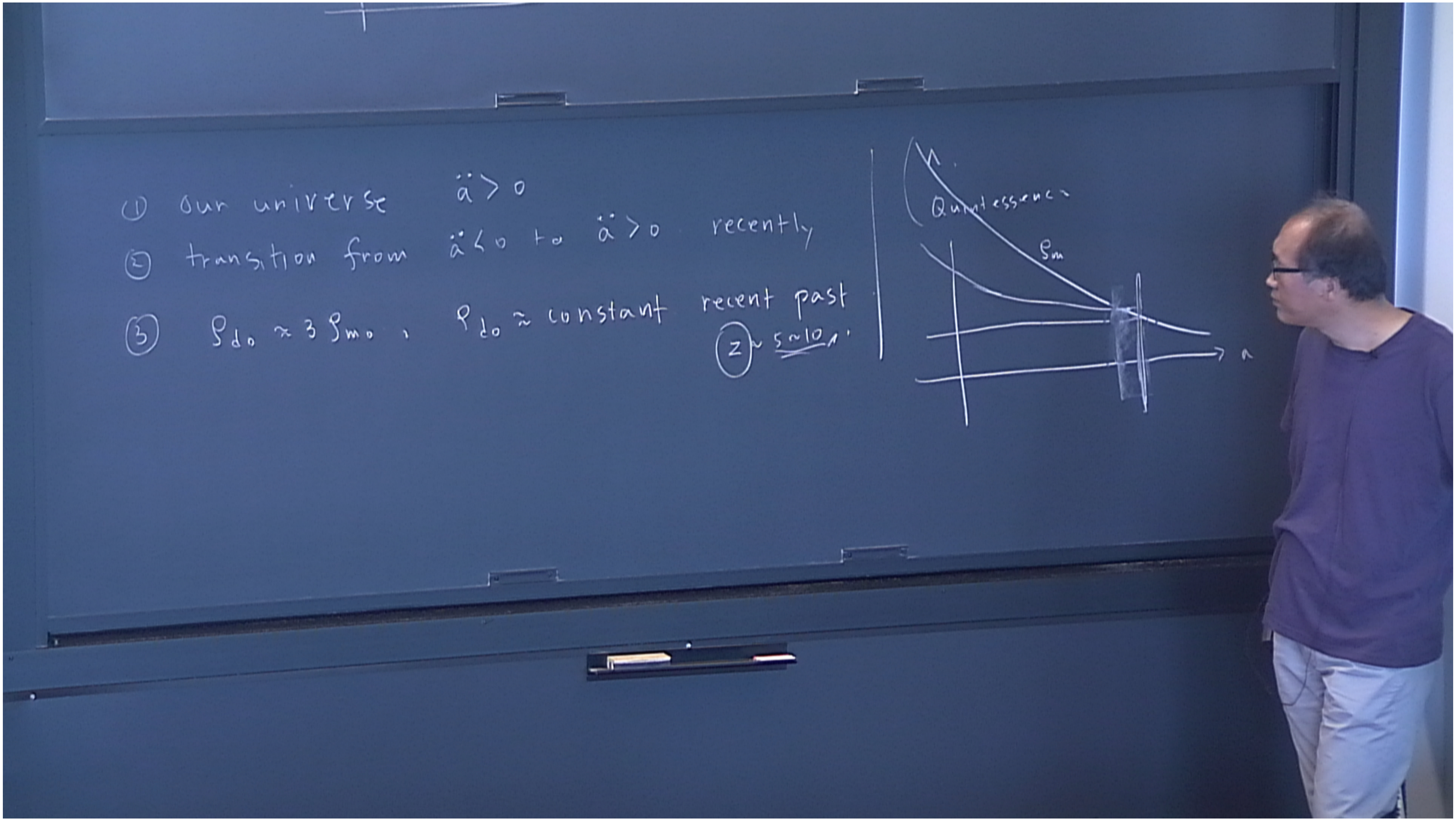

① our universe $\ddot{a} > 0$
② transition from $\ddot{a} < 0$ to $\ddot{a} > 0$ recently
③ $\rho_{d0} \approx 3\rho_{m0}$, $\rho_{d0} \approx$ constant recent past

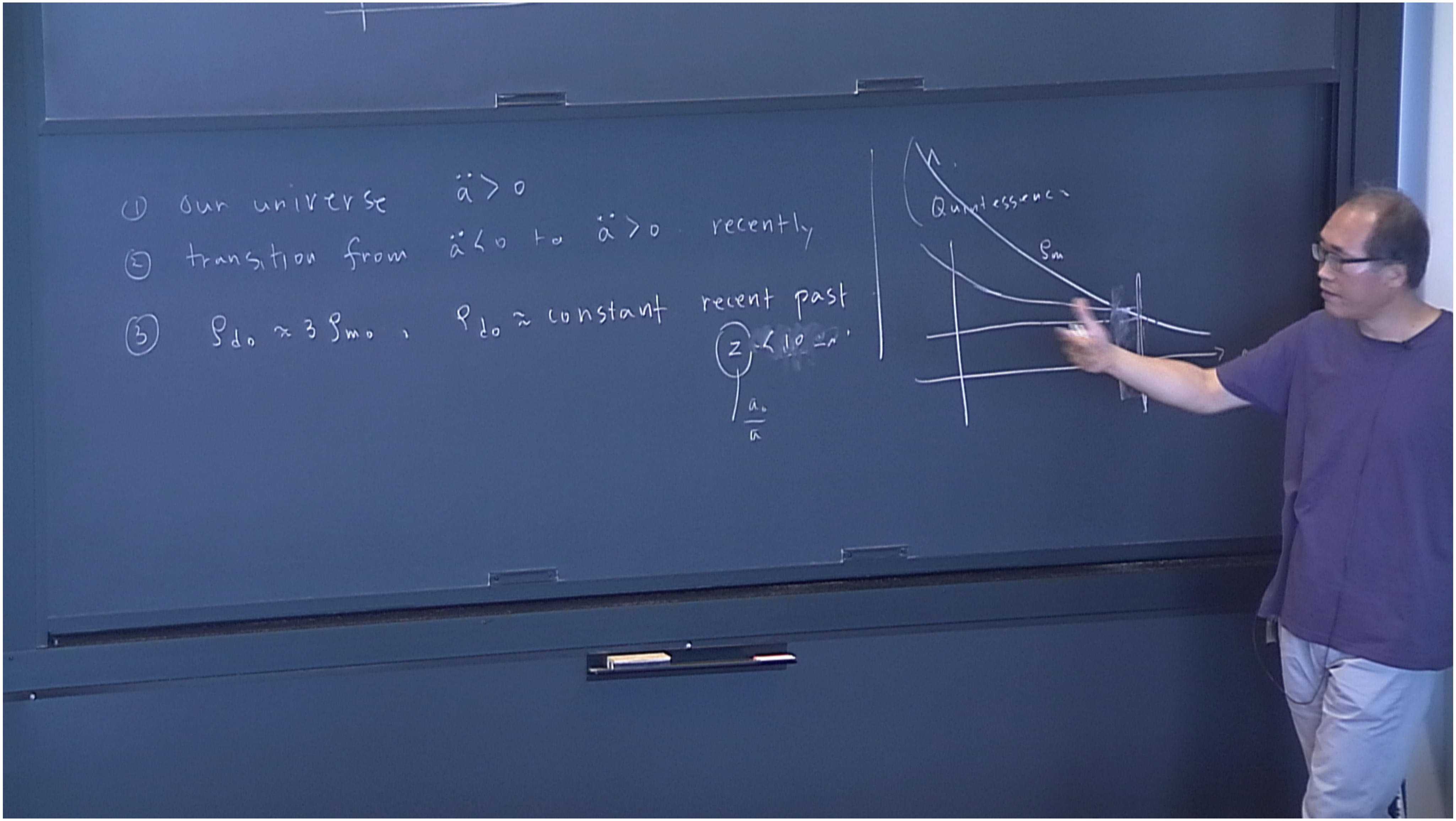

① our universe ä > 0
② transition from ä < 0 to ä > 0 recently
③ ρd0 ≈ 3 ρm0 , ρd0 ≈ constant recent past
z ~ 5~10
Λ.
Quintessence

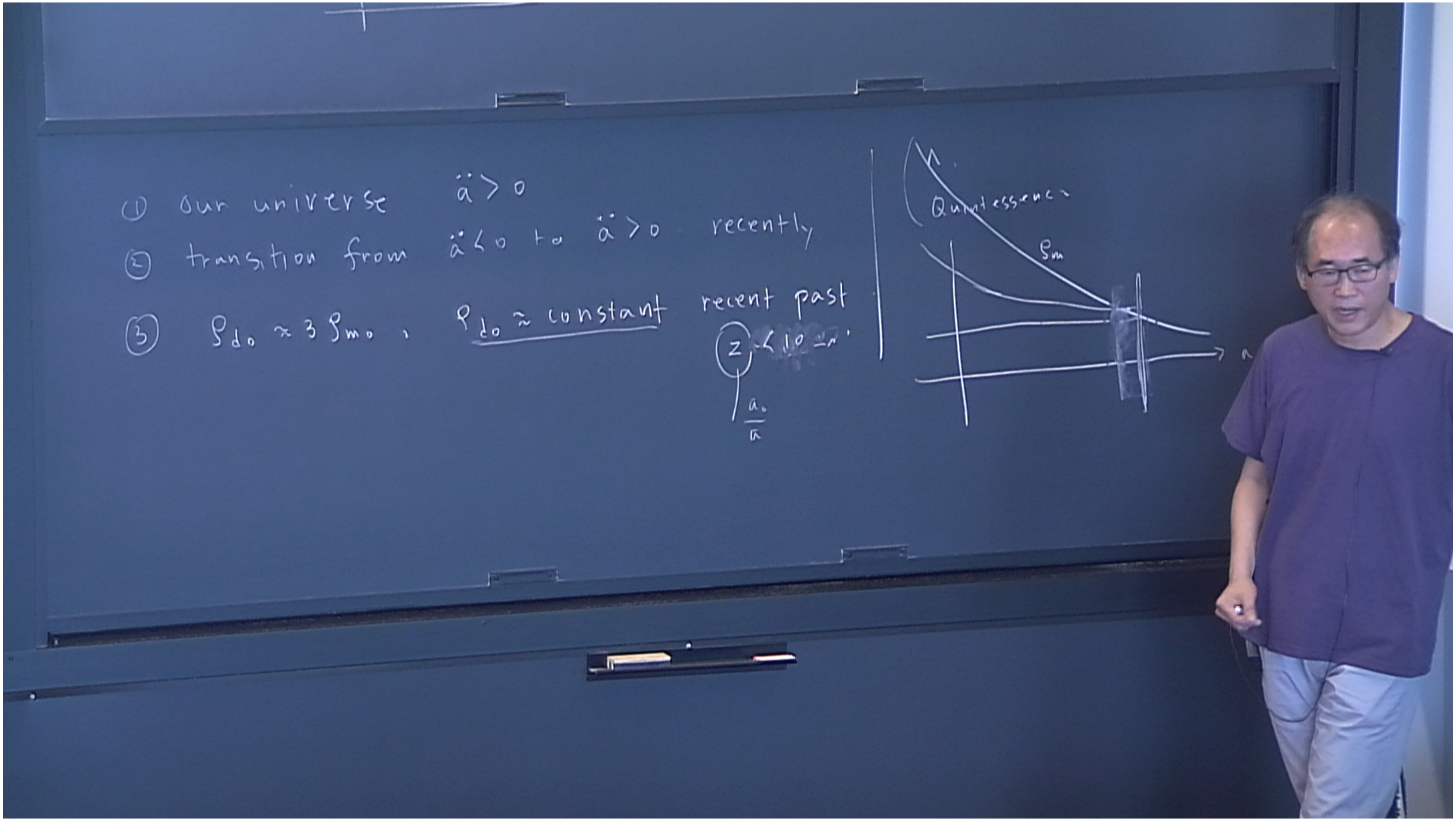

① our universe ä > 0
② transition from ä < 0 to ä > 0 recently
③ ρd0 ≈ 3 ρm0 , ρd0 ≈ constant recent past
Ⓩ ~ 5~10
Λ.
Quintessence

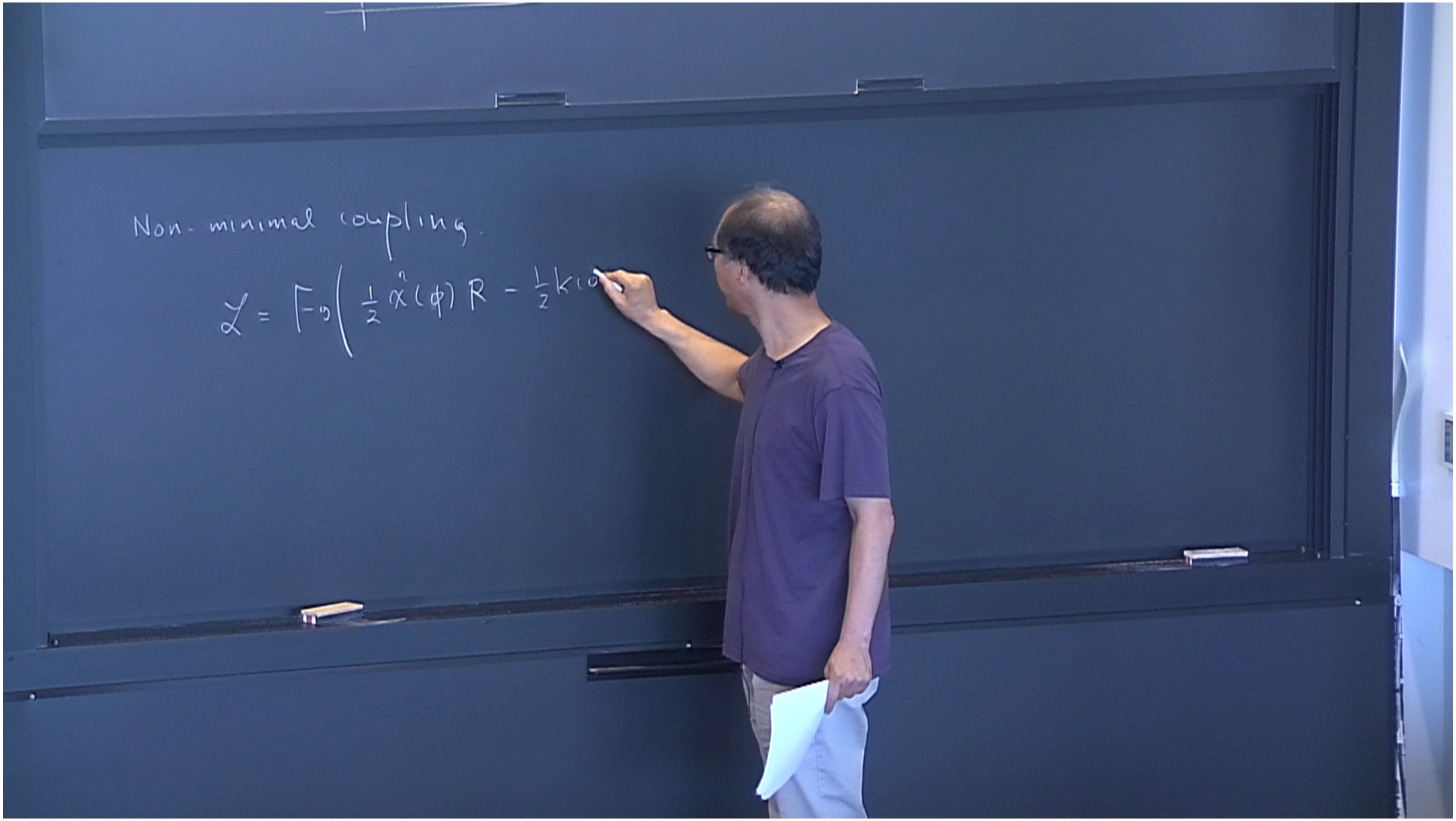

① our universe ä > 0
② transition from ä < 0 to ä > 0 recently
③ ρd0 ≈ 3 ρm0 , ρd0 ≈ constant recent past
z ~ 5~10
Quintessence
ρm

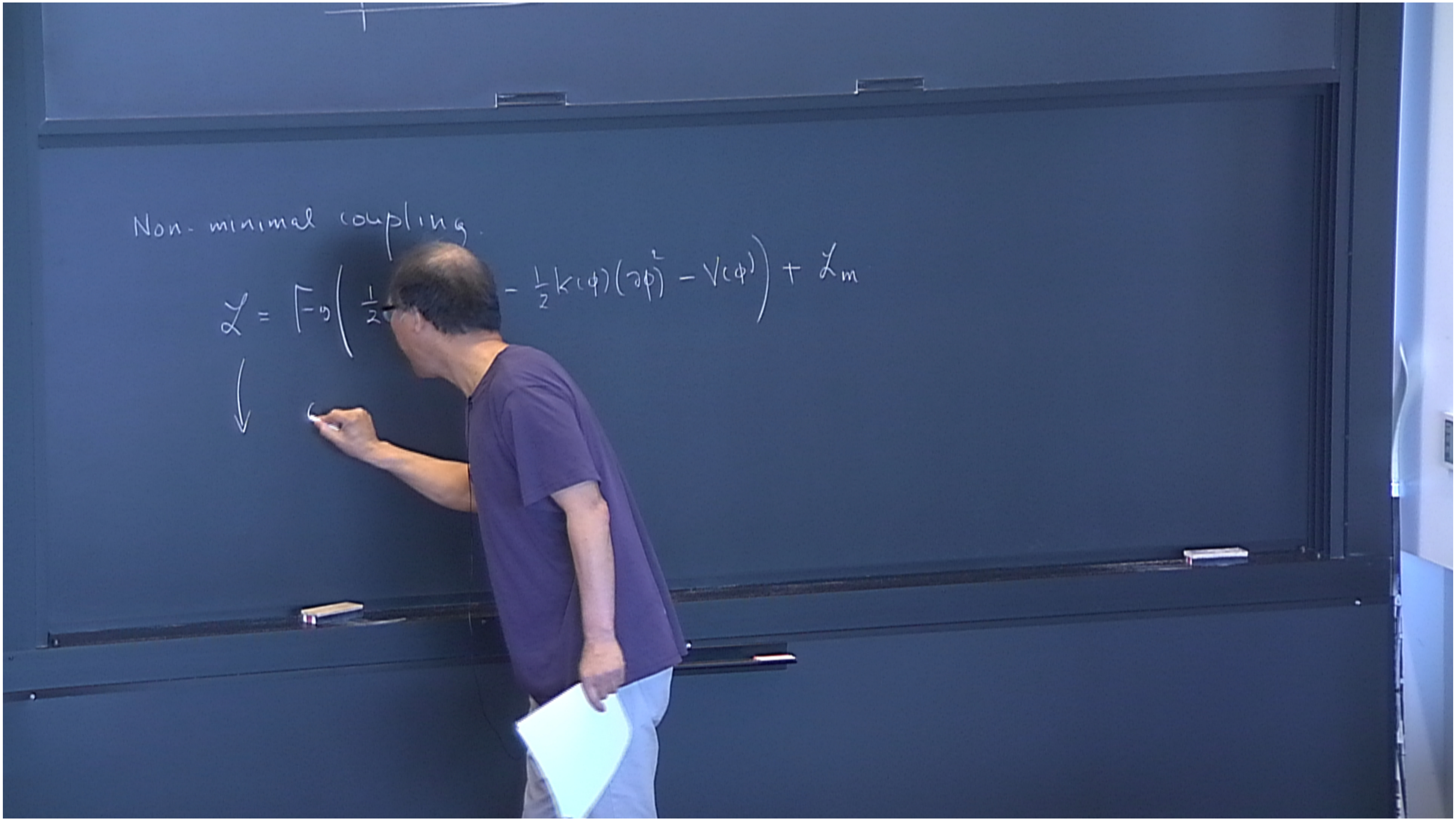

① our universe $\ddot{a} > 0$
② transition from $\ddot{a} < 0$ to $\ddot{a} > 0$ recently
③ $\rho_{d0} \approx 3\rho_{m0}$, $\rho_{d0} \approx$ constant recent past
$z \sim 5 \sim 10$
Λ
Quintessence
ρ_m

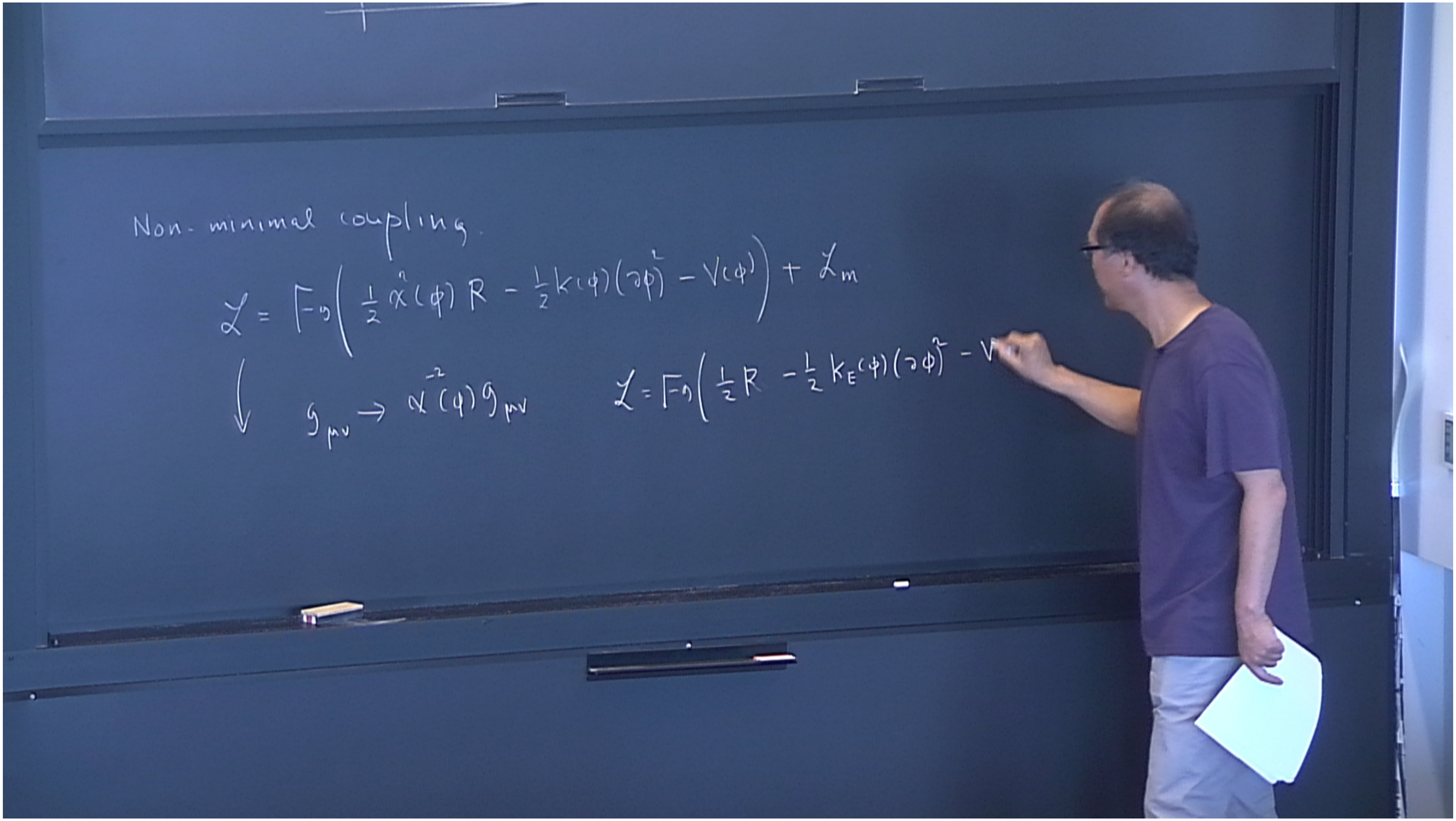

① our universe ä > 0
② transition from ä < 0 to ä > 0 recently
③ ρ_d0 ≈ 3 ρ_m0 , ρ_d0 ≈ constant recent past
z ~ 5~10
Quintessence
ρ_m
a

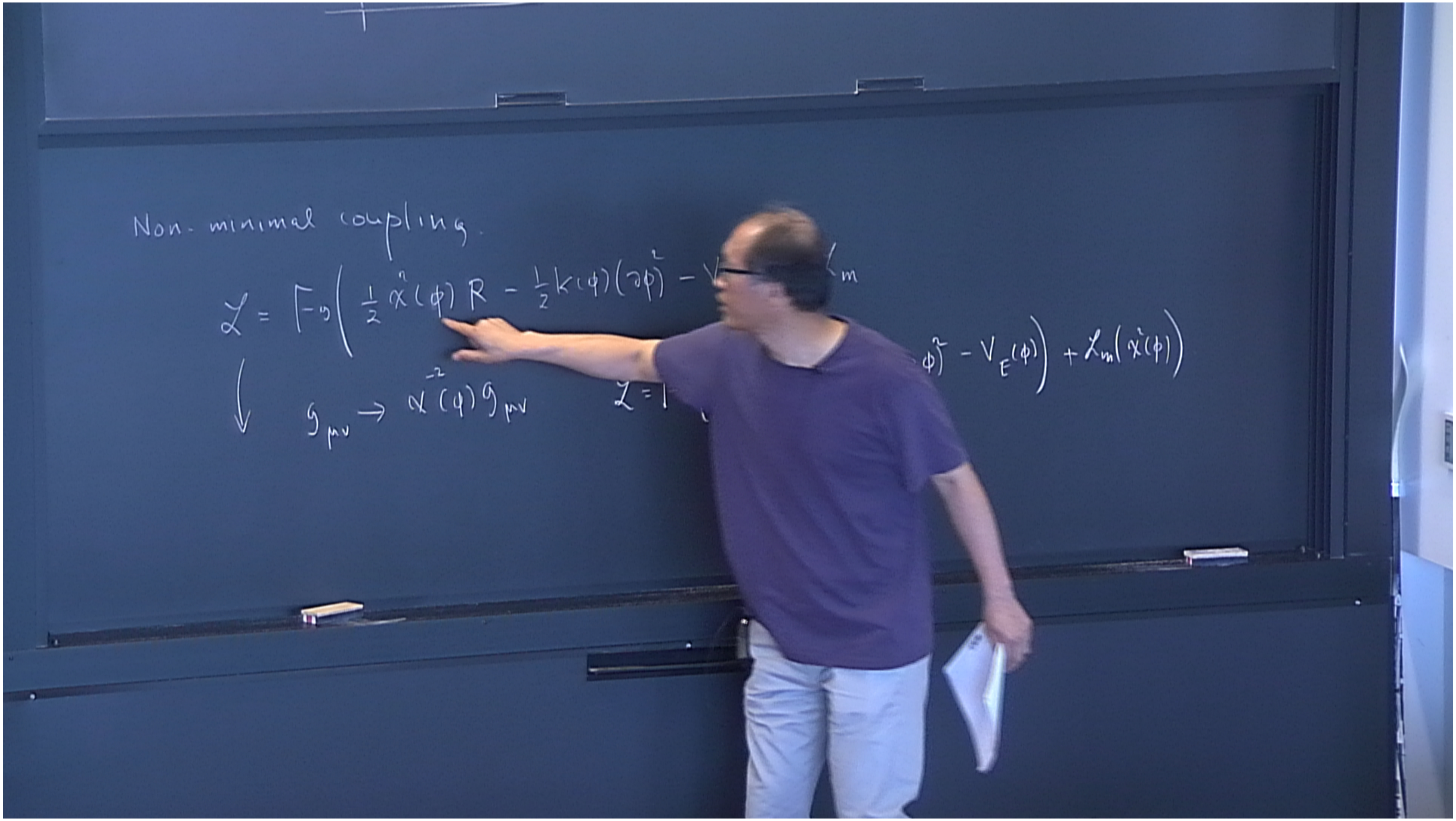

① our universe ä > 0
② transition from ä < 0 to ä > 0 recently
③ ρd0 ≈ 3 ρm0 , ρd0 ≈ constant recent past
Quintessence
ρm


① our universe ä > 0
② transition from ä < 0 to ä > 0 recently
③ ρd0 ≈ 3 ρm0 , ρd0 ≈ constant recent past
z
a0/a
Quintessence
ρm


Non-minimal coupling.
$\mathcal{L} = \sqrt{-g}\left(\frac{1}{2}\alpha^2(\phi) R - \frac{1}{2}K(\right.$


Non-minimal coupling.
- ½ k(φ)(∂φ)² - V(φ)) + ℒm


Non-minimal coupling.
$\mathcal{L} = \sqrt{-g}\left(\frac{1}{2}\alpha^2(\phi) R - \frac{1}{2}k(\phi)(\partial\phi)^2 - V(\phi)\right) + \mathcal{L}_m$
$g_{\mu\nu} \to \alpha^{-2}(\phi) g_{\mu\nu}$
$\mathcal{L} = \sqrt{-g}\left(\frac{1}{2}R - \frac{1}{2}k_E(\phi)(\partial\phi)^2 - V\right.$


Non-minimal coupling.
$\mathcal{L} = \sqrt{-g}\left(\frac{1}{2}\alpha^2(\phi) R - \frac{1}{2}k(\phi)(\partial\phi)^2 - V\right.$
$g_{\mu\nu} \to \alpha^{-2}(\phi) g_{\mu\nu}$
$\phi)^2 - V_E(\phi)\big) + \mathcal{L}_m(\alpha^2(\phi))\big)$

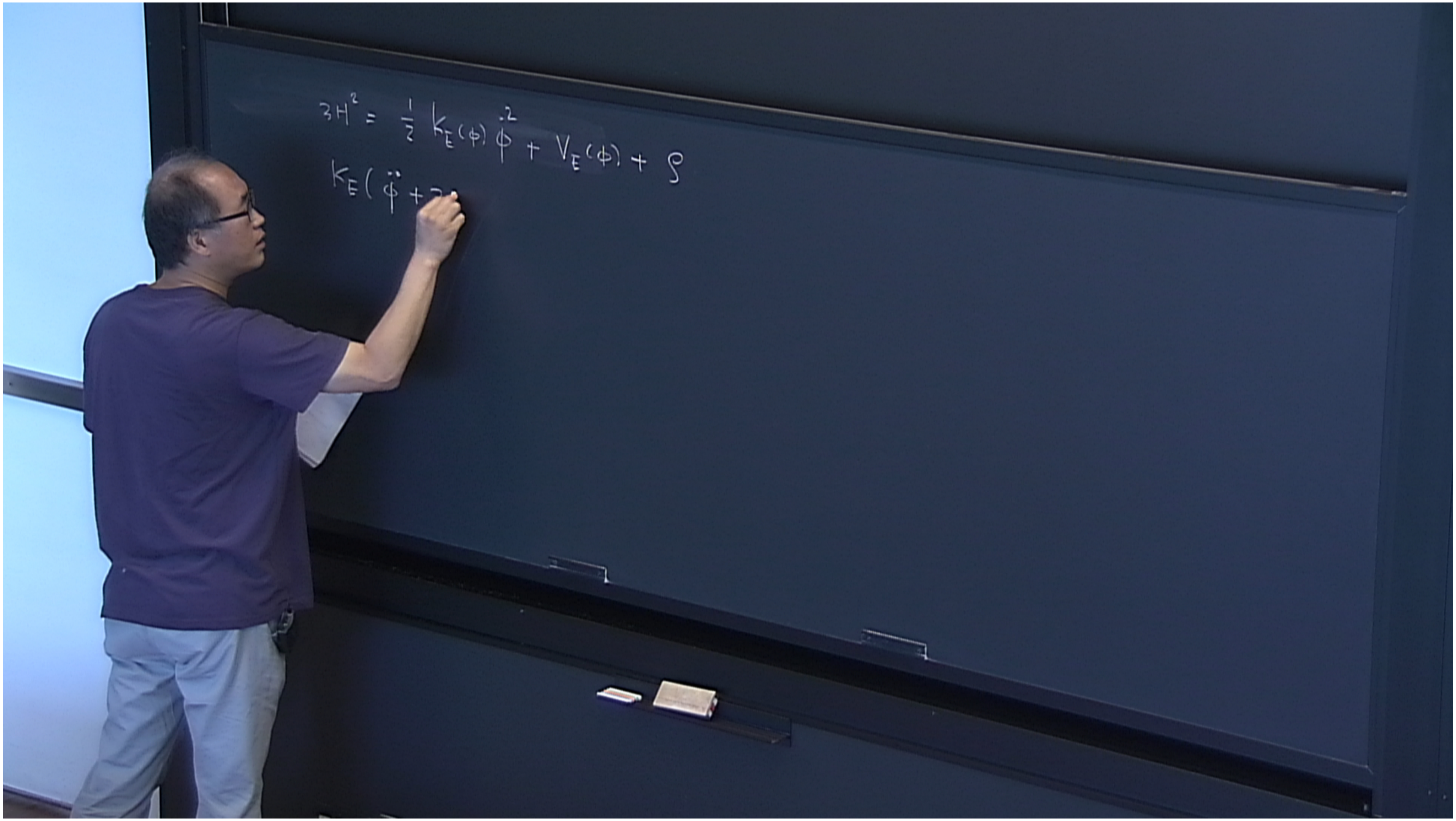
Non-minimal coupling.

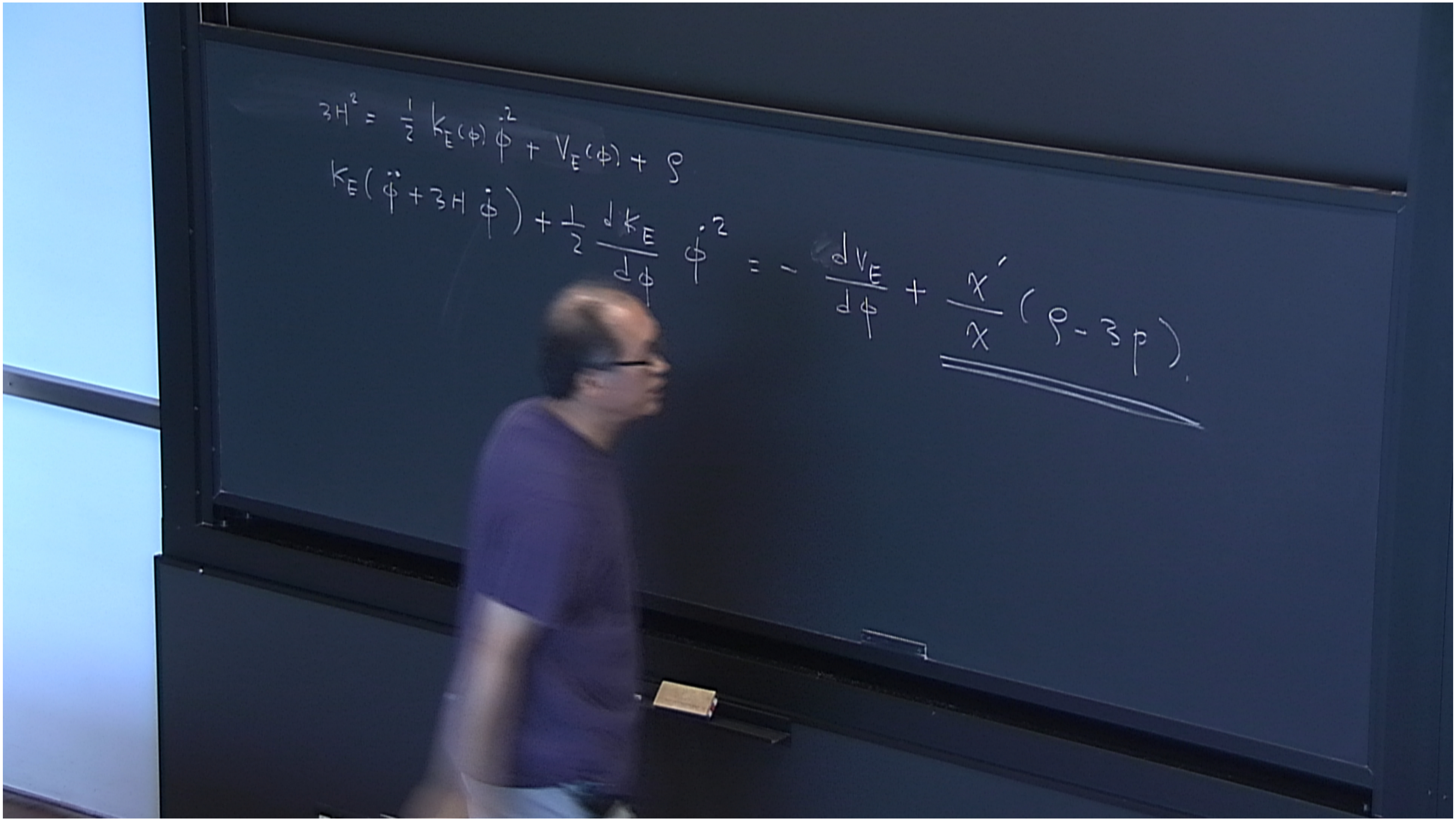
$$\mathcal{L} = \sqrt{-g}\left(\frac{1}{2}\alpha^2(\phi) R - \frac{1}{2}k(\phi)(\partial\phi)^2 - V(\phi)\right) + \mathcal{L}_m$$

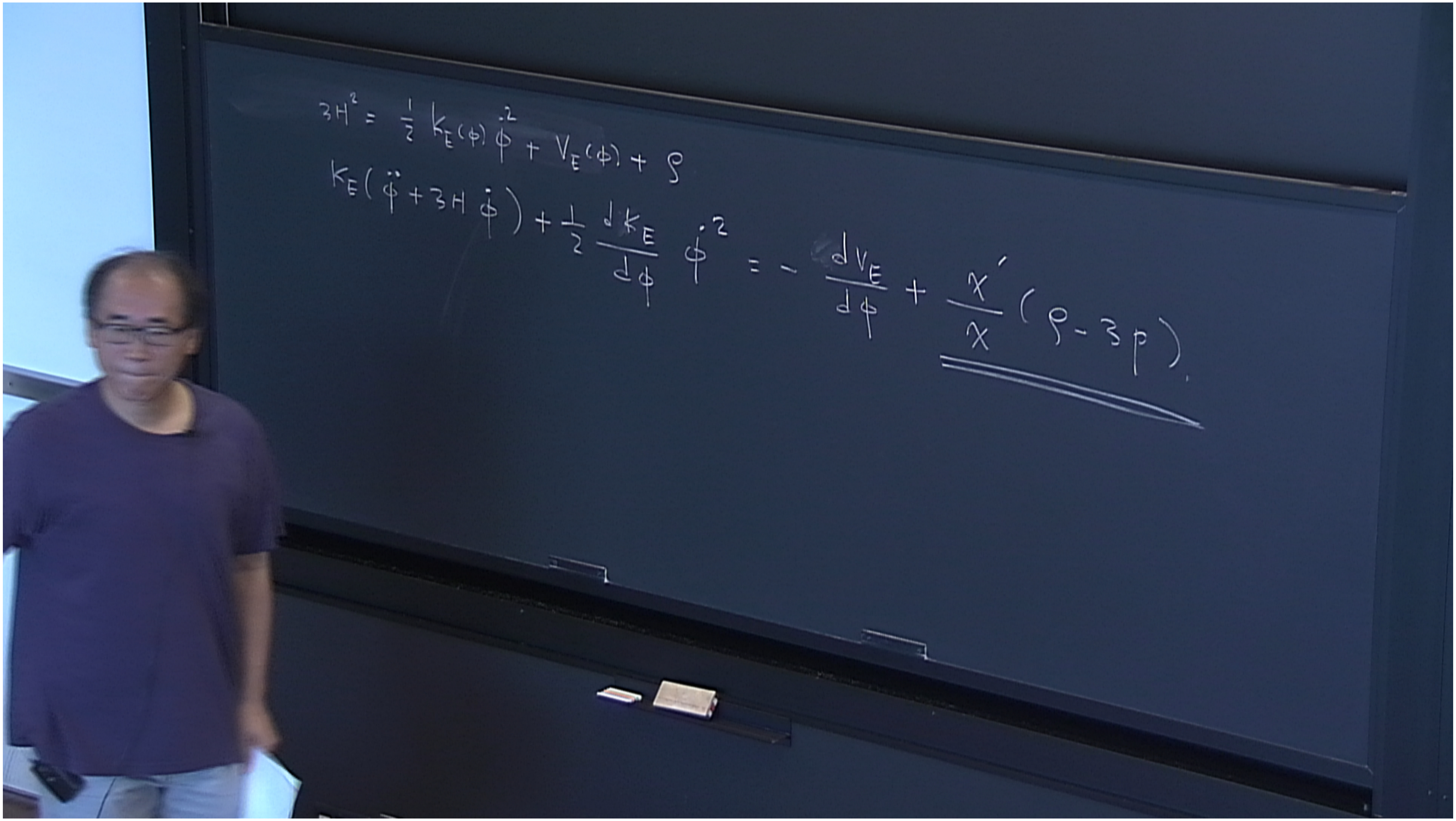
$\downarrow \quad g_{\mu\nu} \to \alpha^{-2}(\phi)\, g_{\mu\nu}$

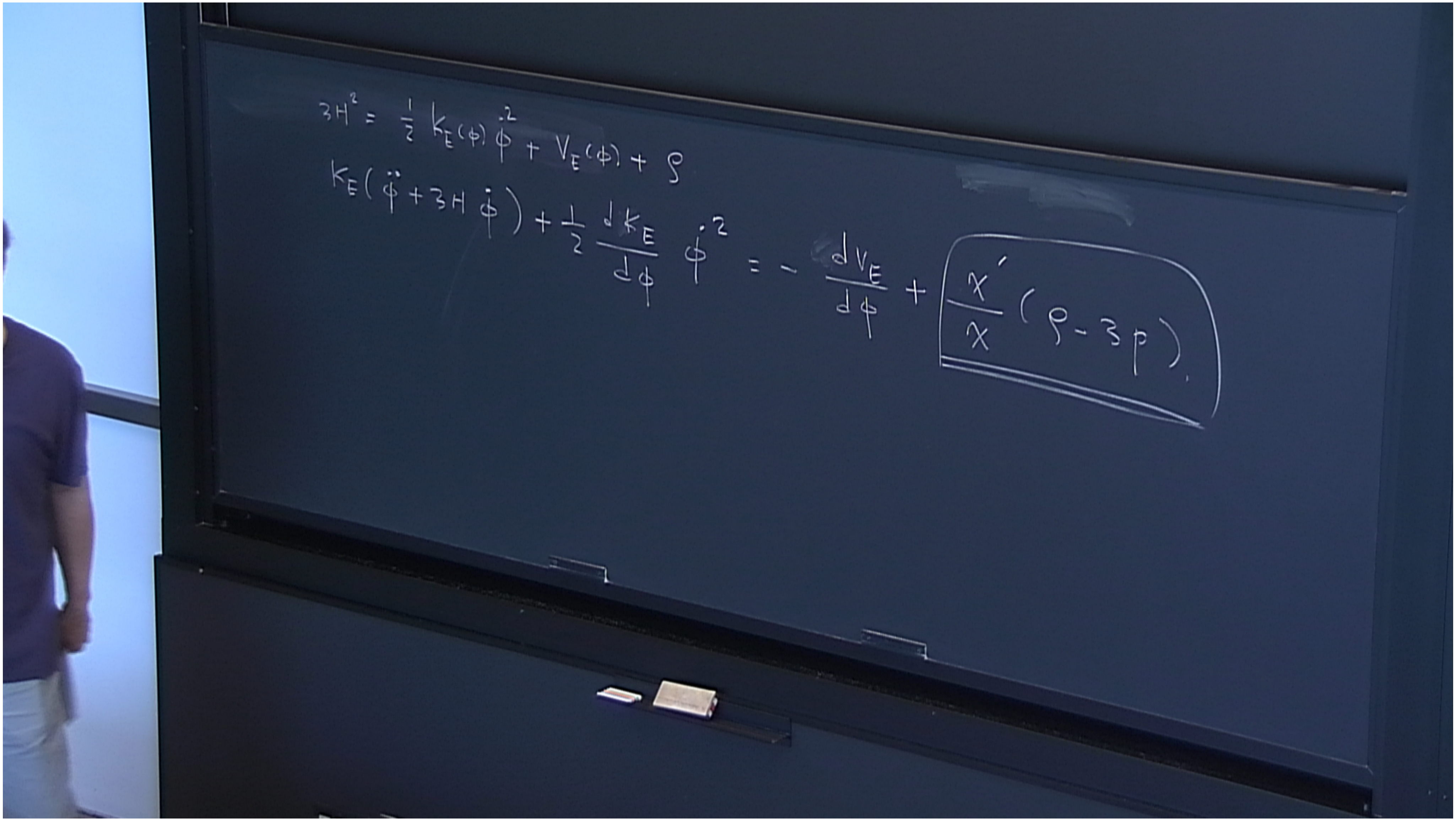
$$\mathcal{L} = \sqrt{-g}\left(\frac{1}{2}R - \frac{1}{2}k_E(\phi)(\partial\phi)^2 - V_E(\phi)\right) + \mathcal{L}_m\left(\alpha^2(\phi)\right)$$

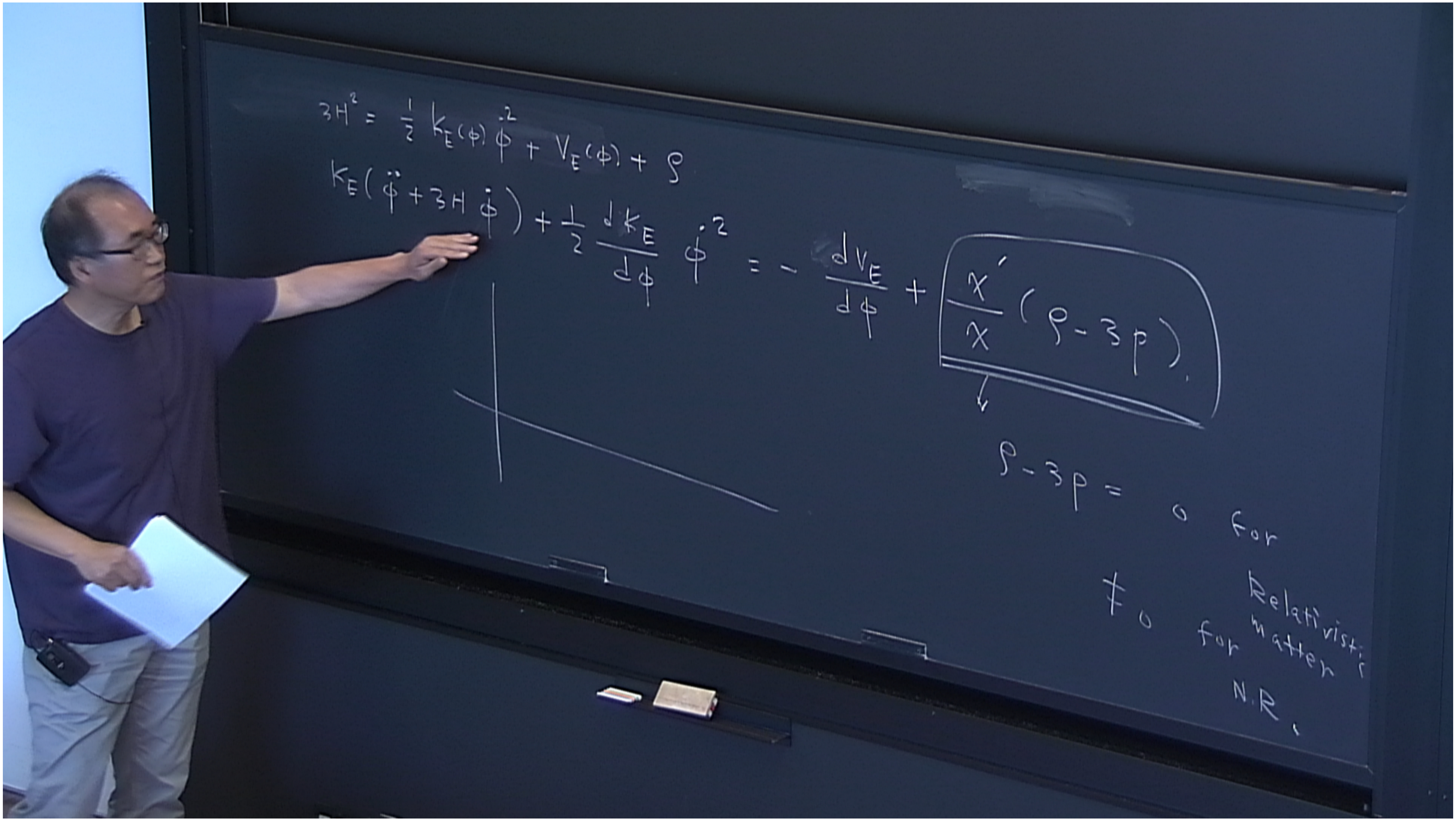
$\downarrow$

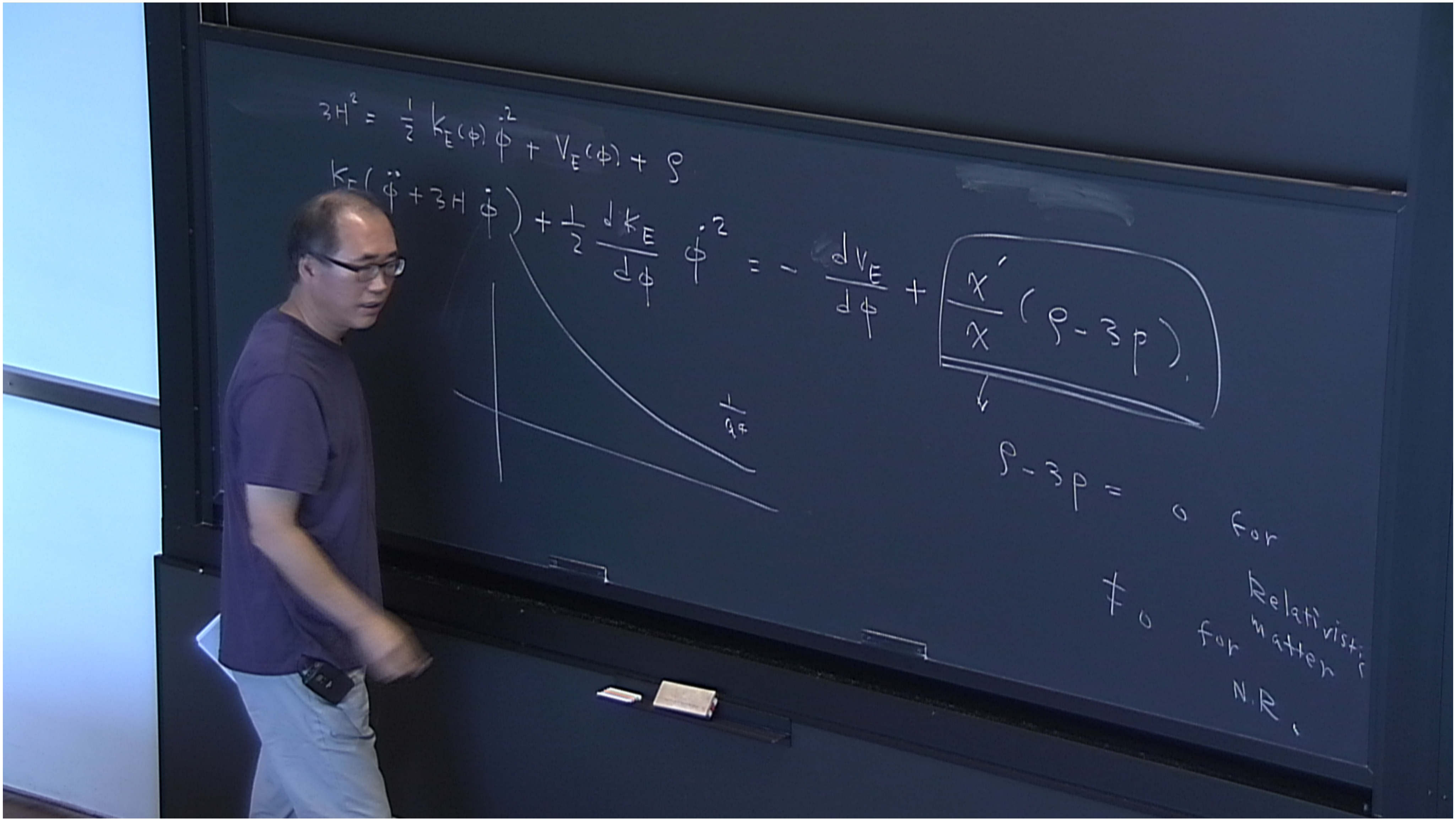

3H^2 = 1/2 K_E(φ) φ̇^2 + V_E(φ) + ρ
K_E (φ̈ +

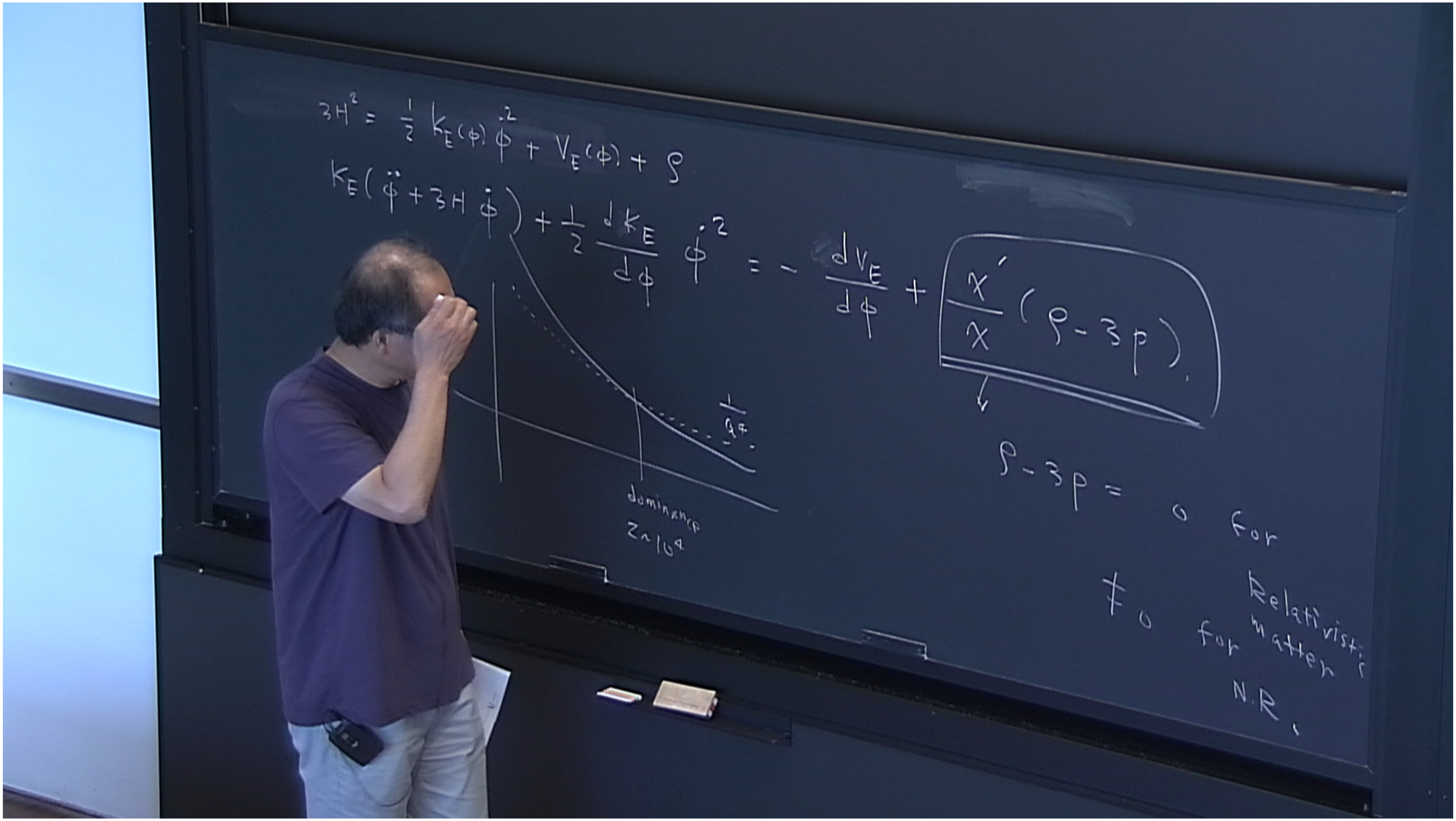

$3H^2 = \frac{1}{2} K_E(\phi) \dot{\phi}^2 + V_E(\phi) + \rho$
$K_E(\ddot{\phi} + 3H\dot{\phi}) + \frac{1}{2}\frac{dK_E}{d\phi}\dot{\phi}^2 = -\frac{dV_E}{d\phi} + \frac{\chi'}{\chi}(\rho - 3p)$


$3H^2 = \frac{1}{2} K_E(\phi)\dot{\phi}^2 + V_E(\phi) + \rho$
$K_E(\ddot{\phi} + 3H\dot{\phi}) + \frac{1}{2}\frac{dK_E}{d\phi}\dot{\phi}^2 = -\frac{dV_E}{d\phi} + \frac{\chi'}{\chi}(\rho - 3p)$

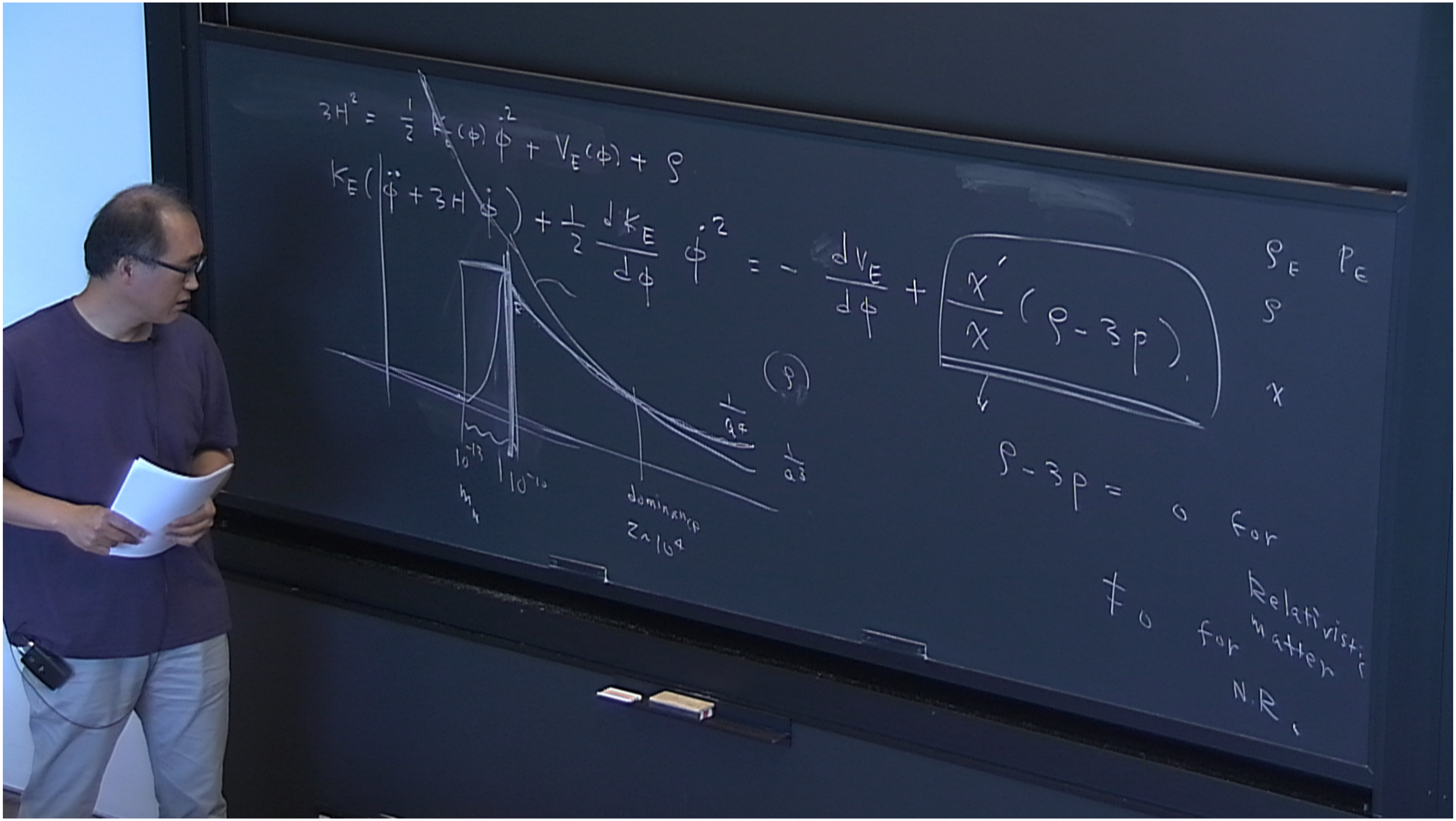

$3H^2 = \frac{1}{2} K_E(\phi)\dot{\phi}^2 + V_E(\phi) + \rho$
$K_E(\ddot{\phi} + 3H\dot{\phi}) + \frac{1}{2}\frac{dK_E}{d\phi}\dot{\phi}^2 = -\frac{dV_E}{d\phi} + \frac{\chi'}{\chi}(\rho - 3p)$.


$3H^2 = \frac{1}{2} K_E(\phi)\dot{\phi}^2 + V_E(\phi) + \rho$
$K_E(\ddot{\phi} + 3H\dot{\phi}) + \frac{1}{2}\frac{dK_E}{d\phi}\dot{\phi}^2 = -\frac{dV_E}{d\phi} + \frac{\chi'}{\chi}(\rho - 3p)$
$\rho - 3p = 0$ for Relativistic matter
$\neq 0$ for N.R.

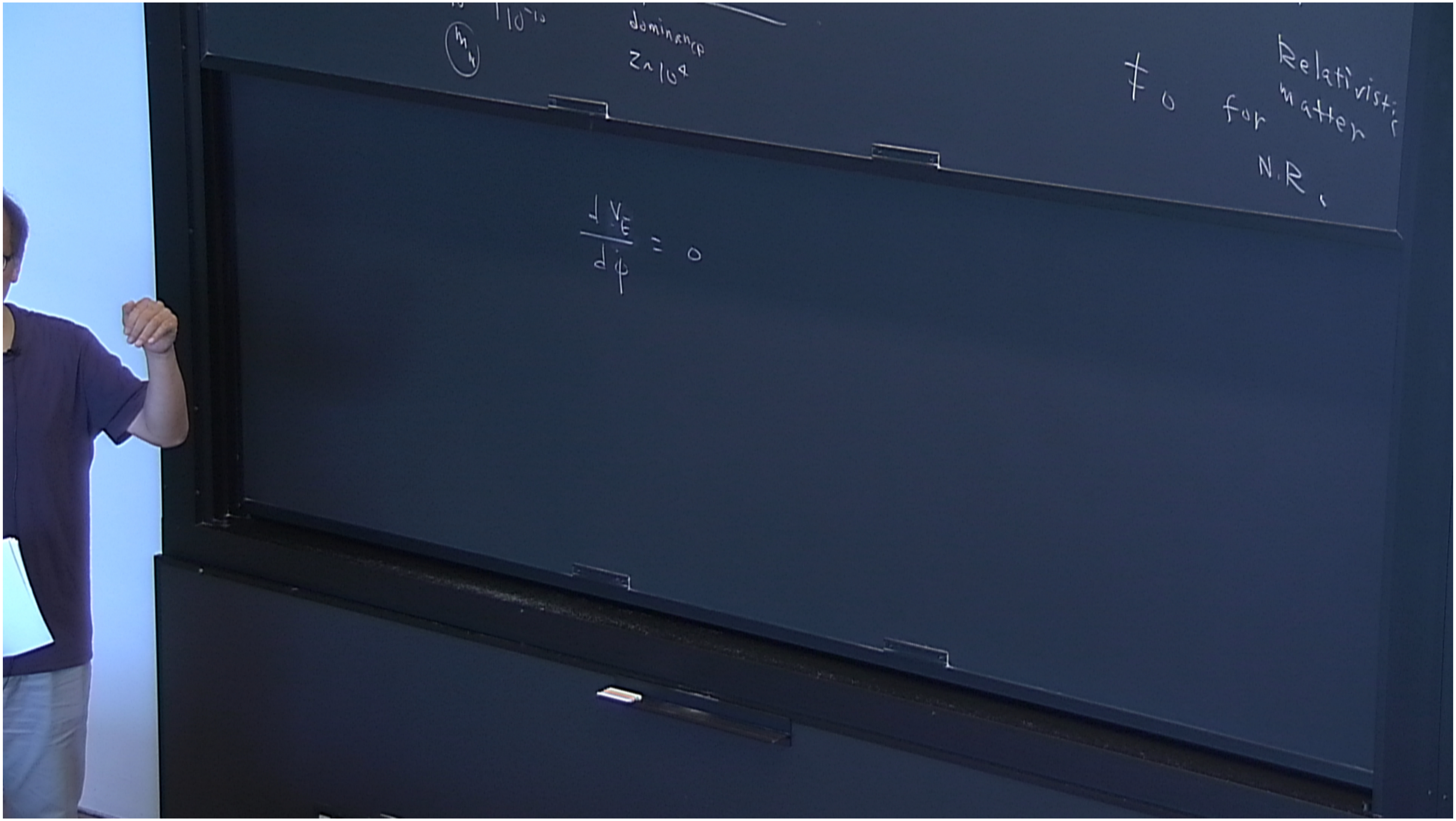

3H^2 = 1/2 K_E(φ) φ̇^2 + V_E(φ) + ρ
K_E(φ̈ + 3H φ̇) + 1/2 dK_E/dφ φ̇^2 = - dV_E/dφ + χ'/χ (ρ - 3p)
1/a^4
ρ - 3p = 0 for Relativistic matter
≠ 0 for N.R.

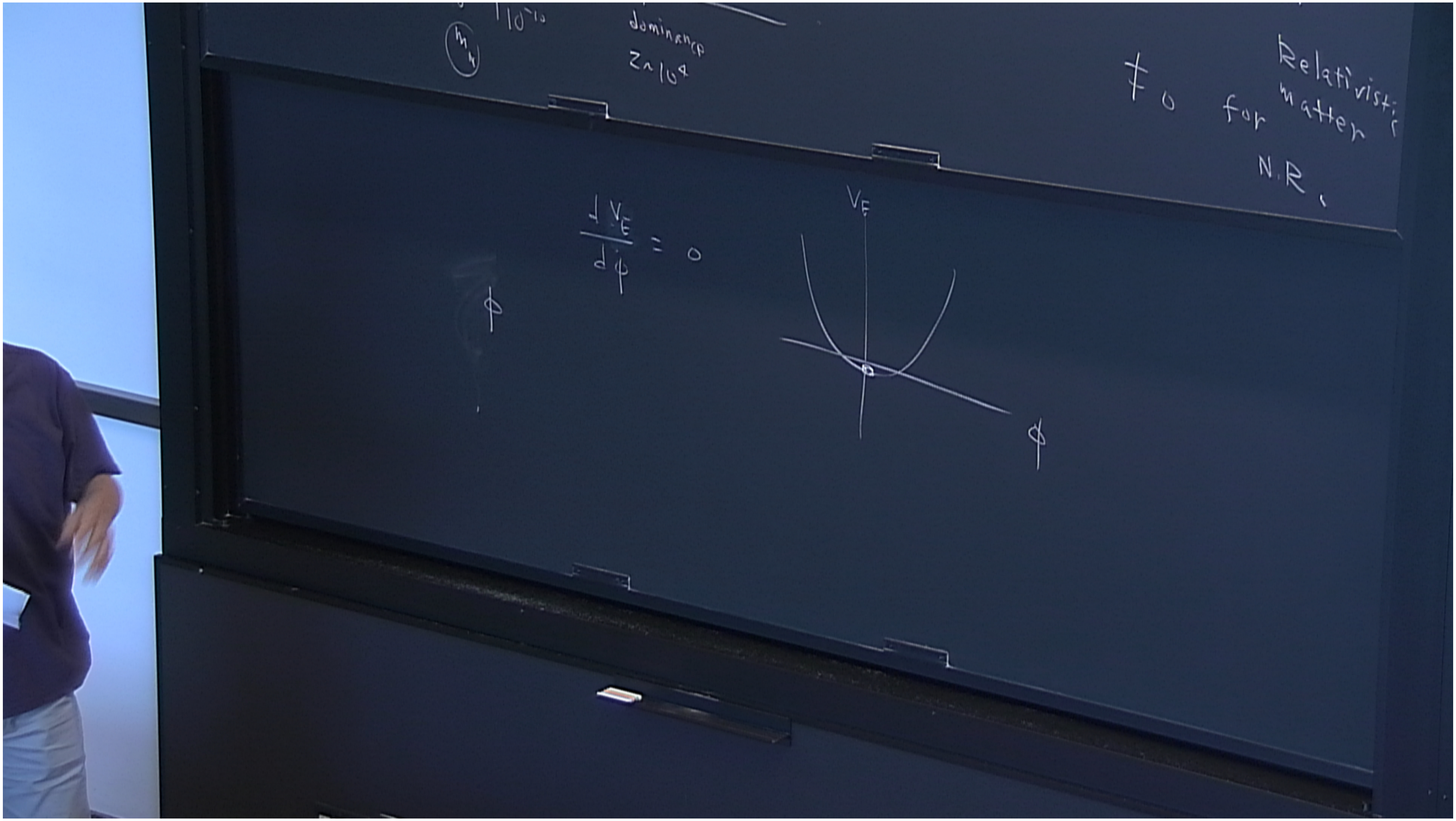


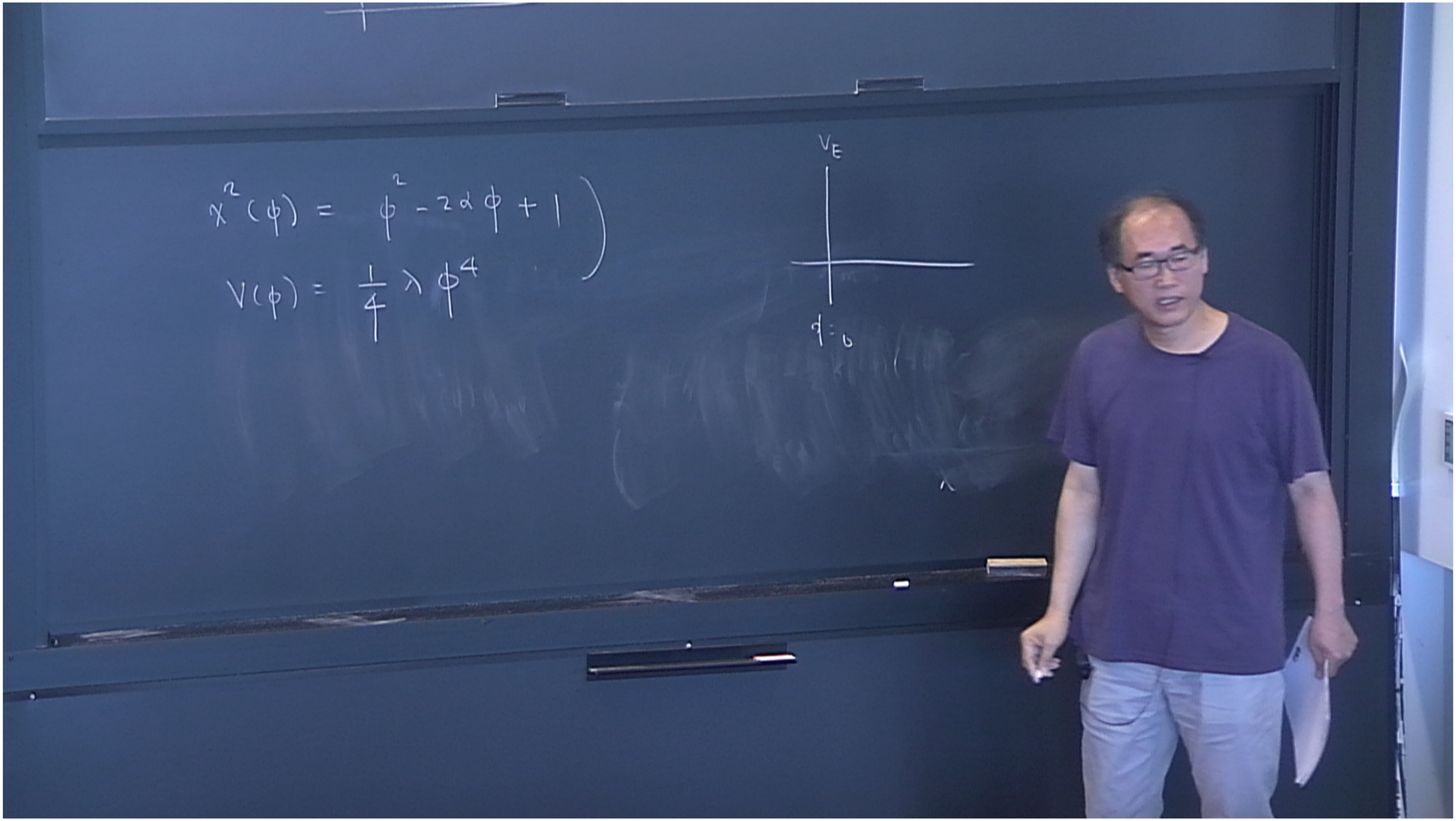
3H² = ½ K_E(φ) φ̇² + V_E(φ) + ρ
K_E(φ̈ + 3H φ̇) + ½ dK_E/dφ φ̇² = − dV_E/dφ + χ'/χ (ρ − 3p)
dominance
z~10⁴
ρ − 3p = 0 for Relativistic matter
≠ 0 for N.R.

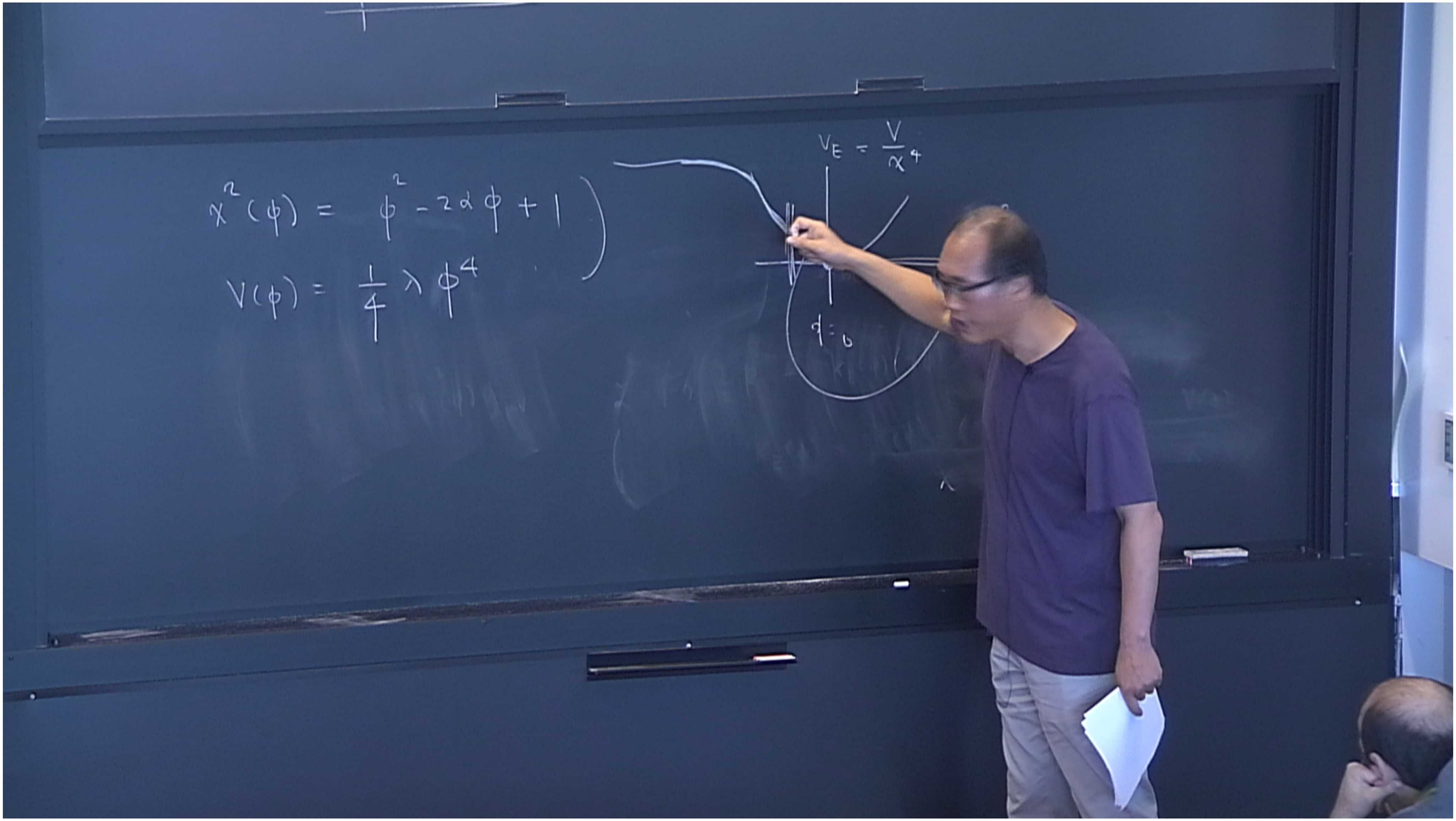


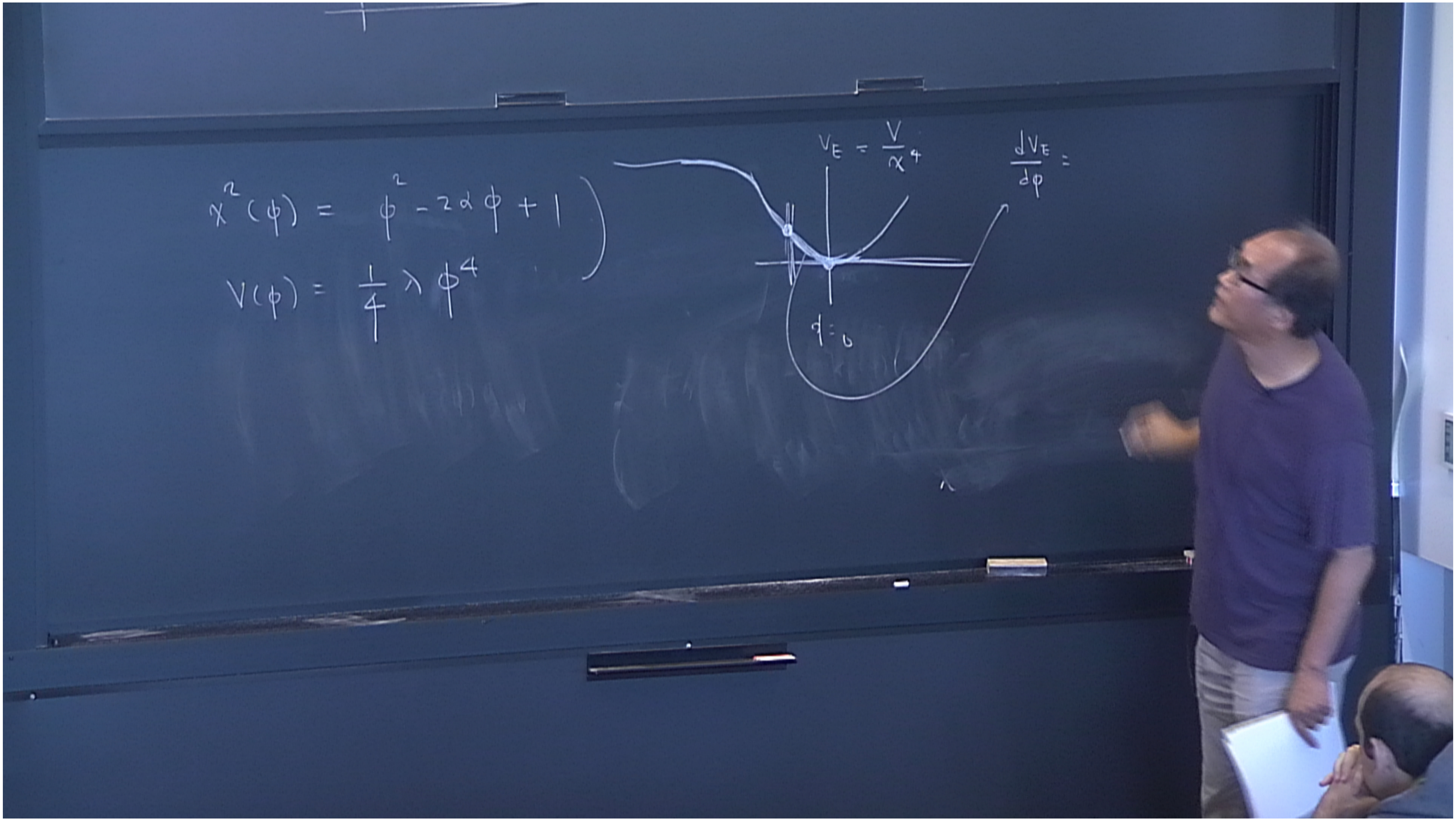
3H² = ½ K_E(φ) φ̇² + V_E(φ) + ρ
K_E(φ̈ + 3H φ̇) + ½ dK_E/dφ φ̇² = − dV_E/dφ + χ′/χ (ρ − 3p)
ρ_E p_E
ρ
χ
1/a⁴
1/a³
10⁻¹³
10⁻¹⁰
dominance
z ~ 10⁴
ρ − 3p = 0 for Relativistic matter
≠ 0 for N.R.

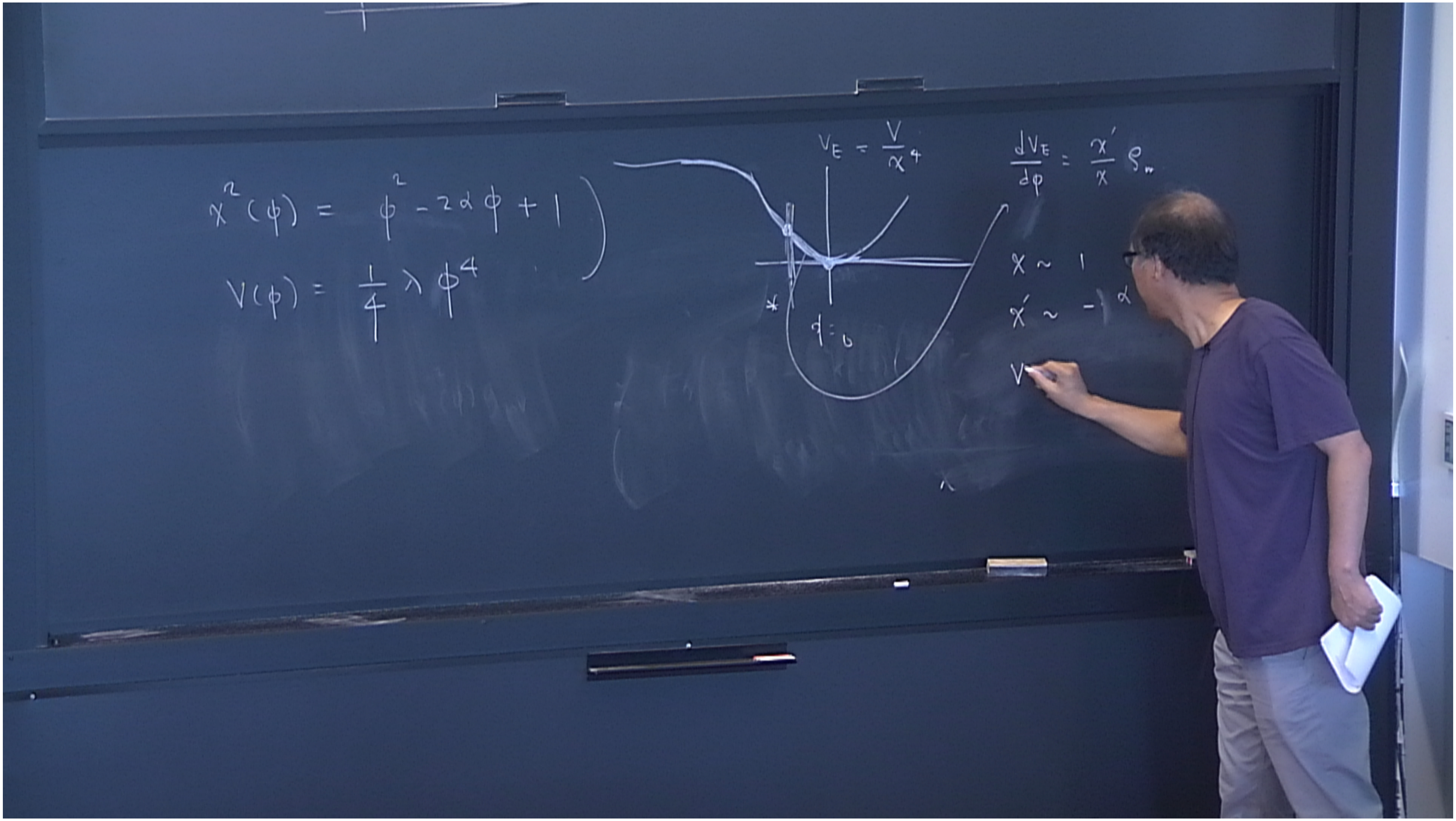

dominance
Relativistic matter
for
N.R.


dominance
Z~10^4
≠ 0 for
Relativistic matter
N.R.
dV_E/dφ = 0
V_E
φ
φ

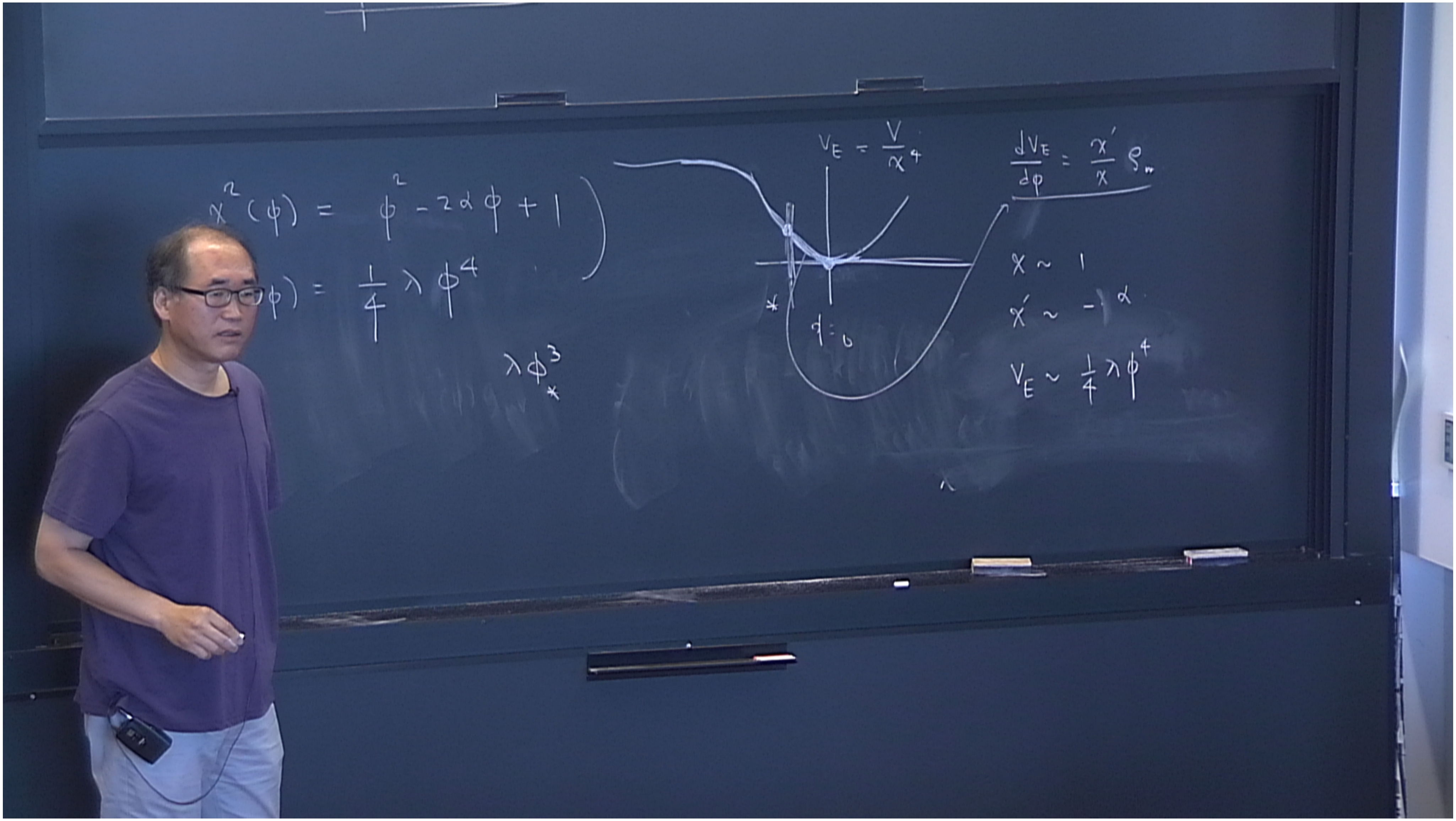

$\chi^2(\phi) = \phi^2 - 2\alpha\phi + 1$
$V(\phi) = \frac{1}{4}\lambda\phi^4$
V_E
$\phi = 0$
λ

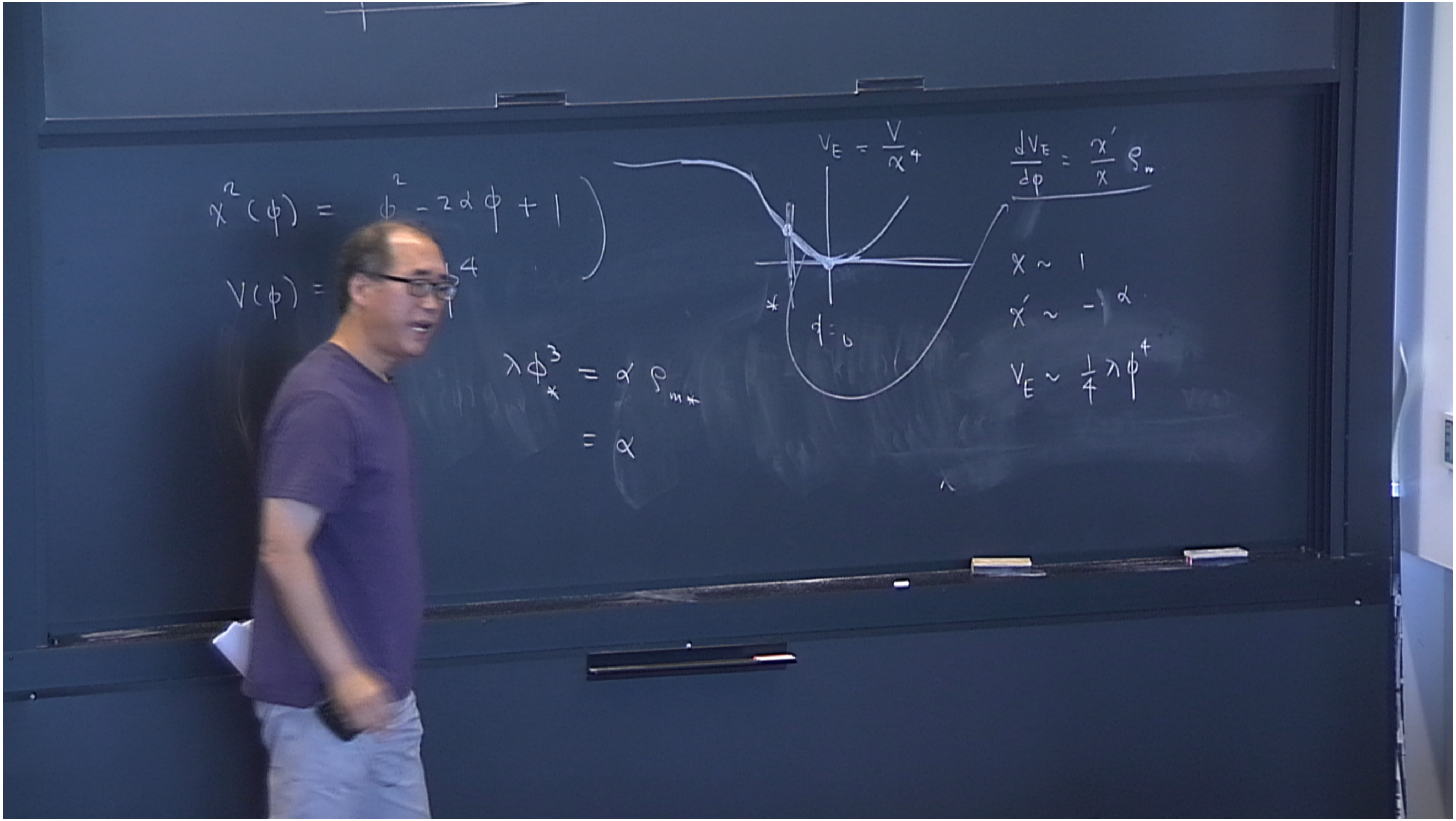

$\chi^2(\phi) = \phi^2 - 2\alpha\phi + 1$
$V(\phi) = \frac{1}{4}\lambda\phi^4$
$V_E = \frac{V}{\chi^4}$
$\phi = 0$

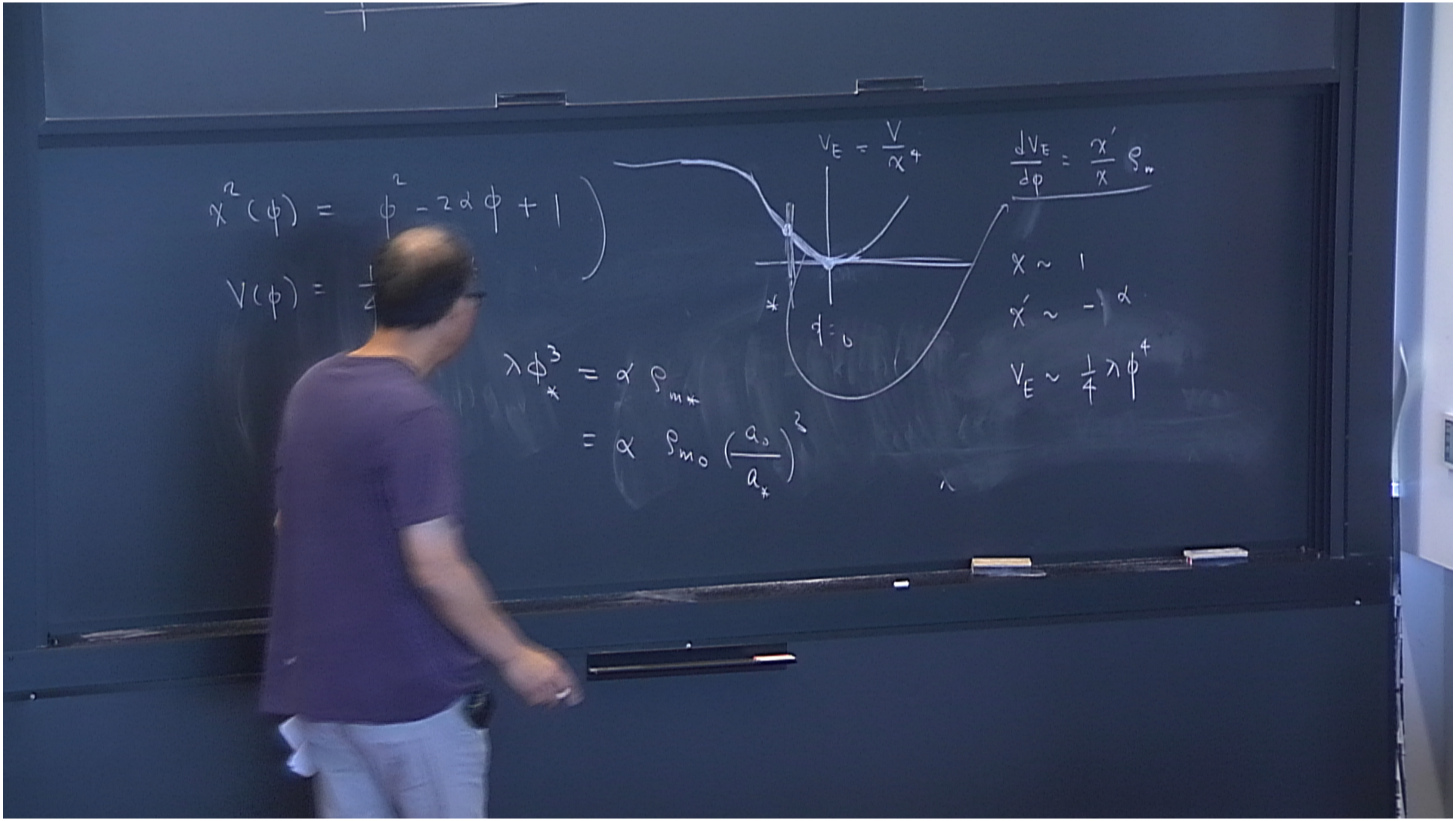

$\chi^2(\phi) = \phi^2 - 2\alpha\phi + 1$
$V(\phi) = \frac{1}{4}\lambda\phi^4$
$V_E = \frac{V}{\chi^4}$
$\frac{dV_E}{d\phi} =$
$\phi = 0$

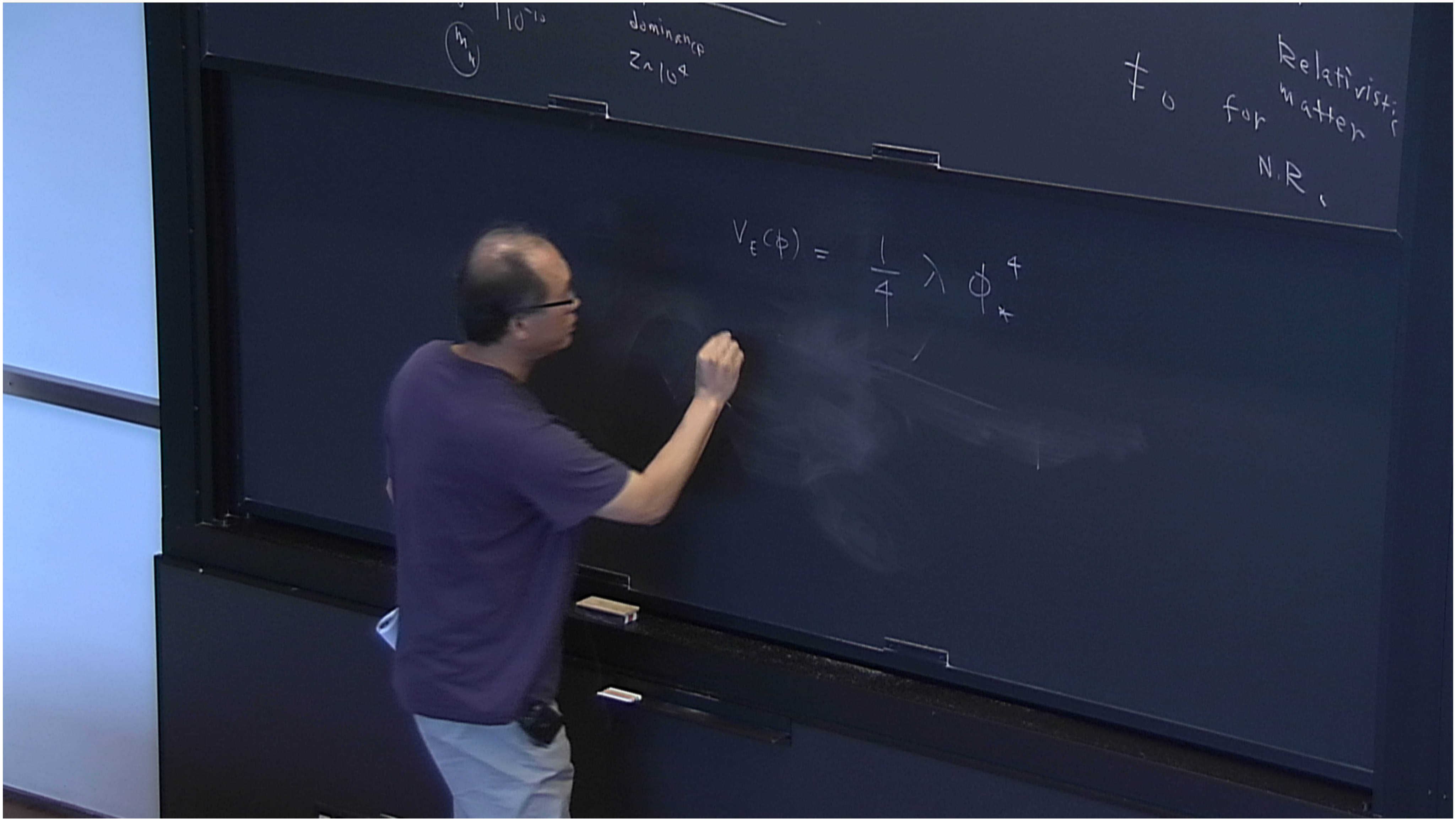


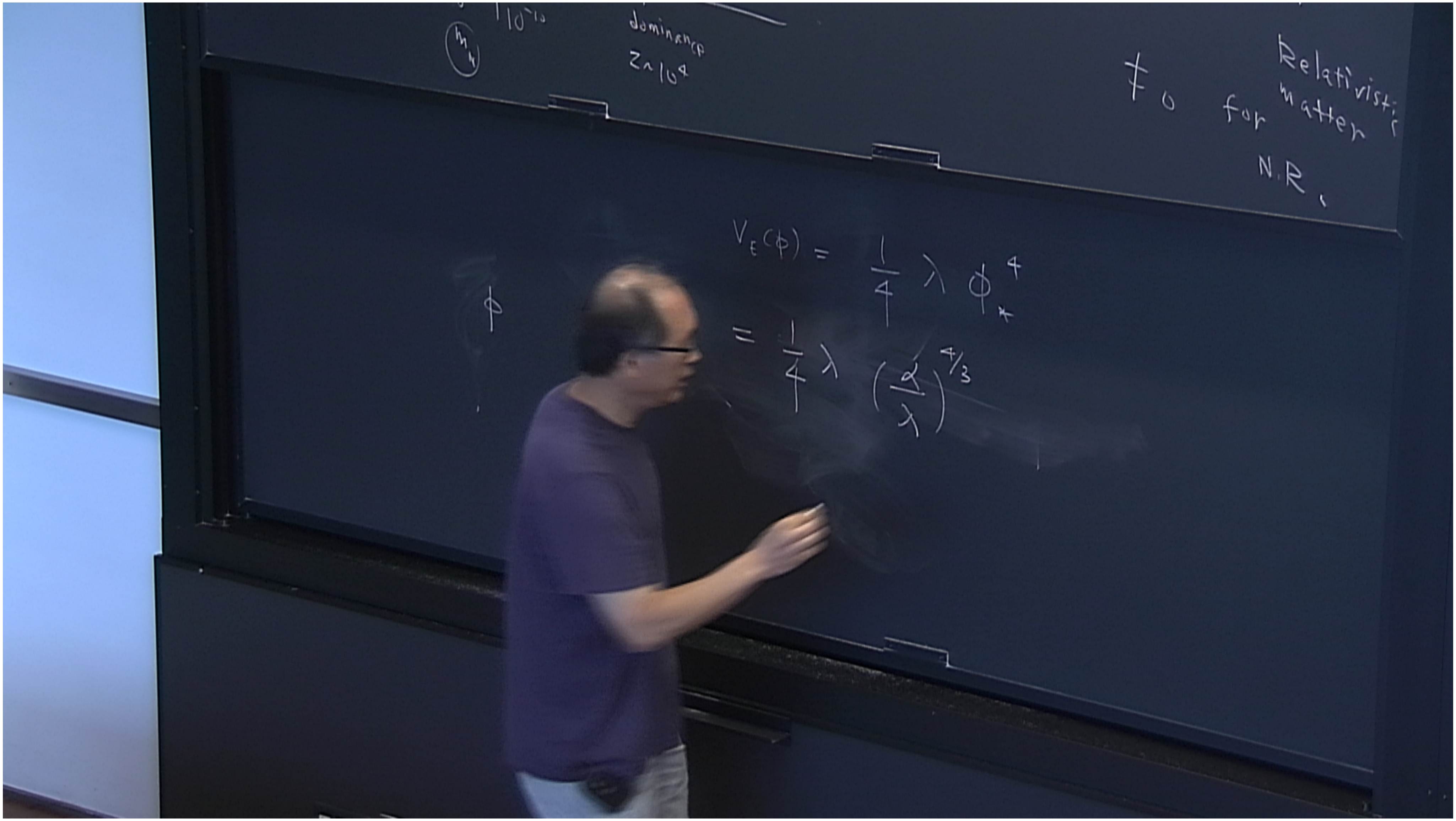
χ²(φ) = φ² − 2αφ + 1
V(φ) = 1/4 λ φ⁴
V_E = V/χ⁴
dV_E/dφ = χ'/χ
χ ~ 1
χ' ~ −α
φ = 0

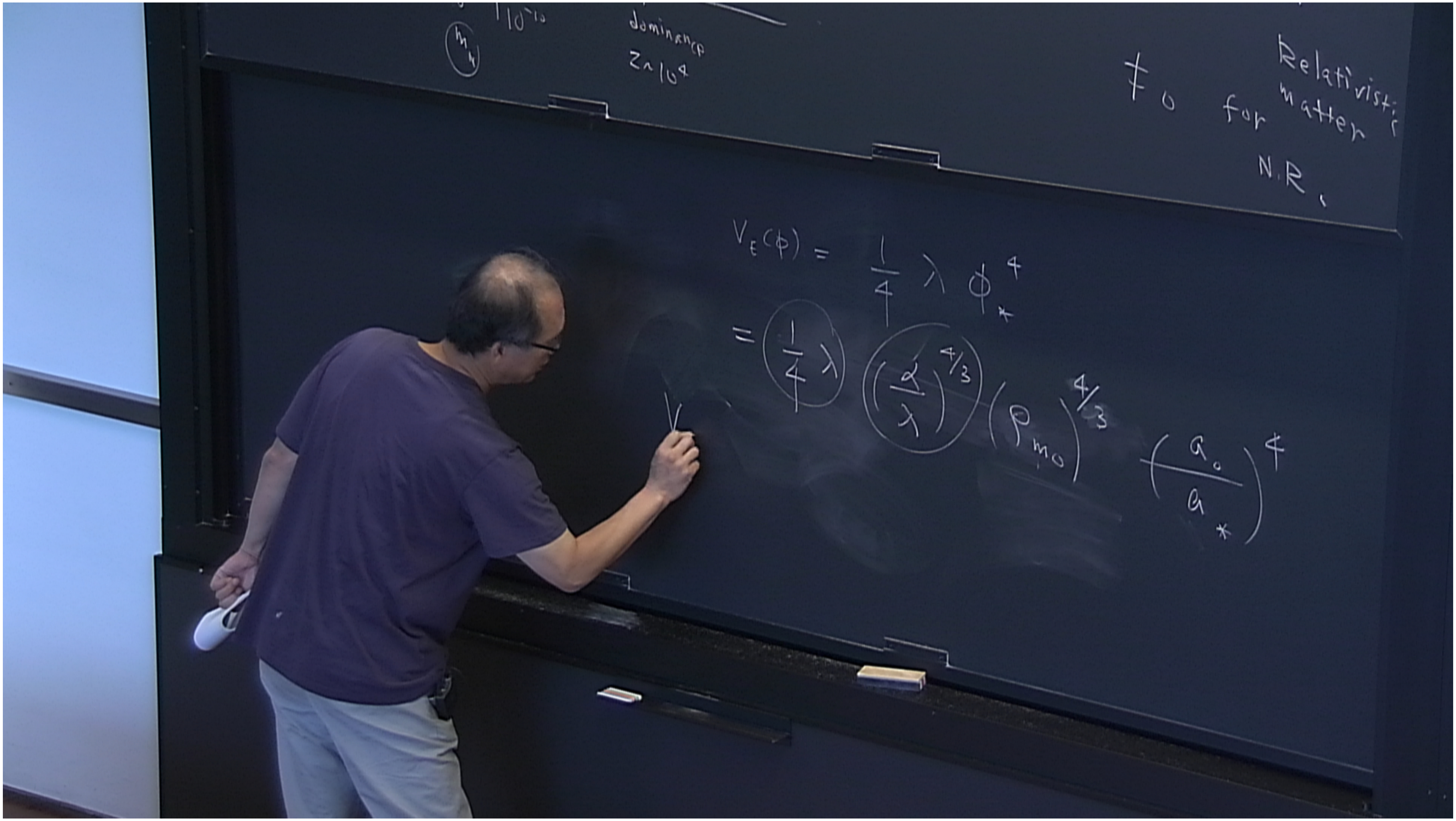

χ²(φ) = φ² − 2αφ + 1
(φ) = 1/4 λ φ⁴
λφ³
*
V_E = V/χ⁴
φ=0
dV_E/dφ = χ'/χ ρ
χ ~ 1
χ' ~ − α
V_E ~ 1/4 λ φ⁴

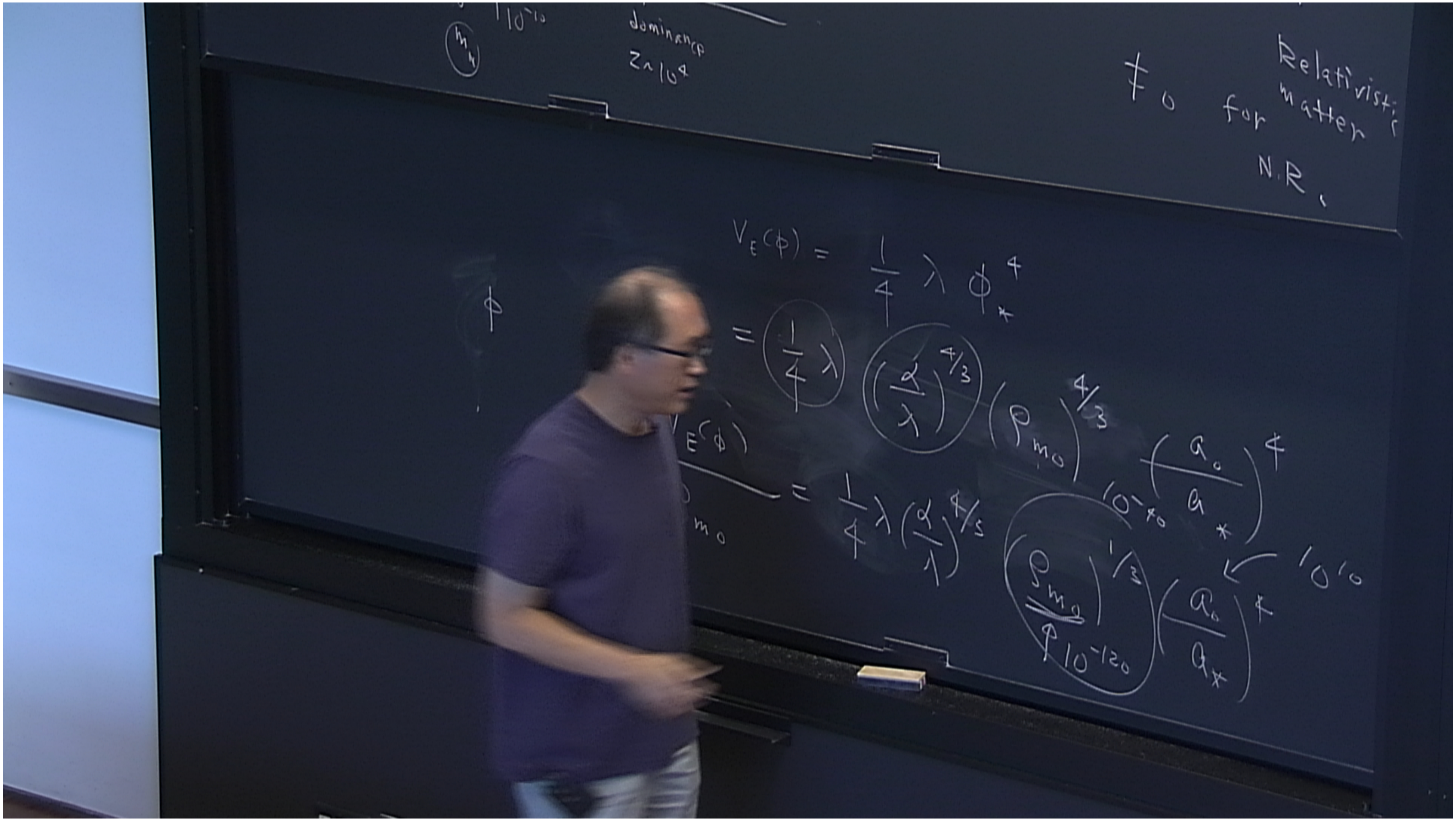

χ²(φ) = φ² − 2αφ + 1
V(φ) =
V_E = V/χ⁴
dV_E/dφ = χ'/χ ρ_m
χ ~ 1
χ' ~ −α
V_E ~ 1/4 λφ⁴
λφ_*³ = α ρ_m*
= α
φ = 0

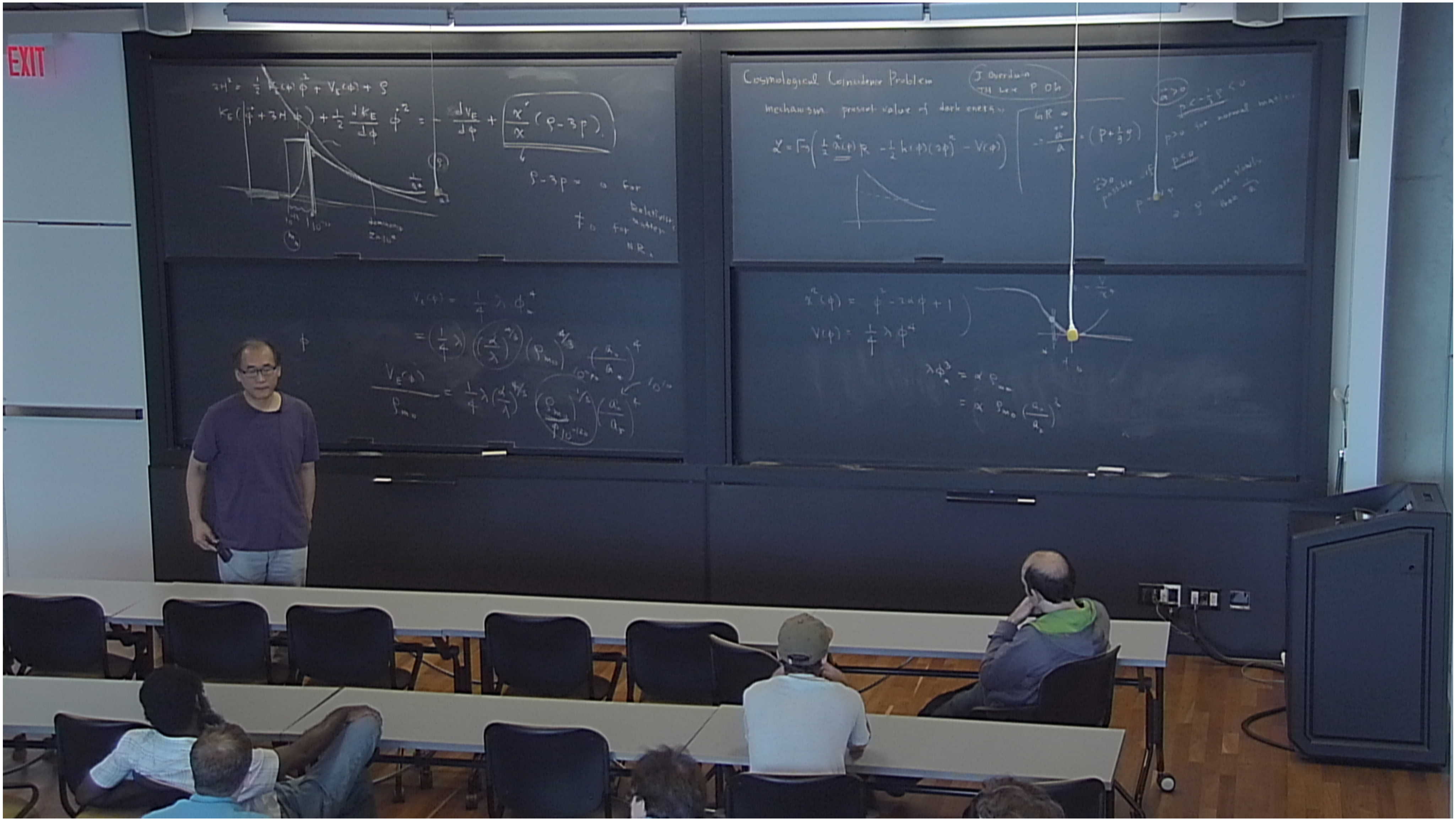

χ²(φ) = φ² − 2αφ + 1
V(φ) = 1/4
V_E = V/χ⁴
dV_E/dφ = χ'/χ ρ_m
χ ~ 1
χ' ~ −α
V_E ~ 1/4 λφ⁴
φ = 0
λφ_*³ = α ρ_m*
= α ρ_m0 (a_0/a_*)³

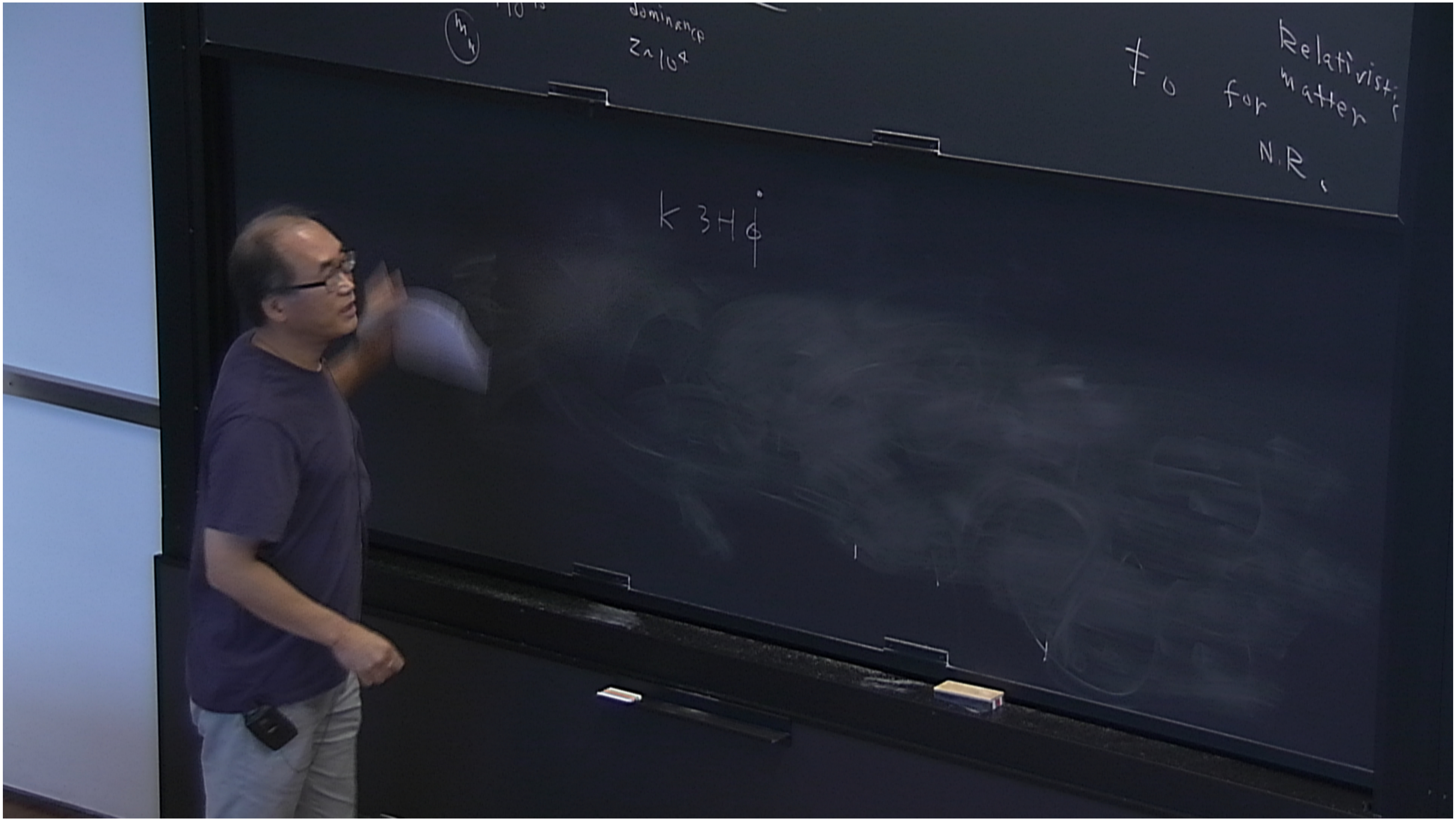

dominance
Relativistic matter
≠ 0 for
N.R.
$V_E(\phi) = \frac{1}{4}\lambda\phi_*^4$

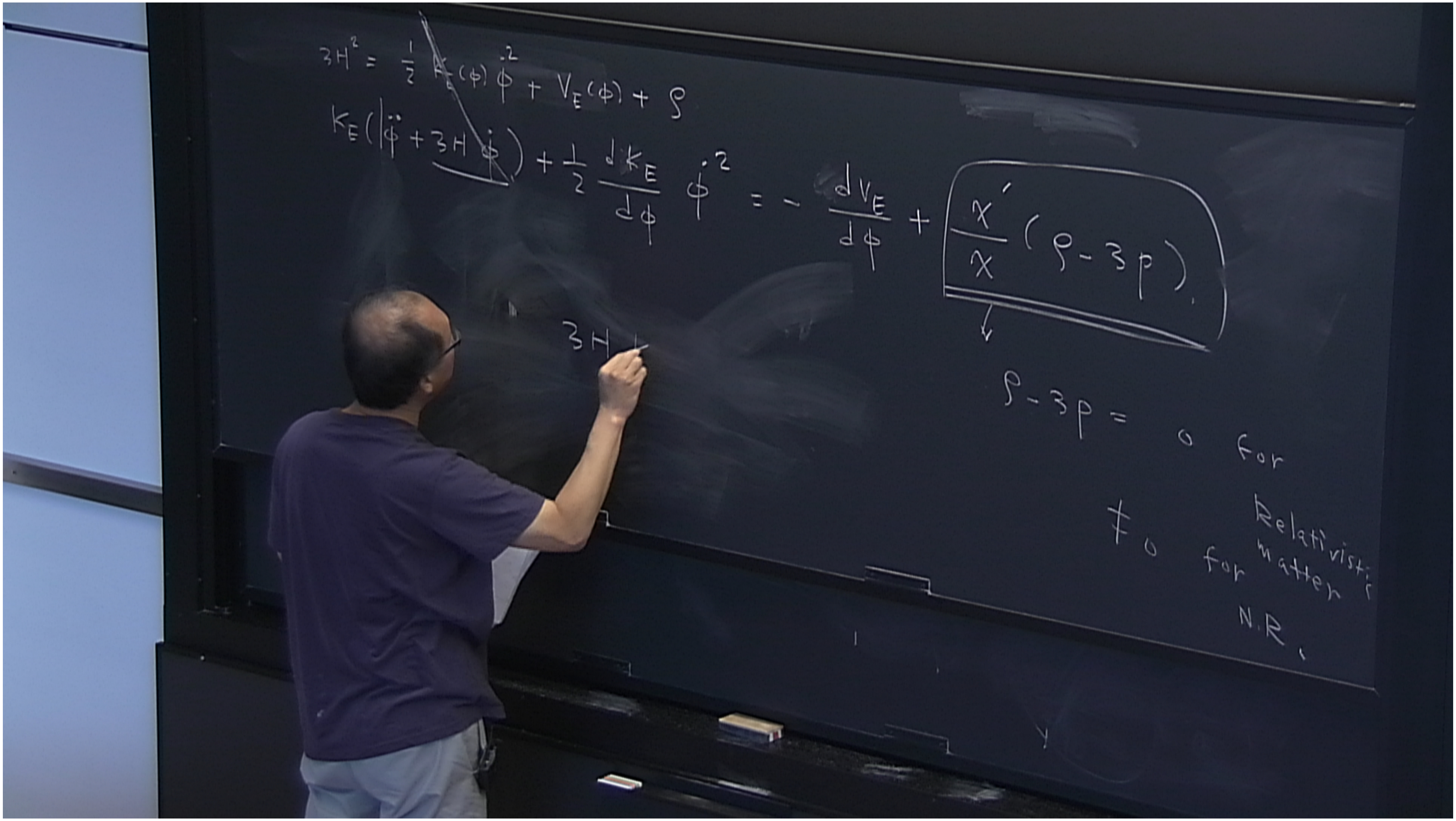

dominance
Relativistic matter
≠ 0 for
N.R.
V_E(φ) = 1/4 λ φ_*^4
= 1/4 λ (α/λ)^{4/3}
φ

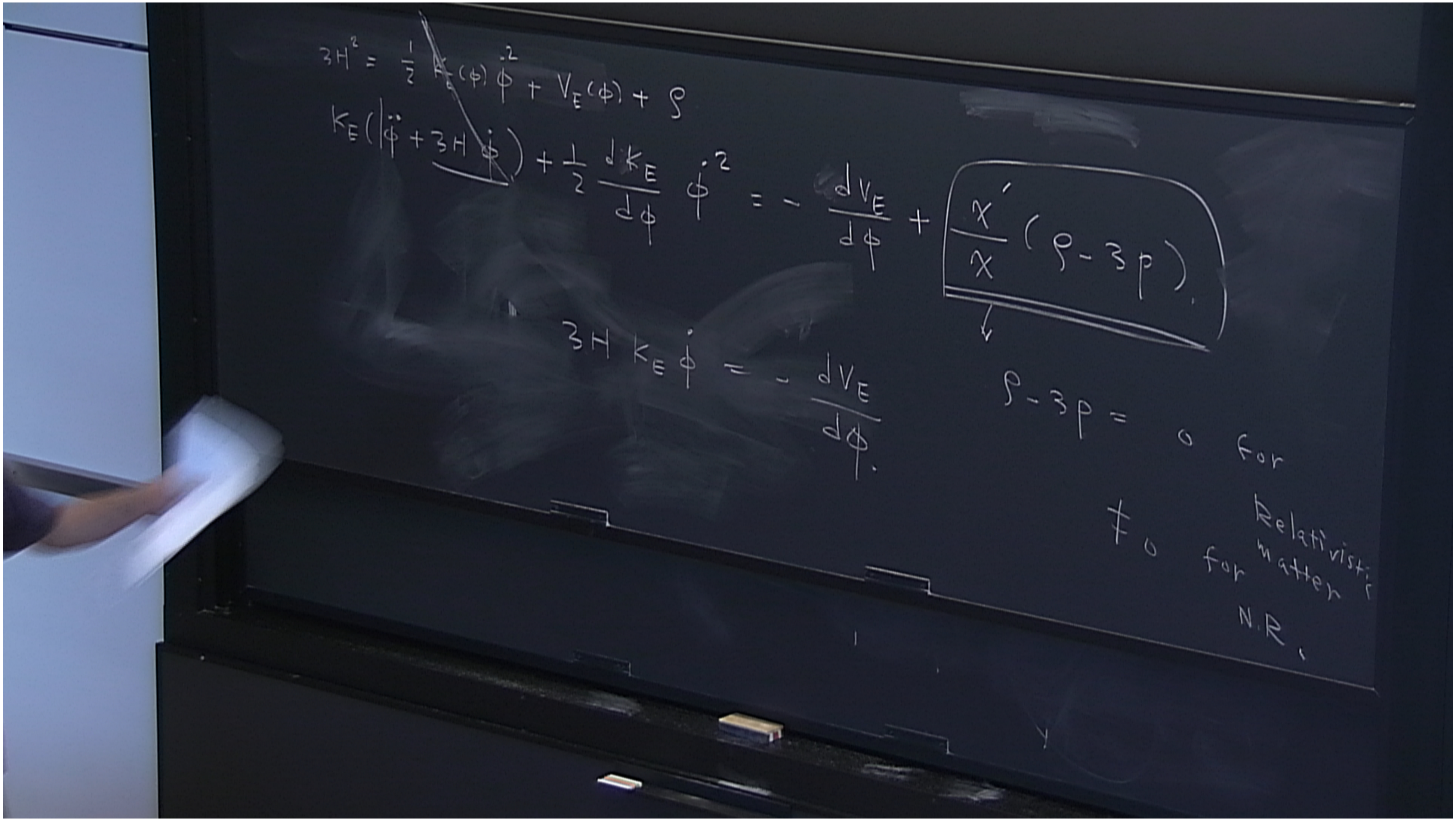

dominance
Relativistic matter
≠ 0 for N.R.
V_E(φ) = 1/4 λ φ_*^4
= (1/4 λ) (α/λ)^{4/3} (ρ_{m0})^{4/3} (a_0/a_*)^4

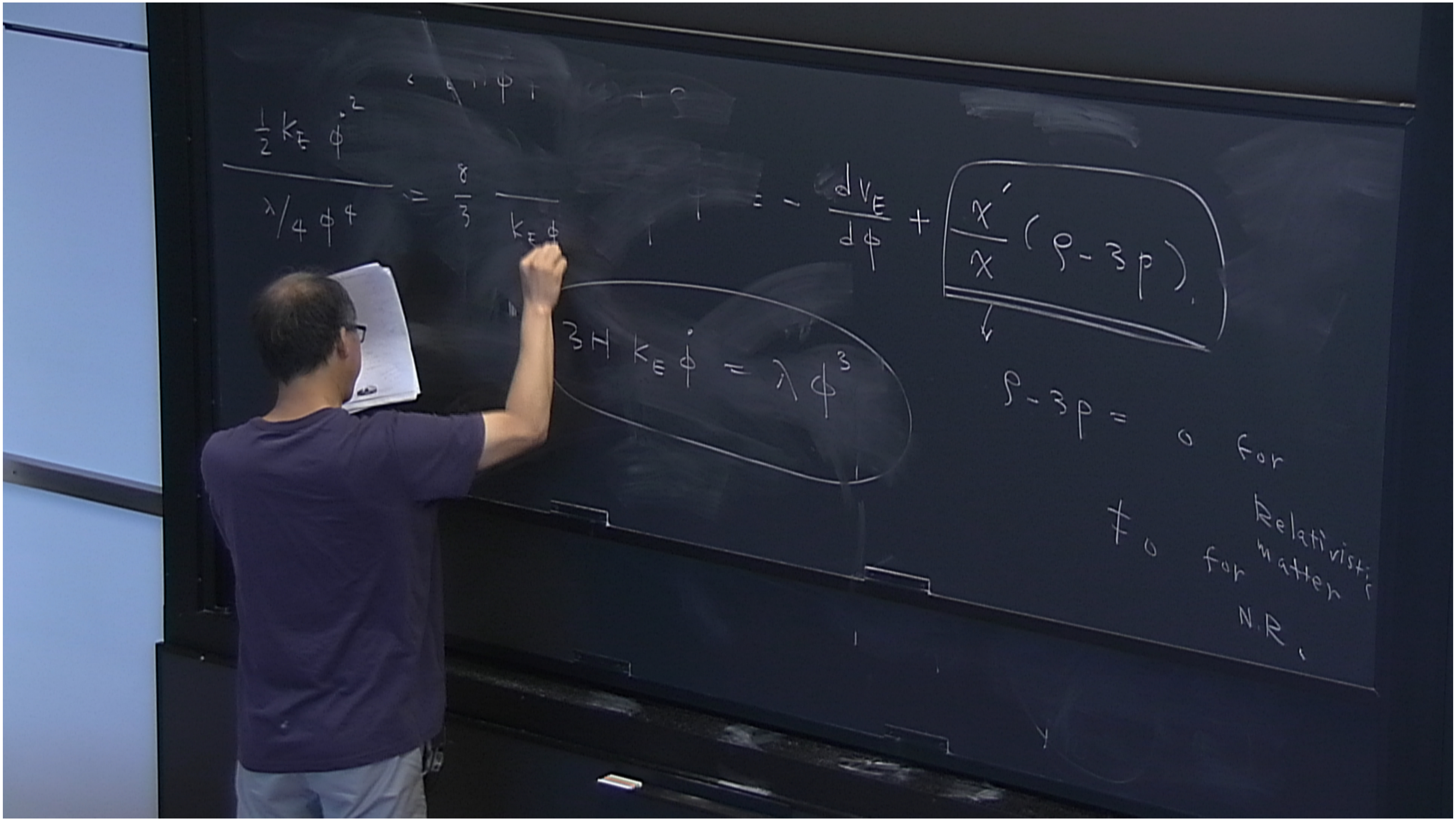

dominance
Relativistic matter
N.R.

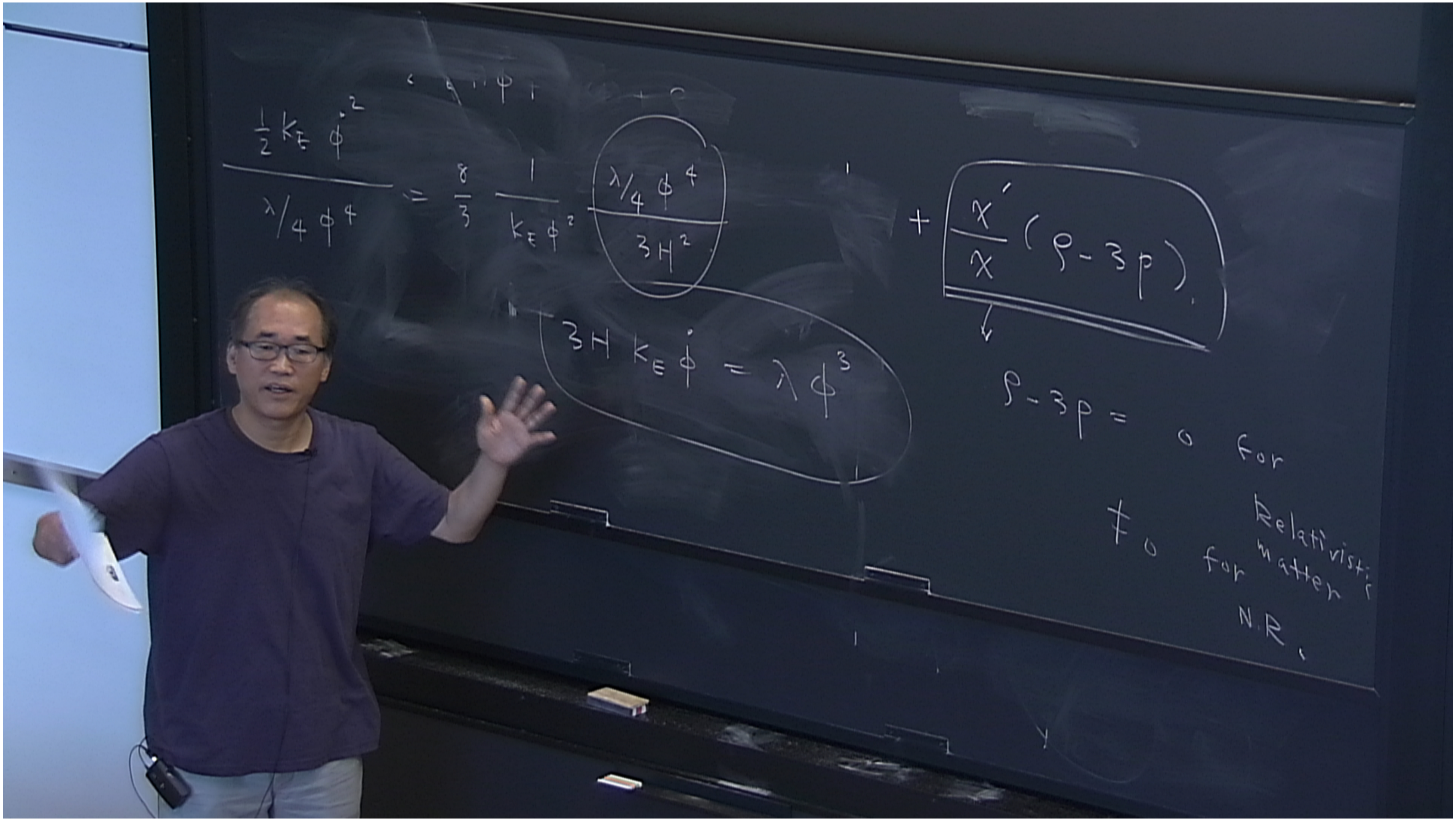

EXIT
Cosmological Coincidence Problem

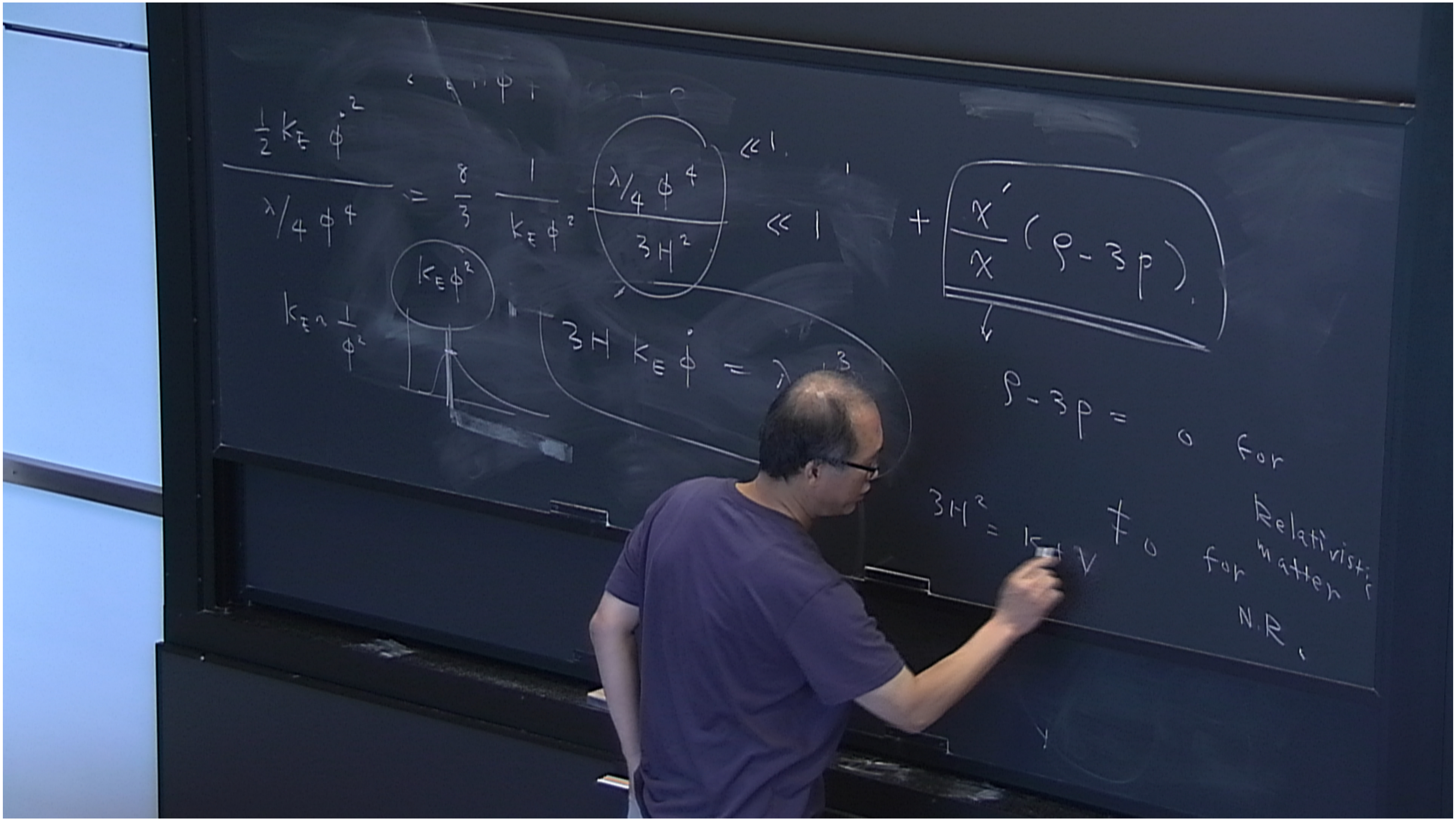

dominance
Relativistic matter
for
N.R.


3H^2 = 1/2 K_E(φ) φ̇^2 + V_E(φ) + ρ
K_E(φ̈ + 3H φ̇) + 1/2 dK_E/dφ φ̇^2 = − dV_E/dφ + χ'/χ (ρ − 3p).
3H
ρ − 3p = 0 for Relativistic matter
≠ 0 for N.R.


$3H^2 = \frac{1}{2} K_E(\phi)\dot{\phi}^2 + V_E(\phi) + \rho$
$K_E(\ddot{\phi} + 3H\dot{\phi}) + \frac{1}{2}\frac{dK_E}{d\phi}\dot{\phi}^2 = -\frac{dV_E}{d\phi} + \frac{\chi'}{\chi}(\rho - 3p).$
$3H K_E \dot{\phi} = -\frac{dV_E}{d\phi}.$
$\rho - 3p = 0$ for Relativistic matter
$\neq 0$ for N.R.


1/2 k_E φ̇^2 / λ/4 φ^4 = 8/3 ... k_E φ
= − dV_E/dφ + χ'/χ (ρ − 3p).
3H k_E φ̇ = λ φ^3
ρ − 3p = 0 for Relativistic matter
≠ 0 for N.R.


1/2 k_E φ̇² / (λ/4 φ⁴) = 8/3 · 1/(k_E φ²) · (λ/4 φ⁴)/(3H²)
+ χ'/χ (ρ - 3p)
3H k_E φ̇ = λφ³
ρ - 3p = 0 for Relativistic matter
≠ 0 for N.R.


≪ 1
+
3H²
ρ - 3p = 0 for
Relativistic matter
for
N.R.