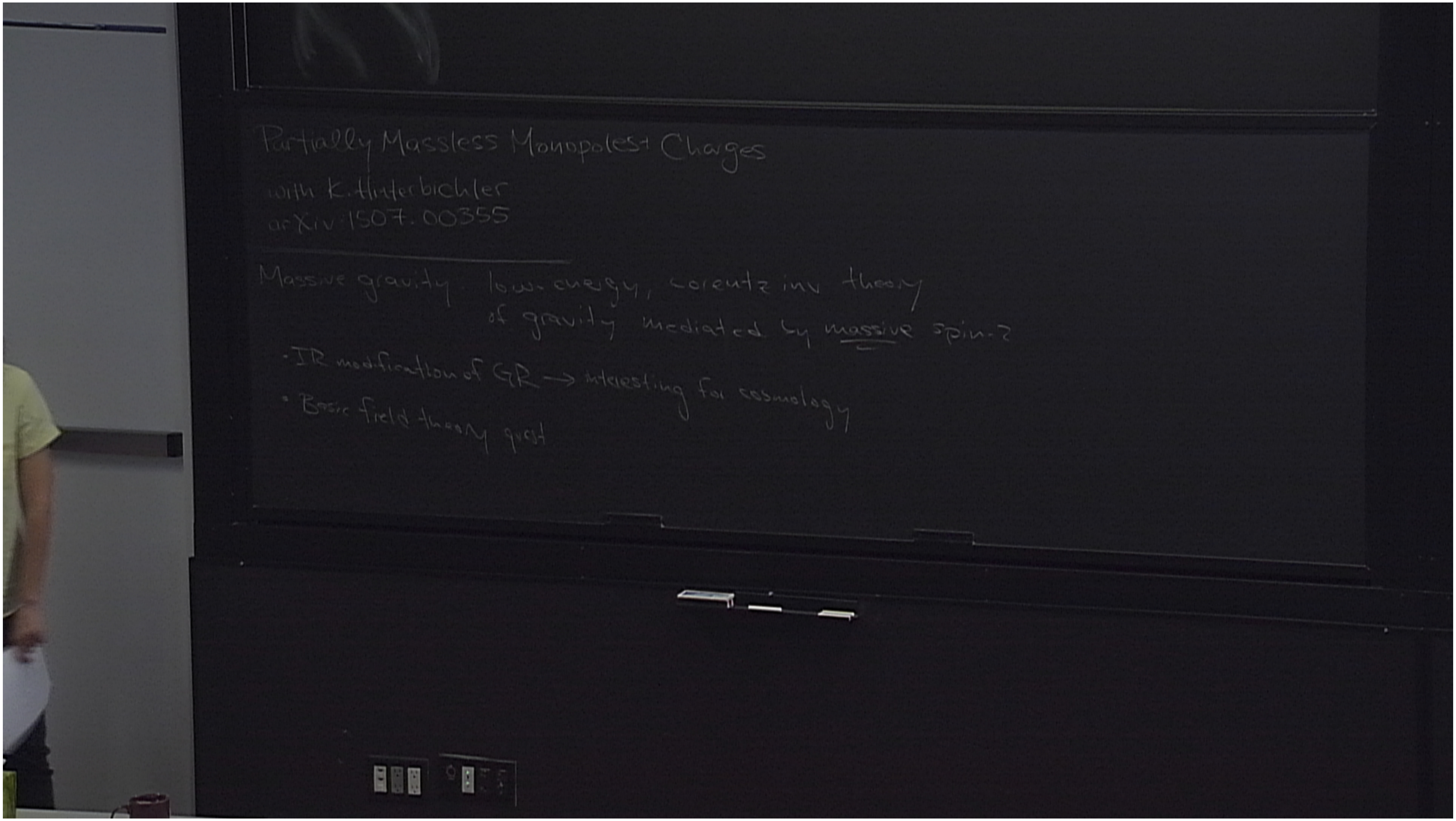
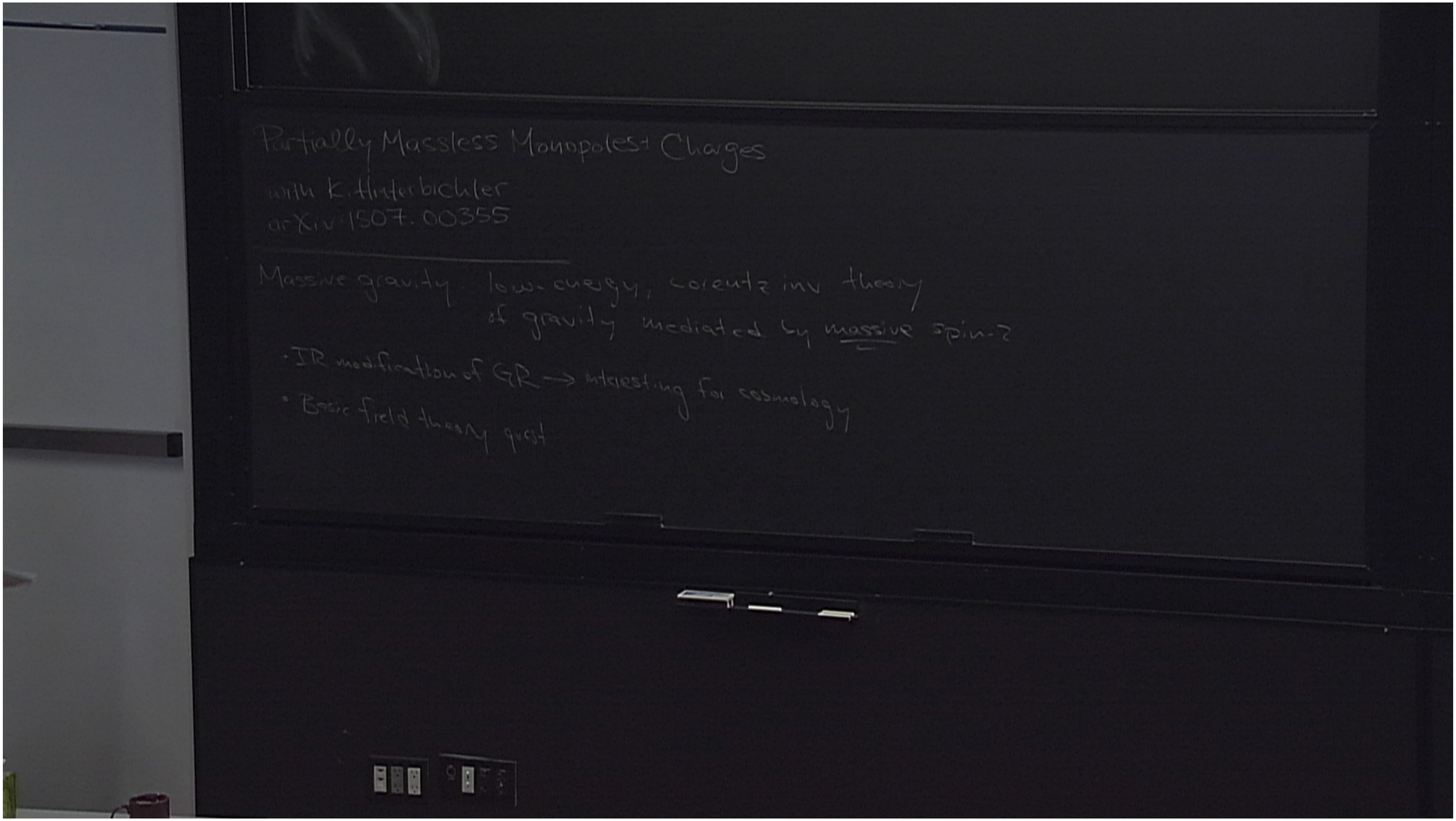
Title: Partially Massless Charges and Monopoles

Date: Sep 08, 2015 11:00 AM

URL: http://pirsa.org/15090024

Abstract: <p>In this talk Iâ€™ll discuss an exotic theory of gravity known as â€œpartially masslessâ€• gravity. The linear partially massless theory displays many features analogous to those of electromagnetism, including an electric/magnetic duality. However, the structure of gauge charges is much richer than in E&M. Iâ€™ll present the analogues of electric point charges and Dirac monopoles.</p>


Partially Massless Monopoles + Charges
with K. Hinterbichler
arXiv:1507.00355
Massive gravity: low-energy, Lorentz inv theory
of gravity mediated by massive spin-2
· IR modification of GR → interesting for cosmology
· Basic field theory quest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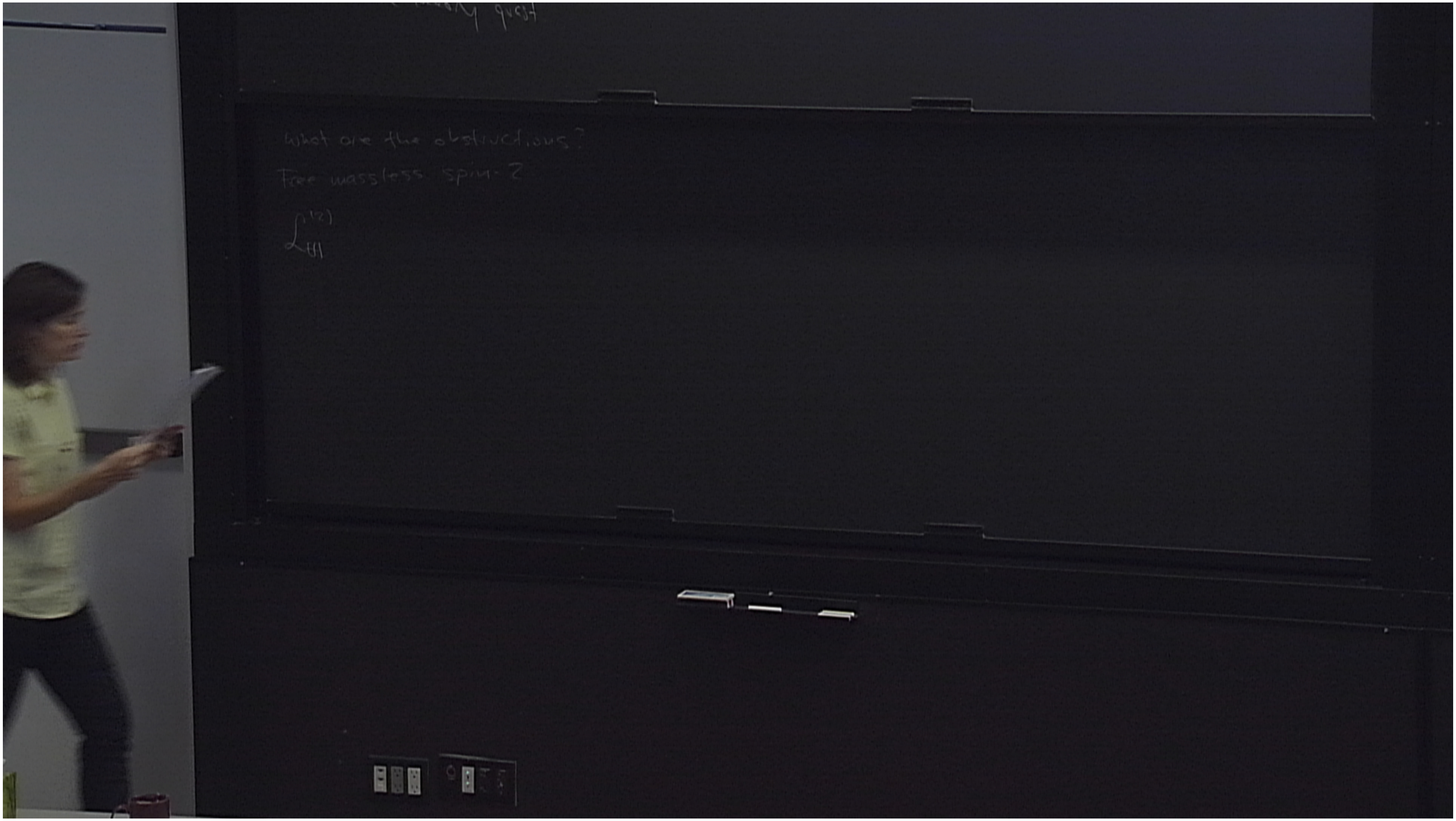
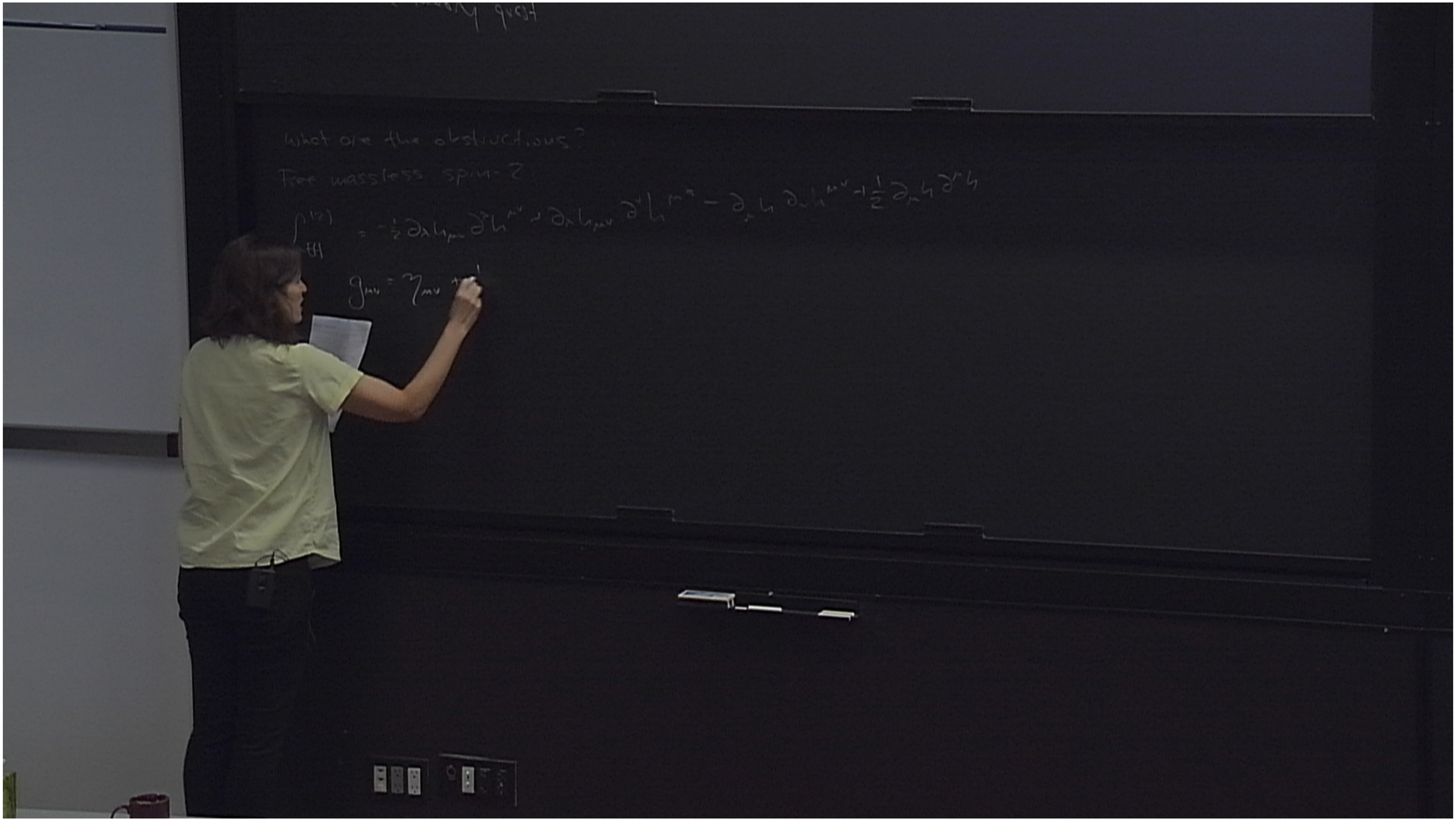
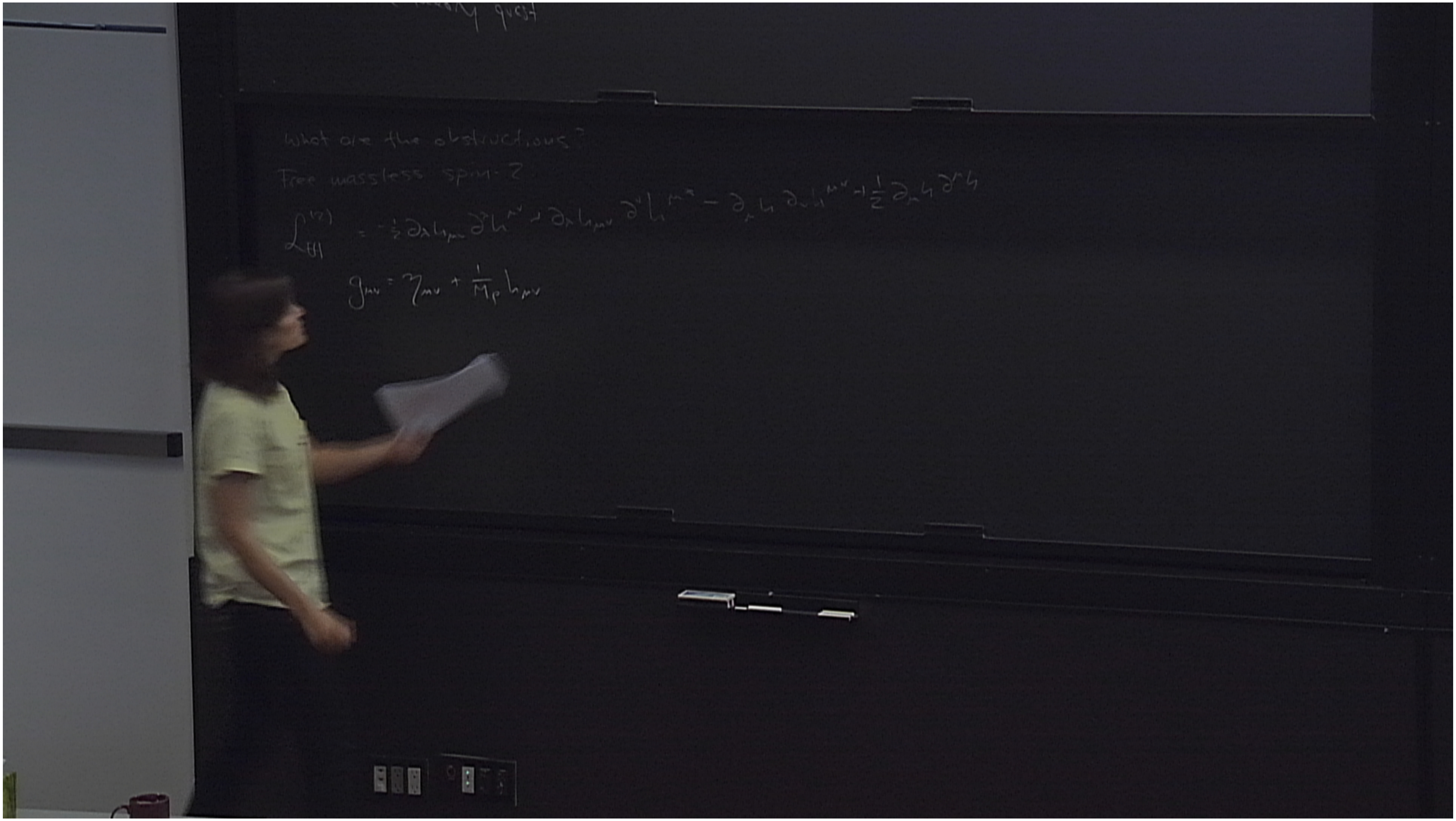

What are the obstructions?
Free massless spin-2
$\mathcal{L}^{(2)}_{FH}$


What are the obstructions?
Free massless spin-2
$\mathcal{L}^{(2)}_{EH} = -\frac{1}{2}\partial_\lambda h_{\mu\nu}\partial^\lambda h^{\mu\nu} + \partial_\lambda h_{\mu\nu}\partial^\nu h^{\mu\lambda} - \partial_\mu h\,\partial_\nu h^{\mu\nu} + \frac{1}{2}\partial_\mu h\,\partial^\mu h$
$g_{\mu\nu} = \eta_{\mu\nu} +$



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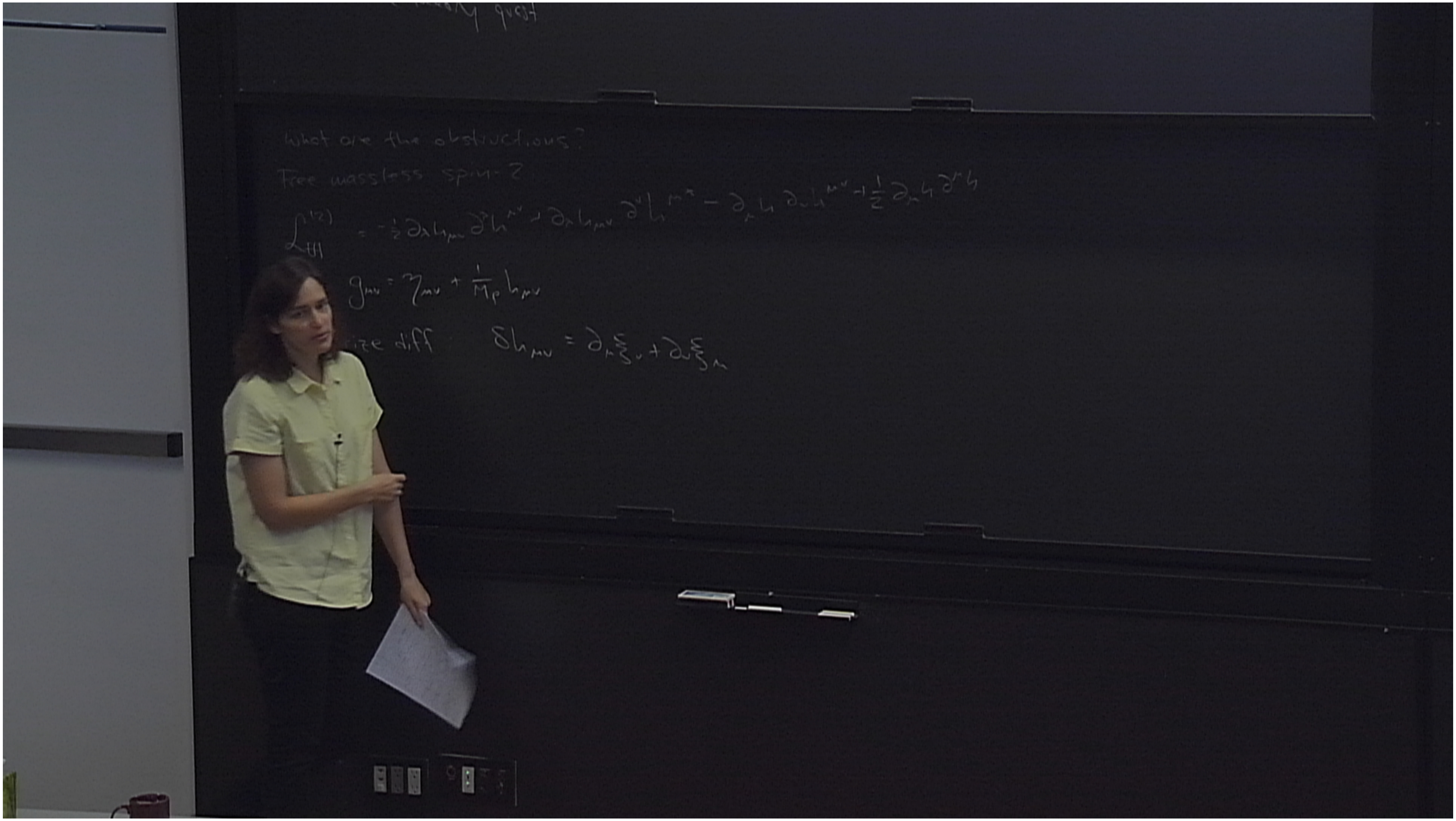
$g_{\mu\nu} = \eta_{\mu\nu} + \frac{1}{M_p} h_{\mu\nu}$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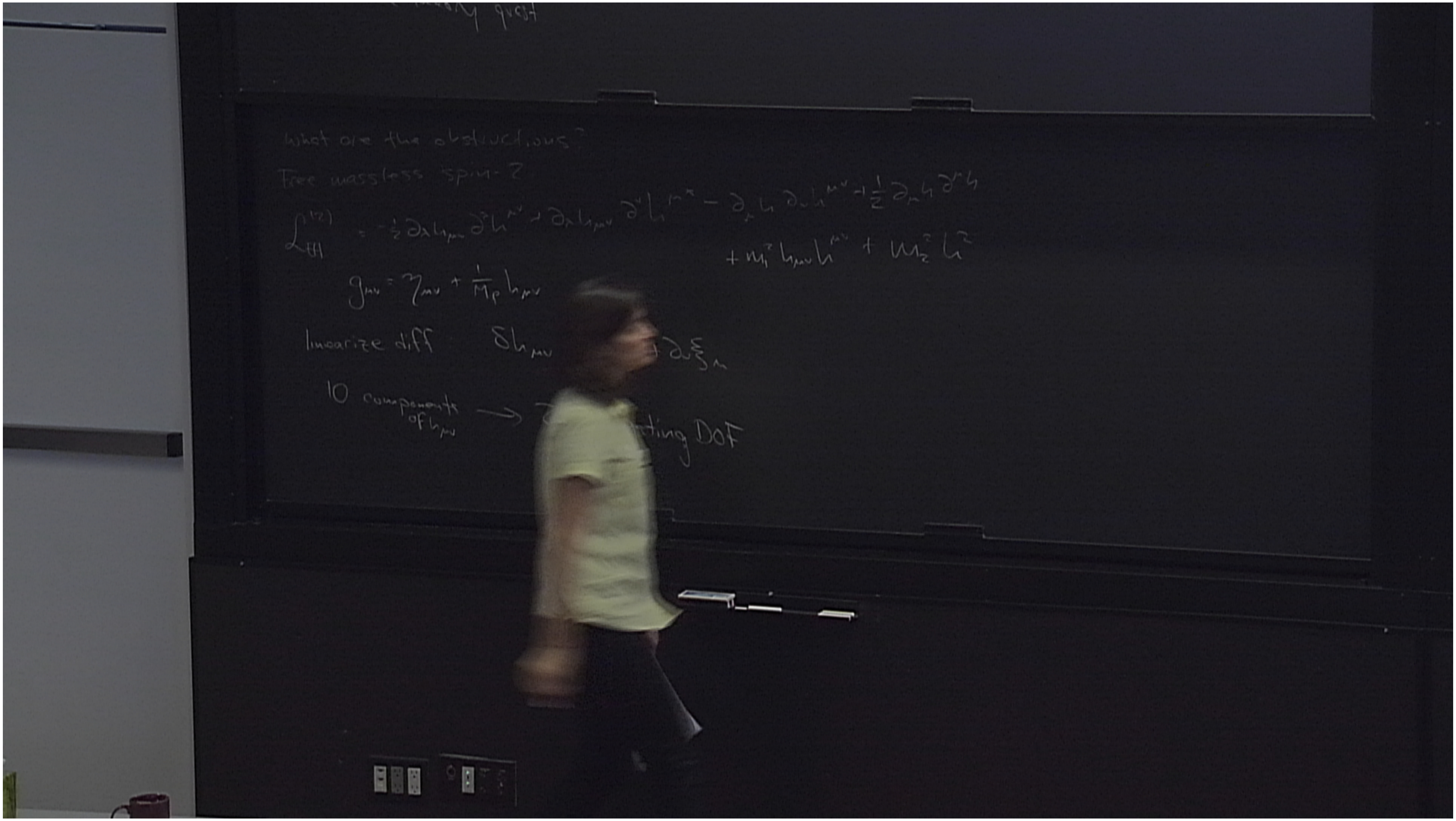
ize diff: $\delta h_{\mu\nu} = \partial_\mu \xi_\nu + \partial_\nu \xi_\mu$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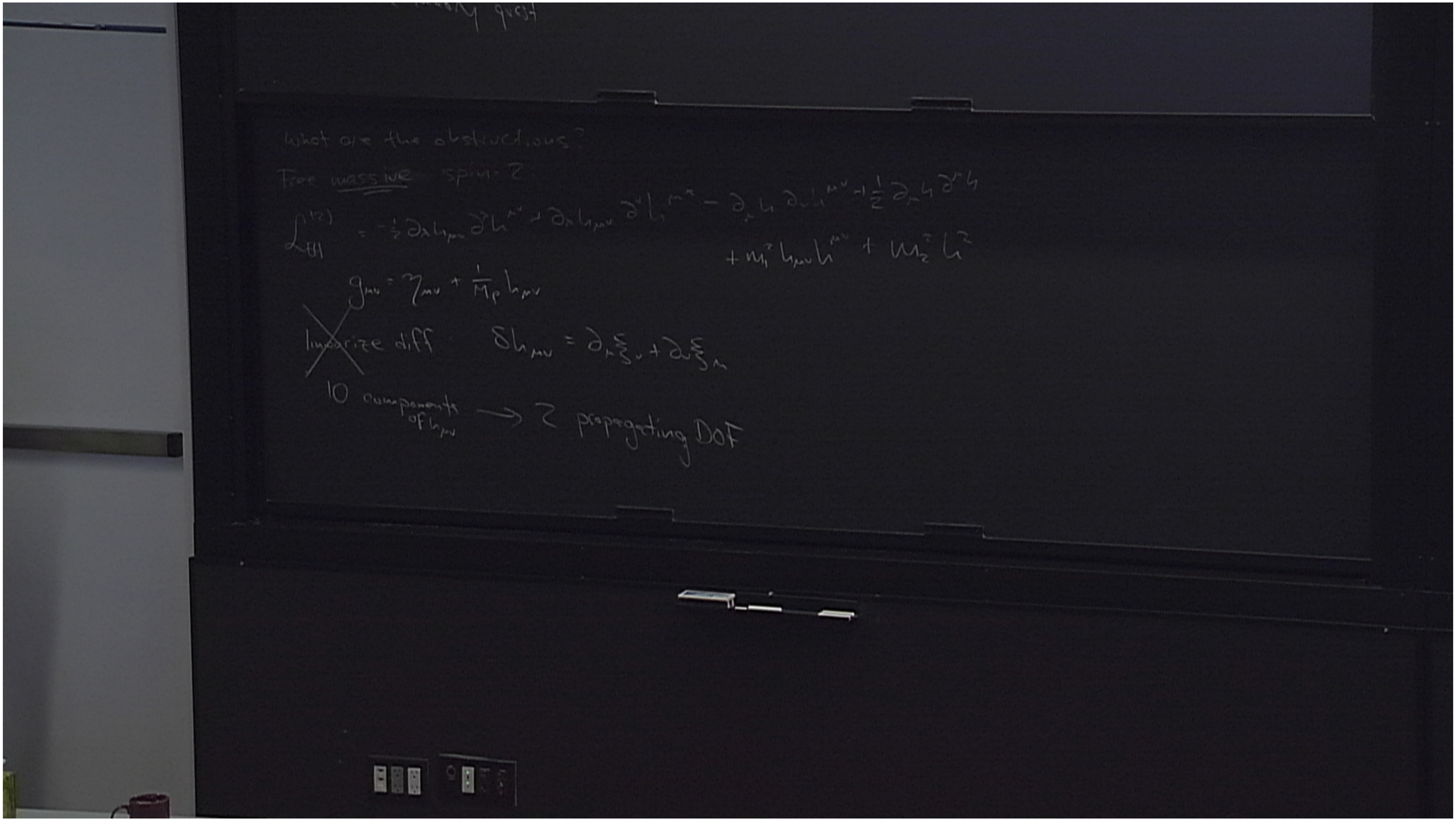
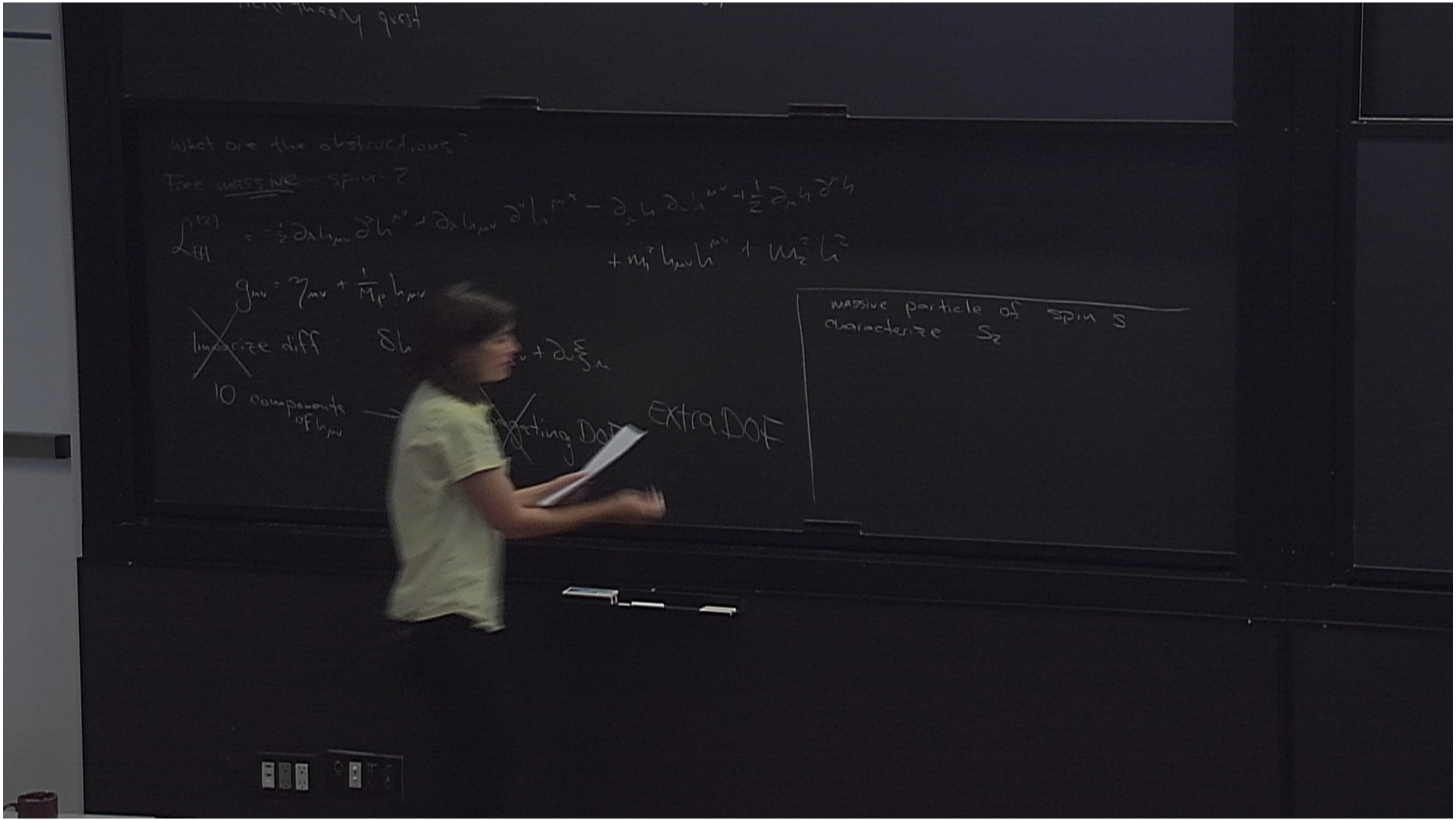
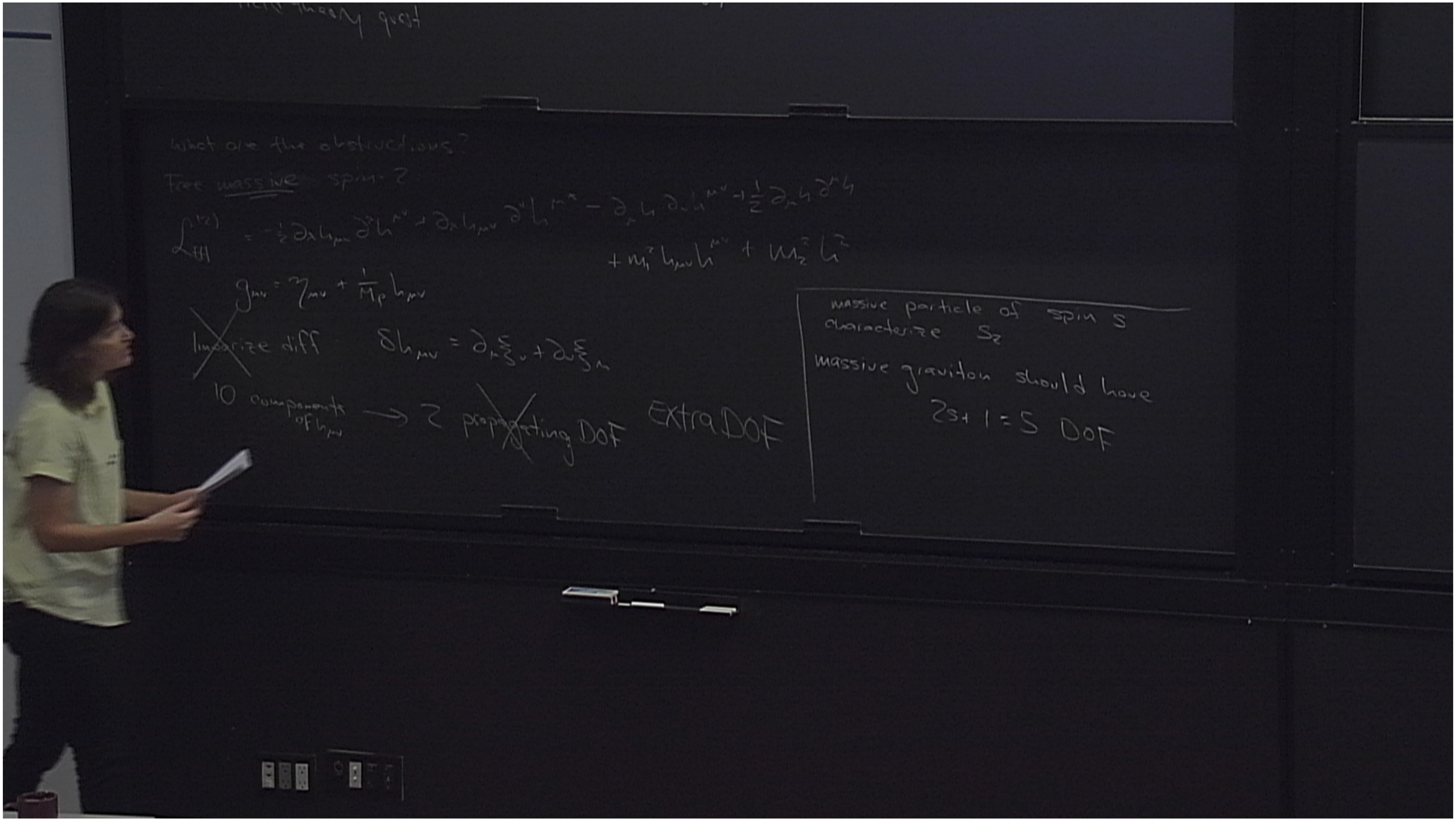
Free massless spin-2
linearize diff
10 components of h
DOF


What are the obstructions?
Free massive spin-2
10 components of h
2 propagating DOF


what are the obstructions?
Free massive spin-2
linearize diff
10 components of h
Extra DOF
massive particle of spin s
characterize Sz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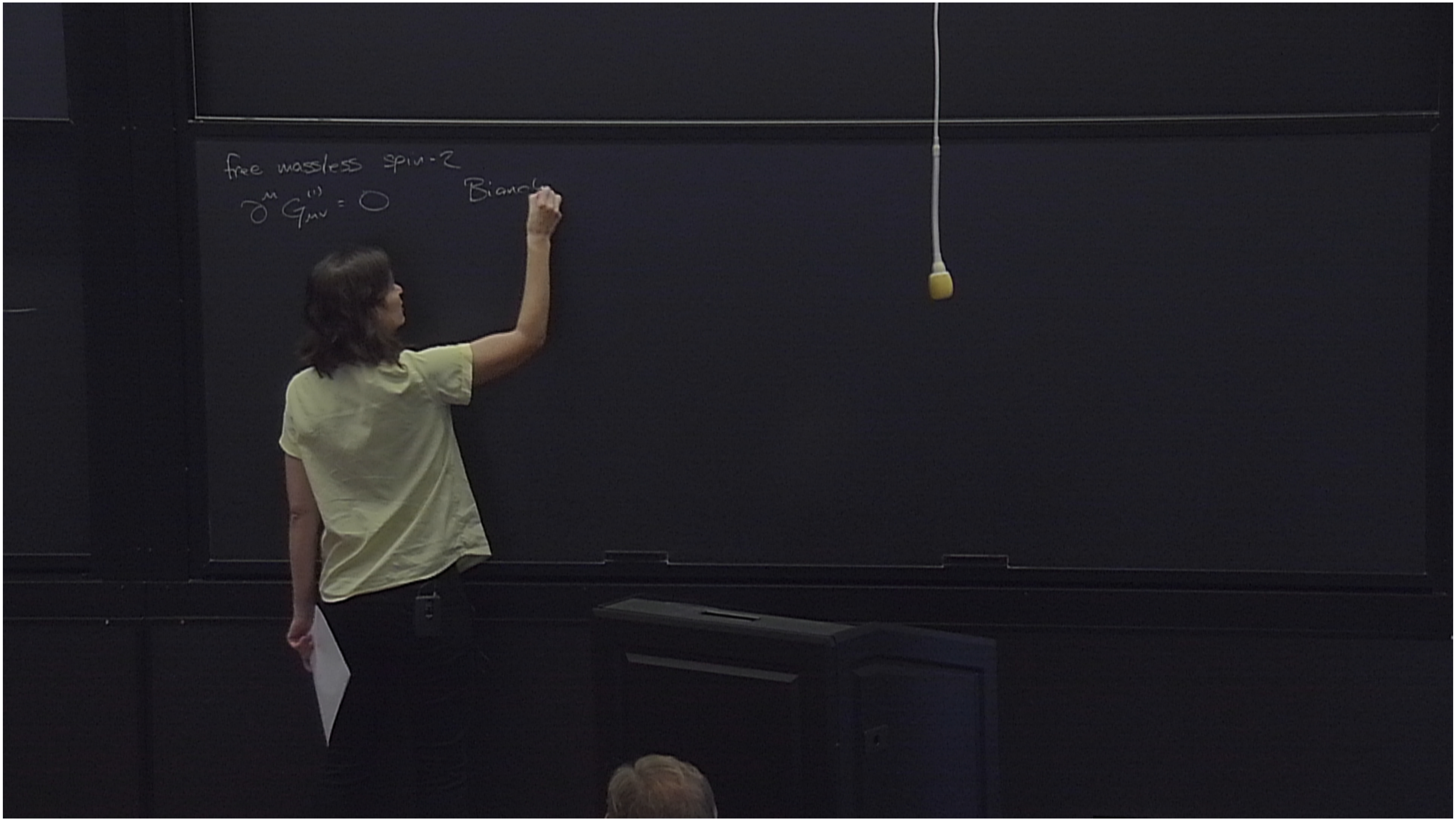
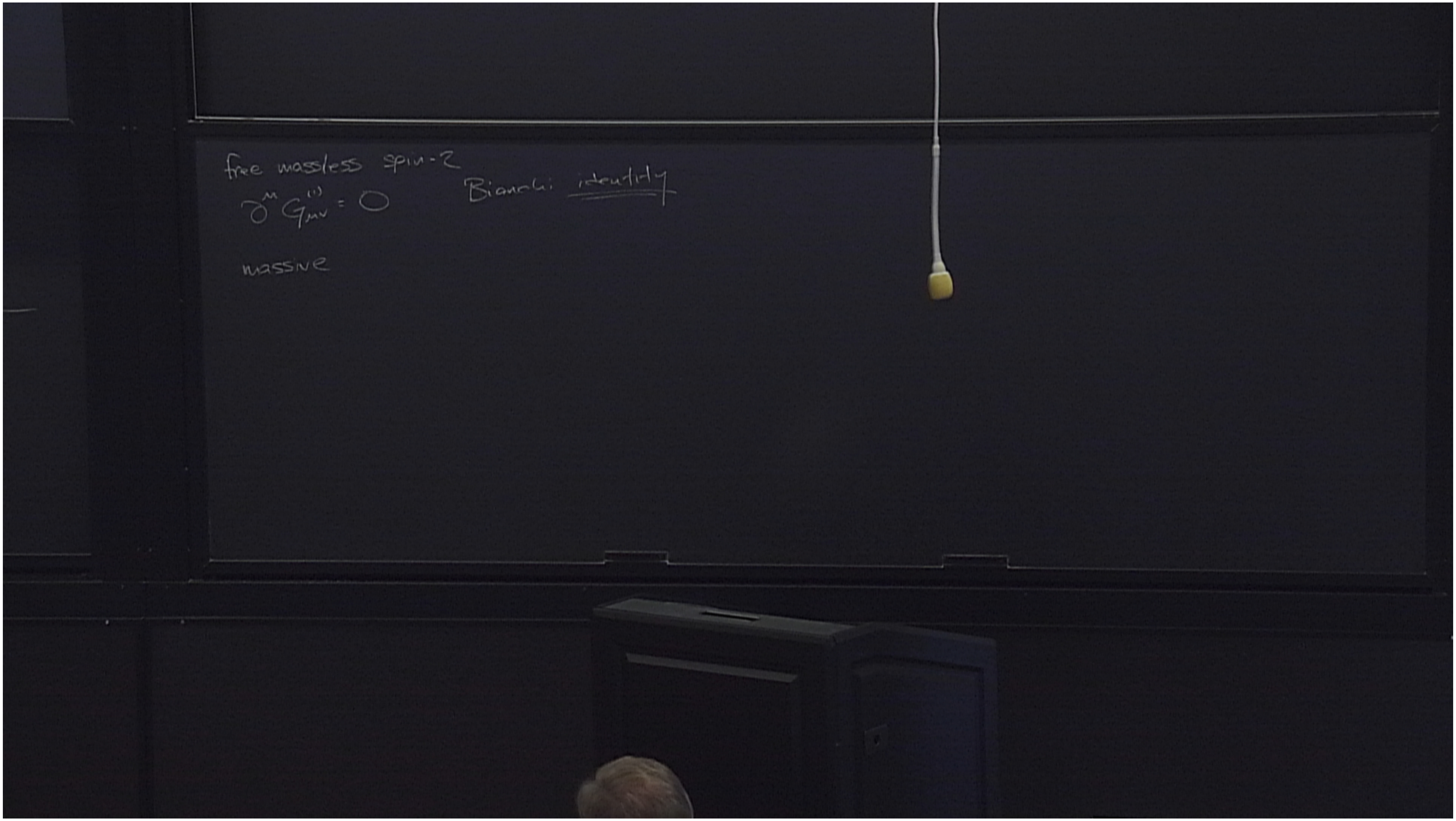
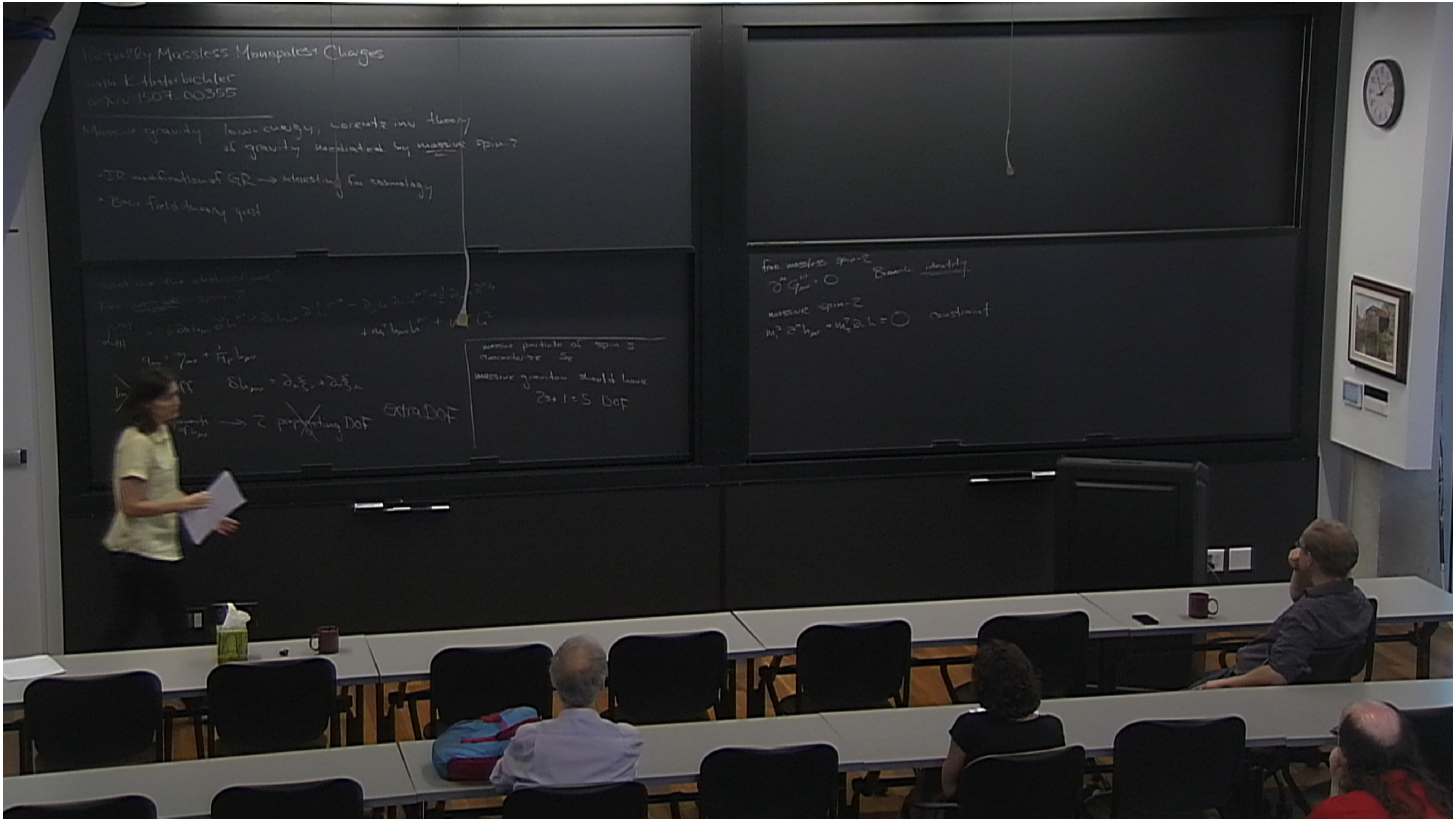
Free massive spin-2
massive particle of spin s
characterize Sz
massive graviton should have
2s+1 = 5 DOF
Extra DOF


free massless spin-2
$\partial^\mu G^{(1)}_{\mu\nu} = 0$
Bianc


free massless spin-2
∂^μ G^(1)_μν = 0
Bianchi identity
massive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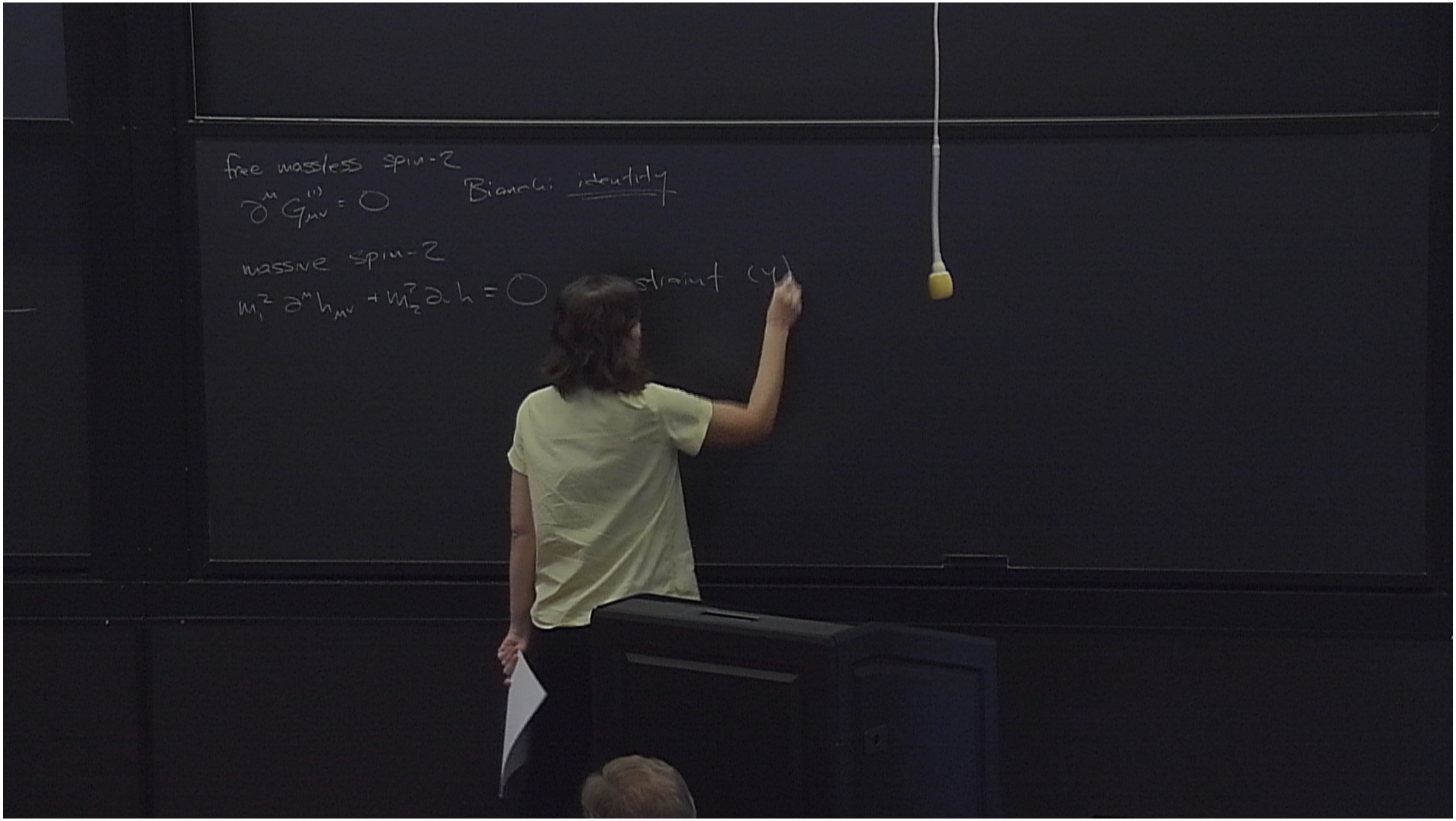
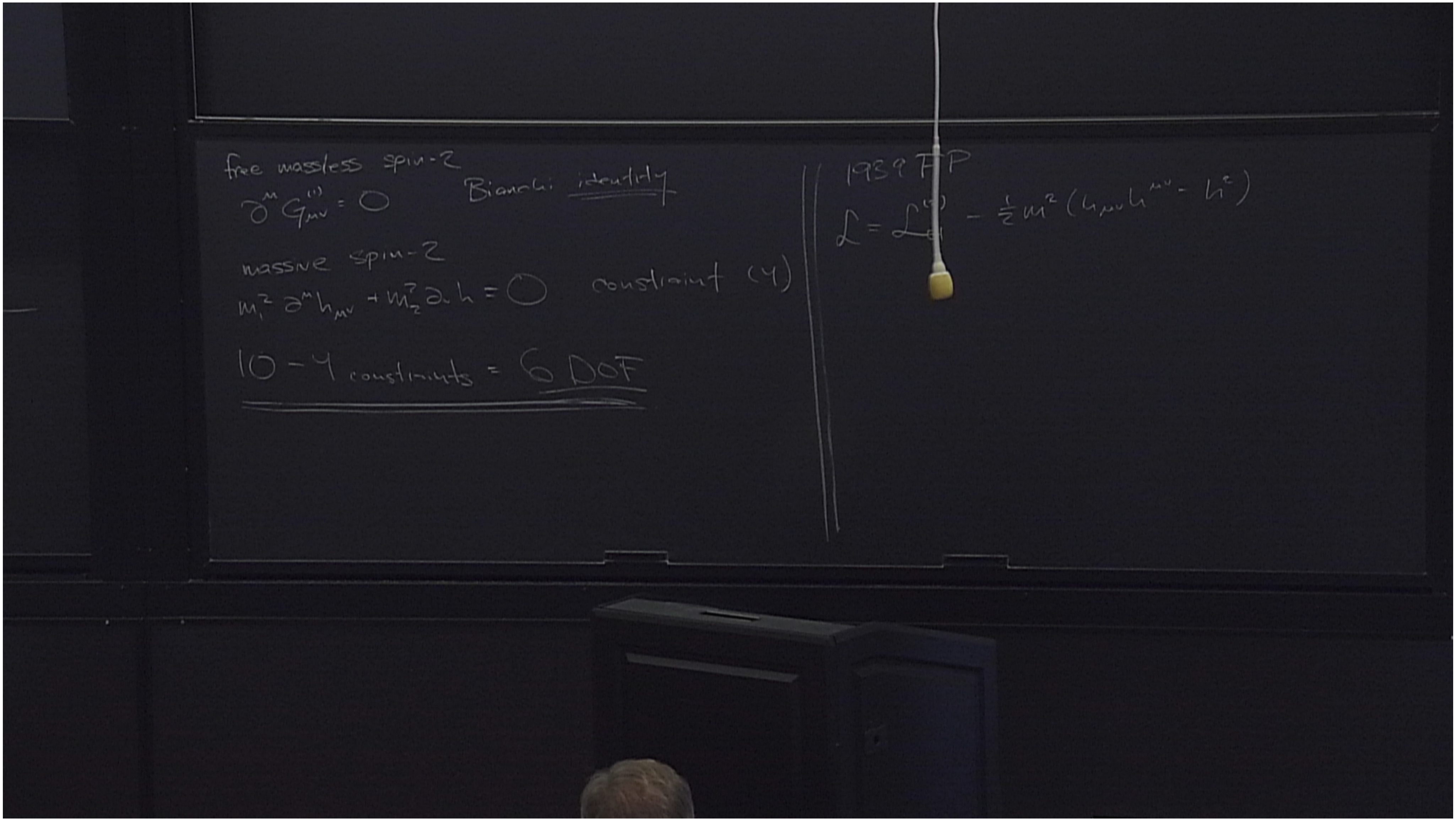
free massless spin-2
Bianchi identity
massive spin-2
constraint


free massless spin-2
∂^μ G^(1)_μν = 0
Bianchi: identity
massive spin-2
m_1^2 ∂^μ h_μν + m_2^2 ∂_ν h = 0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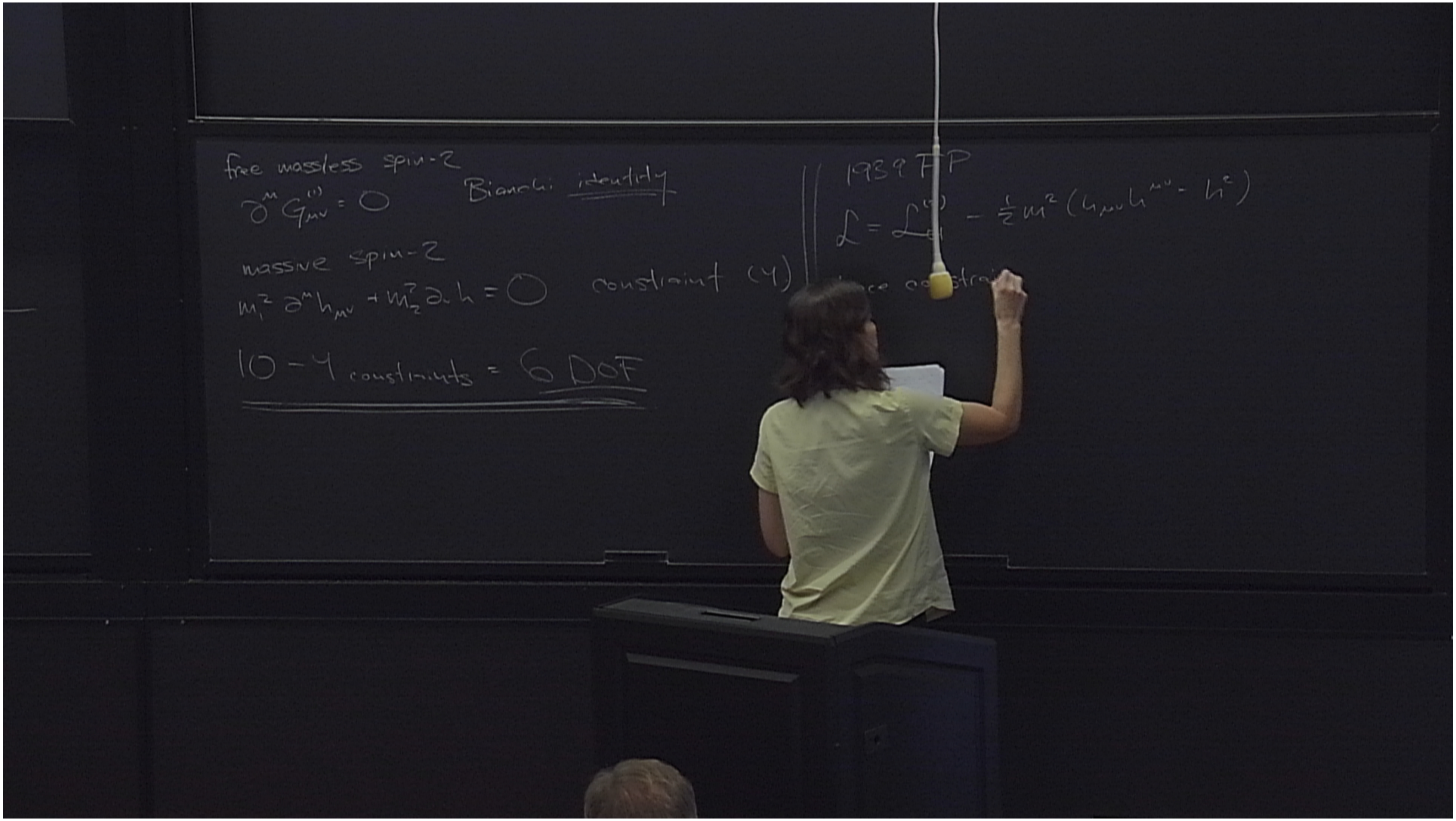
massive spin-2
m_1^2 ∂^μ h_μν + m_2^2 ∂_ν h = 0
constraint (4)
10 − 4 constraints = 6 DOF
1939 FP
L = L^(1) − ½ m^2 (h_μν h^μν − h^2)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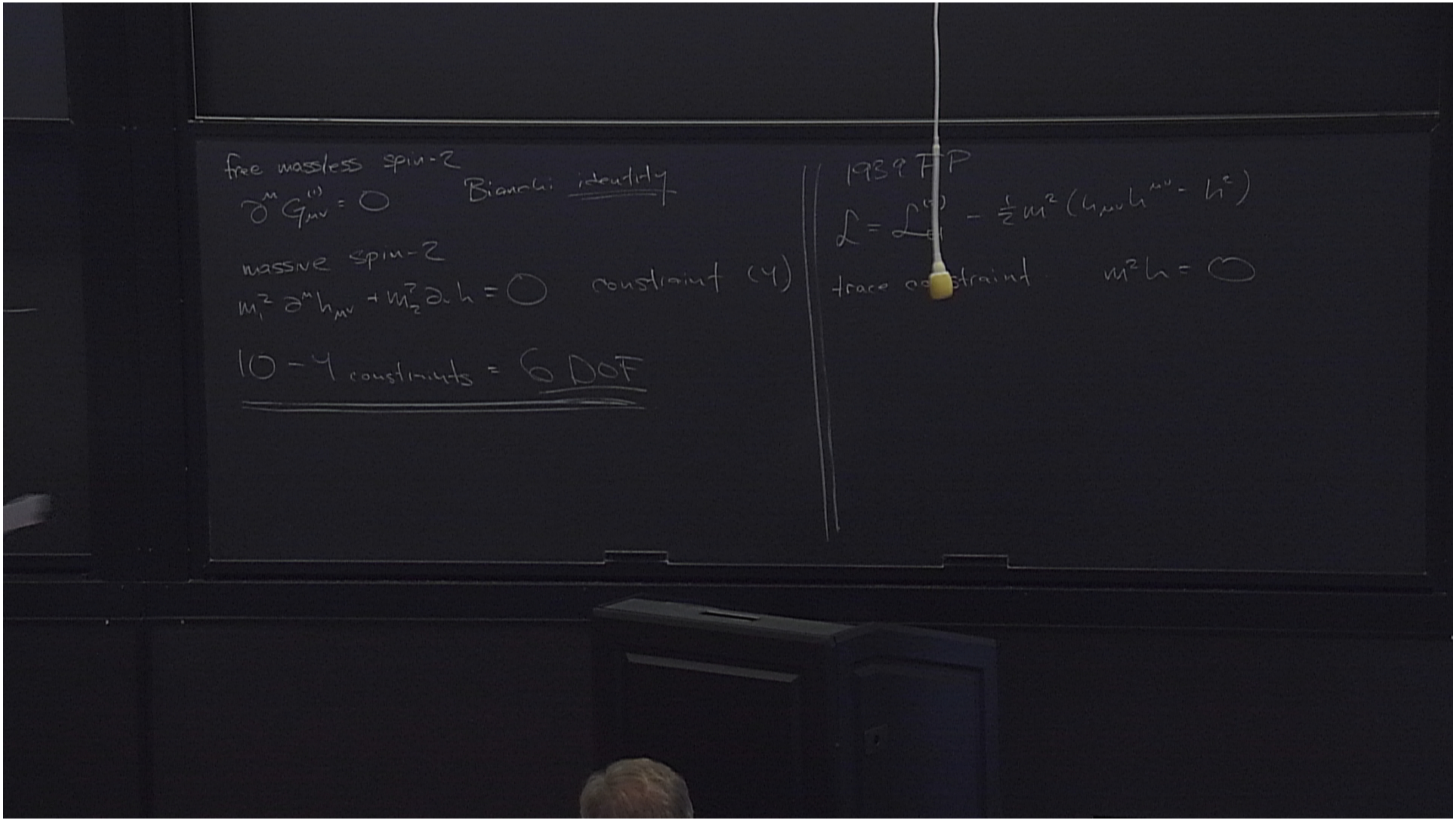
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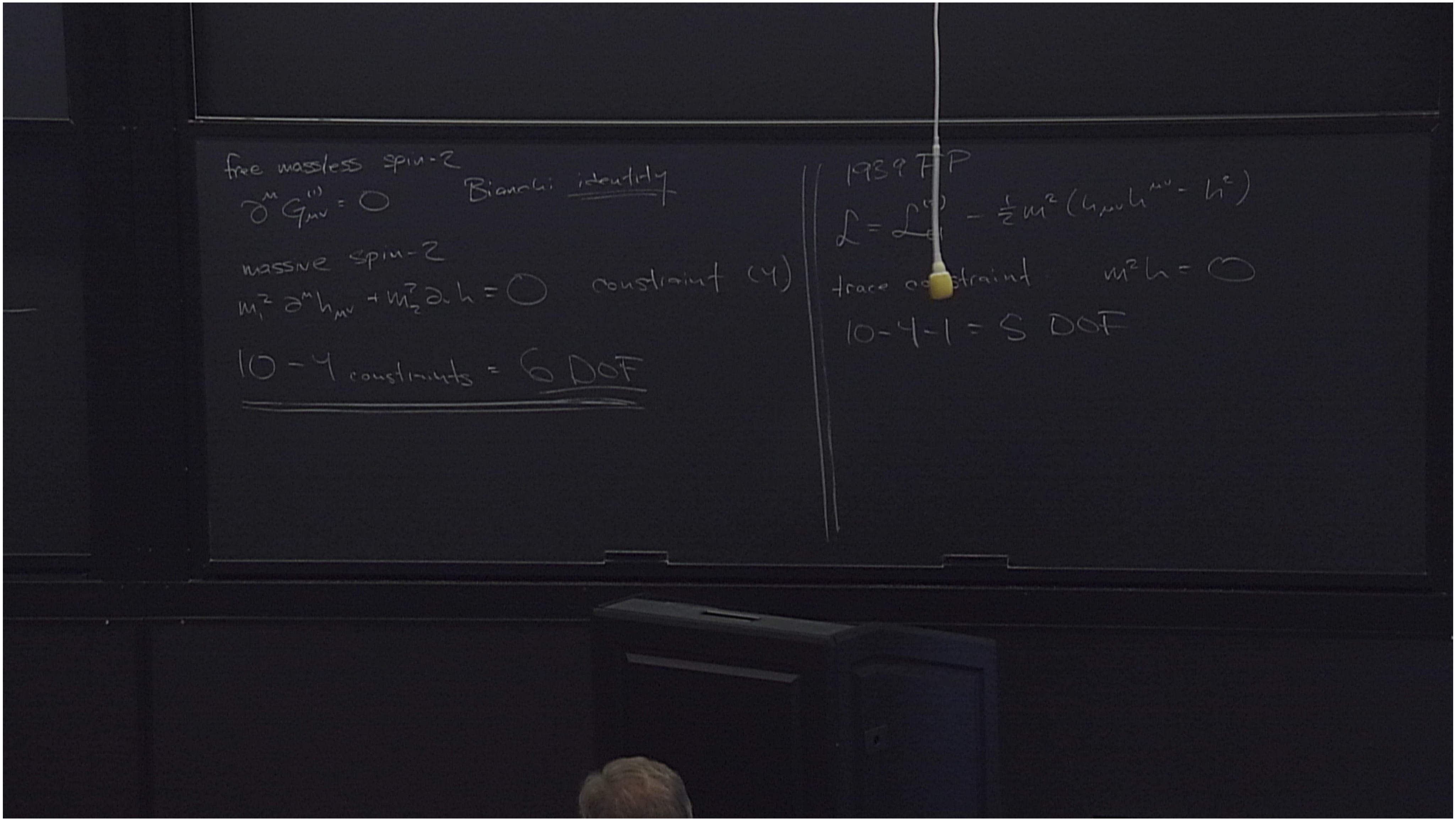
trace constraint
m^2 h = 0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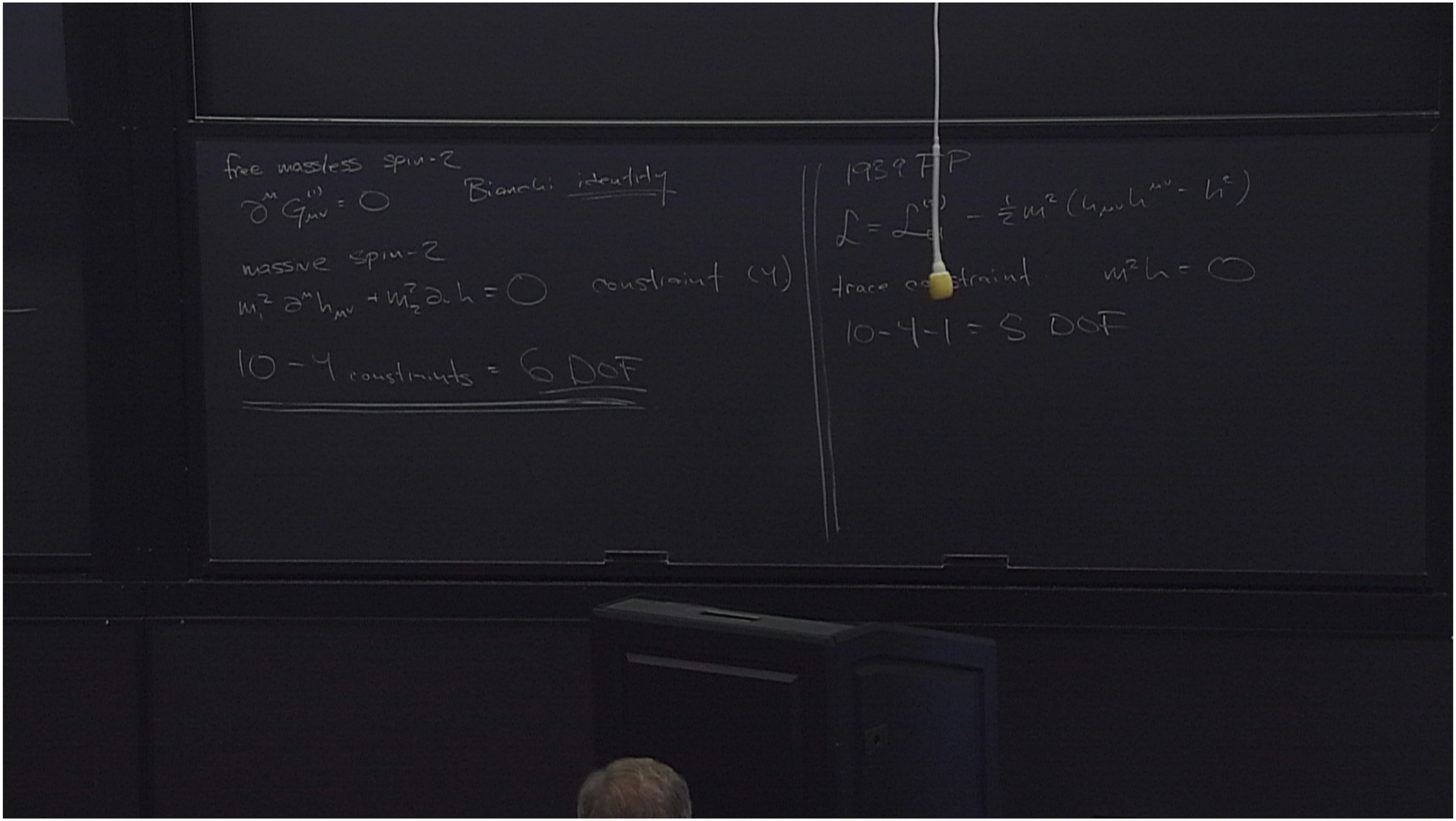
$m^2 h = 0$
10 − 4 − 1 = 5 DOF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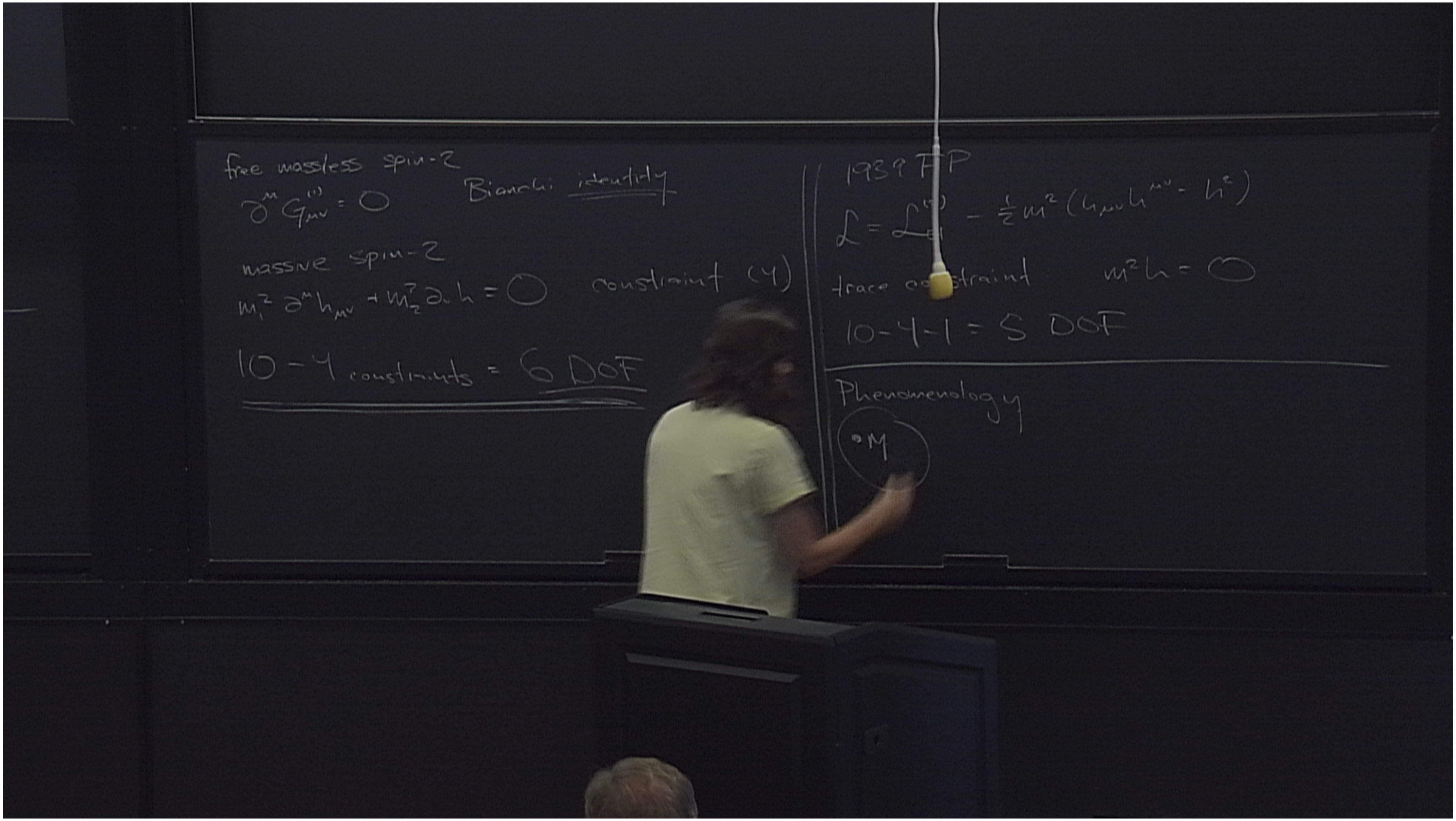
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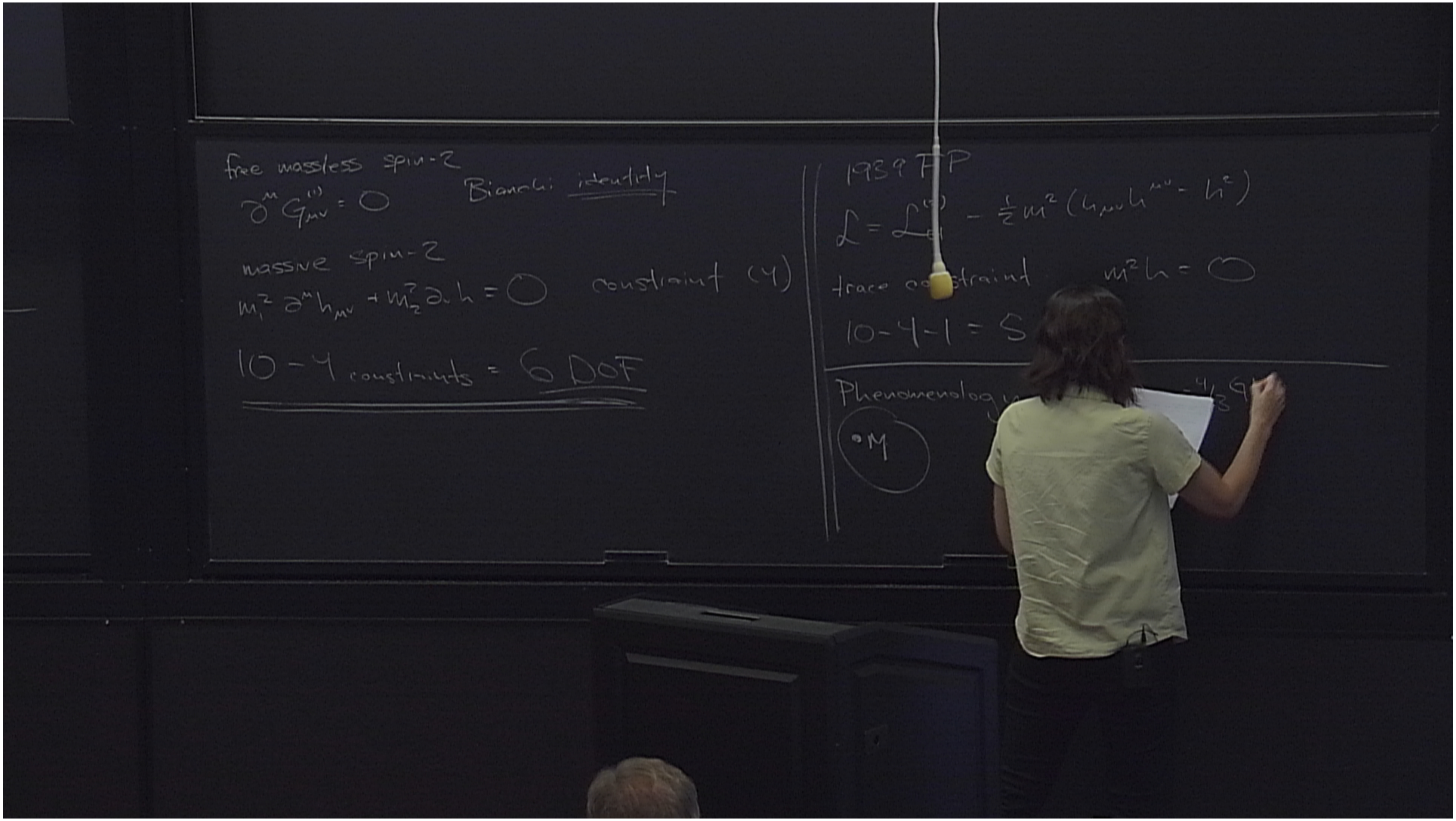
Phenomenology
• M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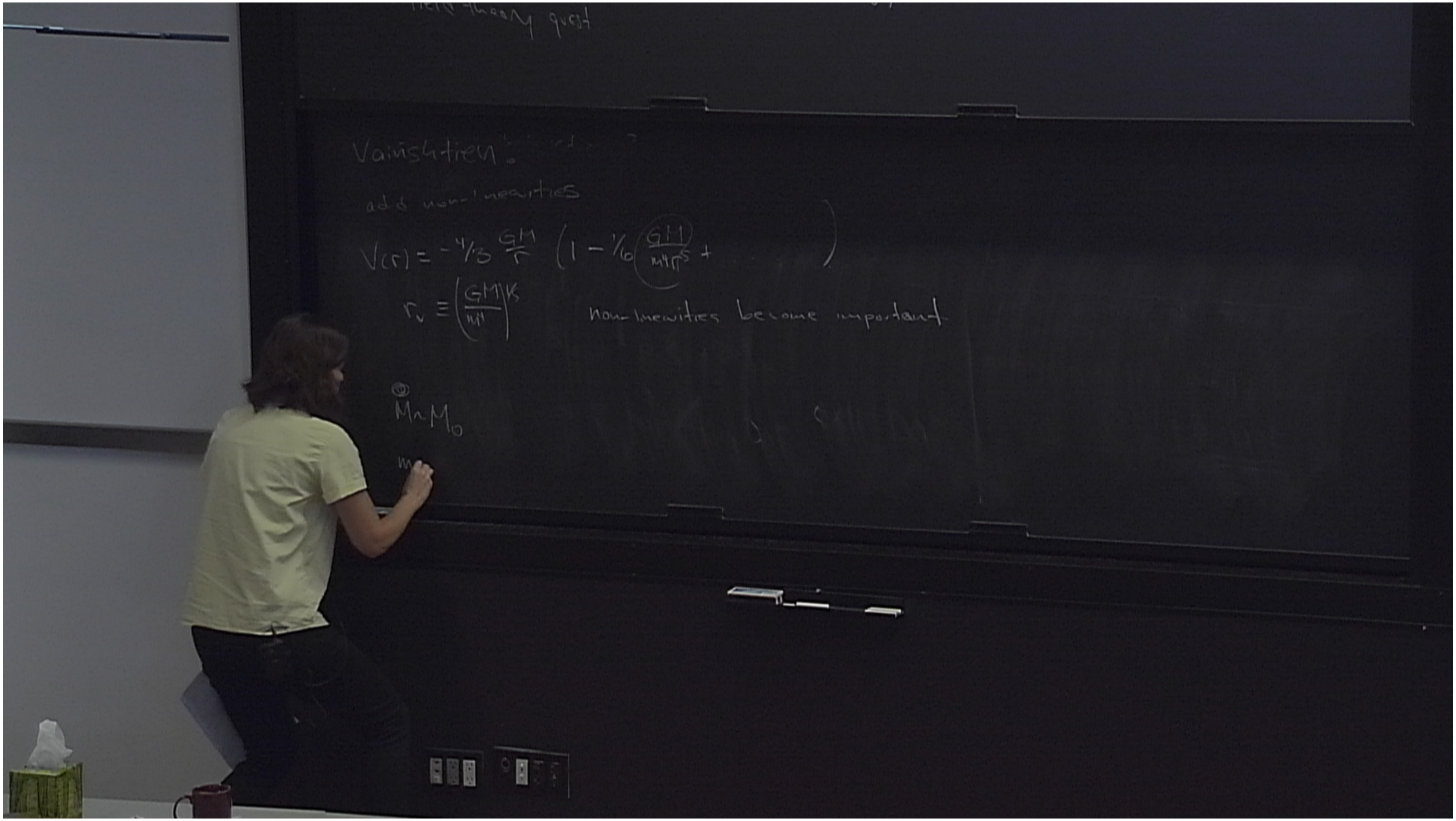
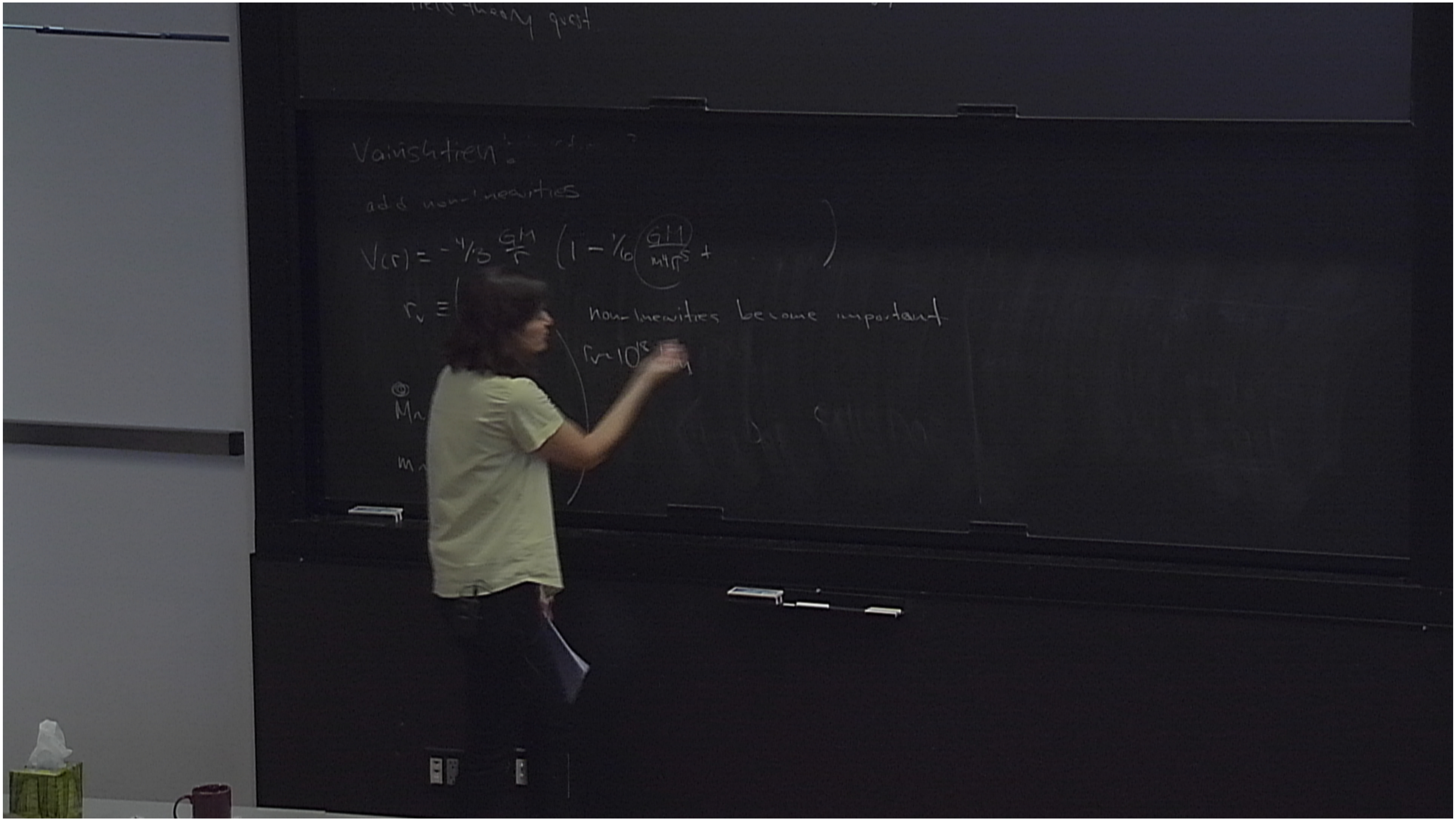
Phenomenology


Vainshtein:
add non-linearities
V(r) = -4/3 GM/r (1 - 1/6 (GM/m⁴r⁵) +
r_V ≡ (GM/m⁴)^{1/5}
non-linearities become important
M ~ M_☉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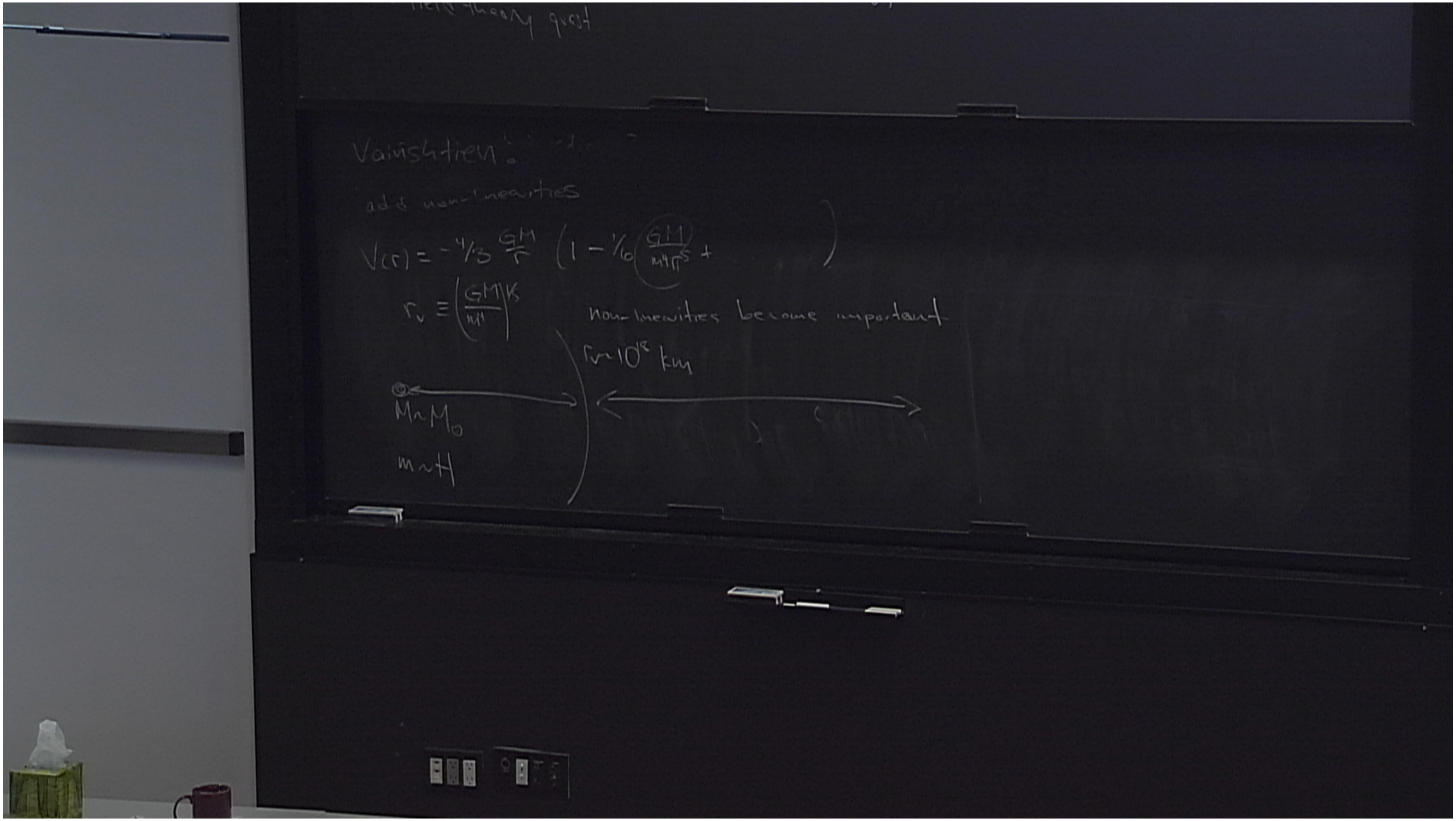
Vainshtien:
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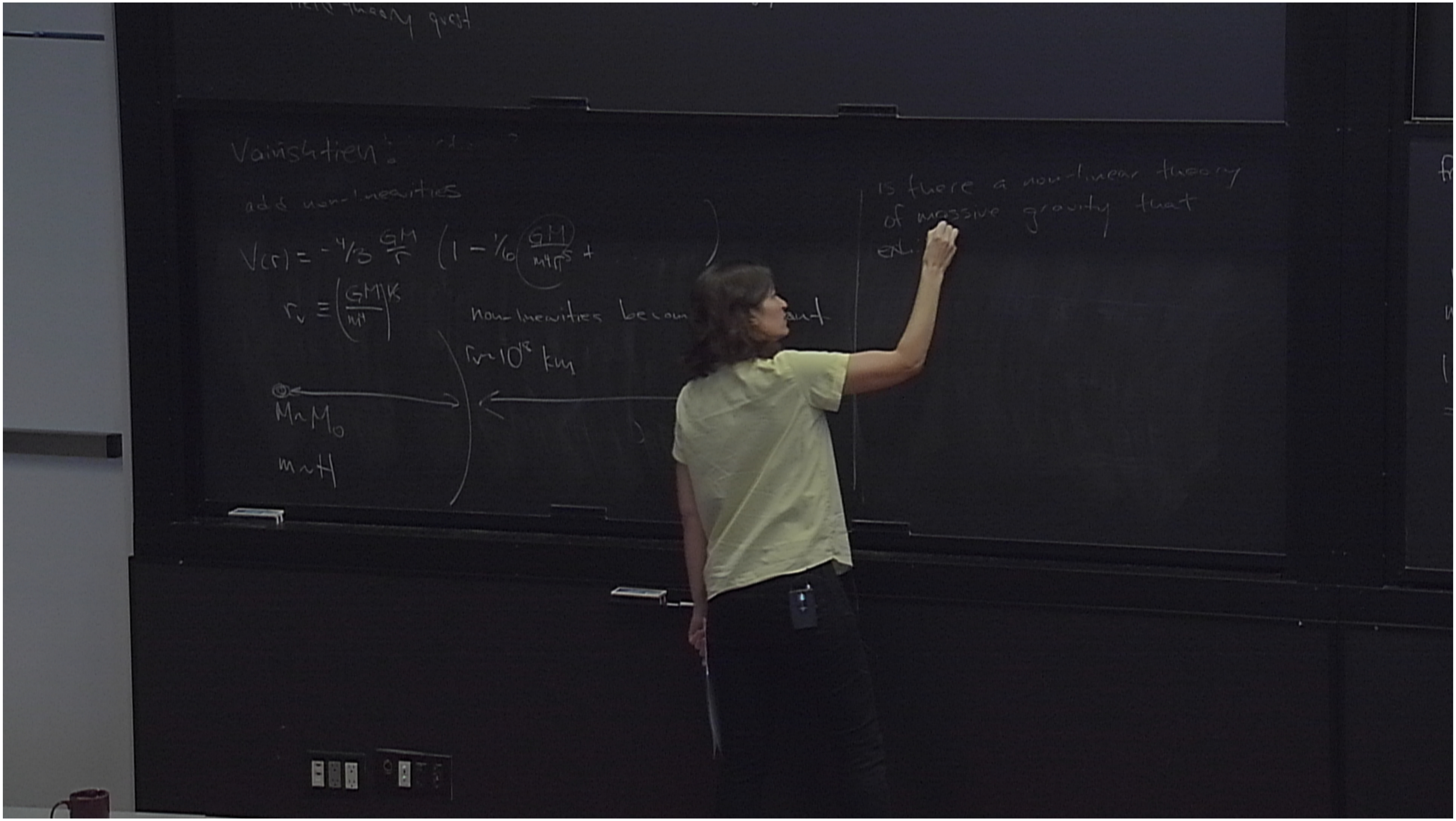
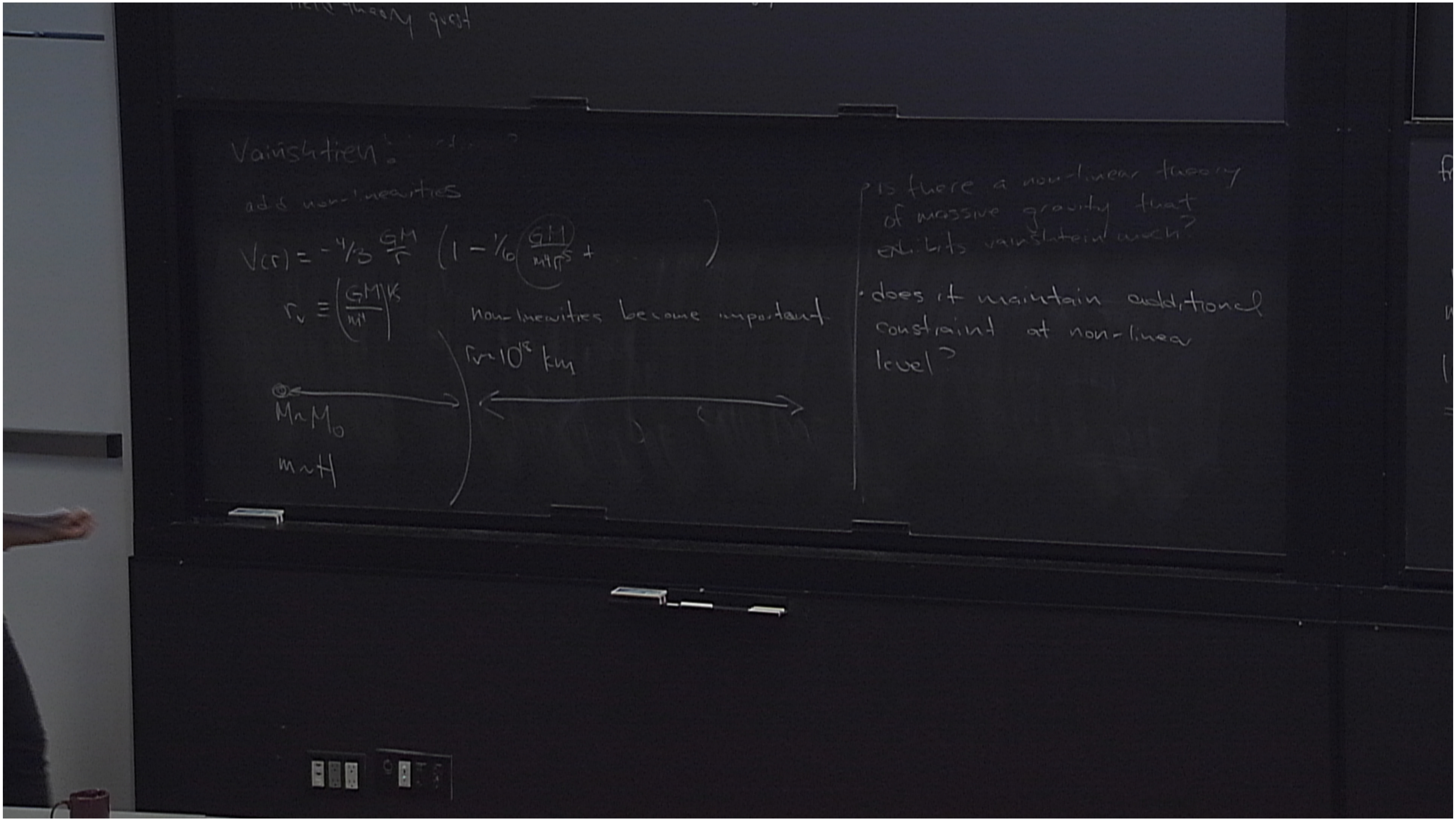
V(r) = -4/3 GM/r (1 - 1/6 (GM/m^4 r^5) +
r_v ≡ (GM/m^4)^1/5
non-linearities become important
r~10^8 km
M~M_⊙
m~H


Vainshtien:
add non-linearities
is there a non-linear theory
of massive gravity that
non-linearities become
r ~ 10^18 km
M ~ M☉
m ~ H


Vainshtien:
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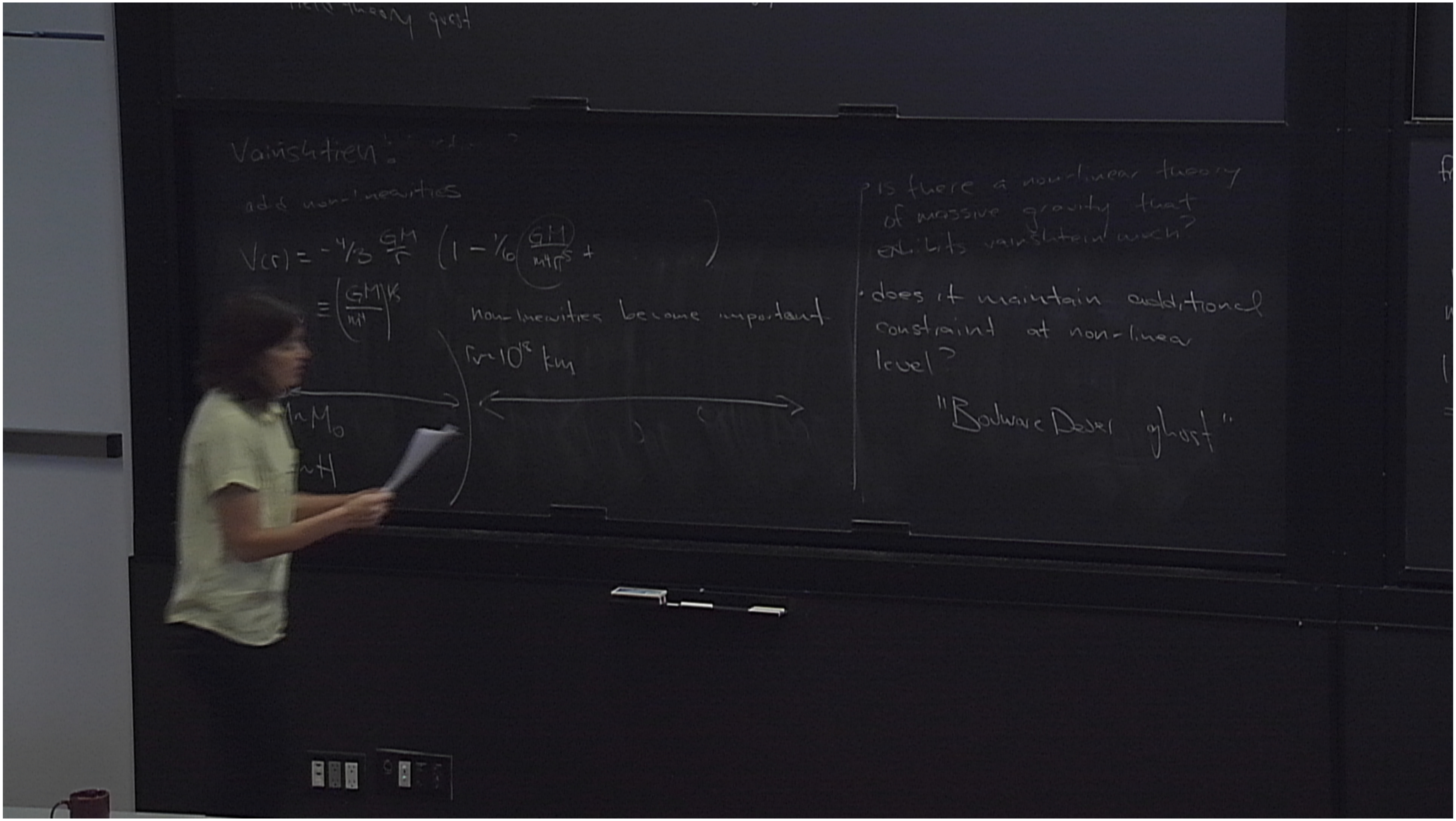
V(r) = -4/3 GM/r (1 - 1/6 (GM/m^4 r^5) + ...)
r_v ≡ (GM/m^4)^1/5
non-linearities become important
r ~ 10^18 km
M ~ M_⊙
m ~ H
is there a non-linear theory of massive gravity that exhibits vainshtein mech?
does it maintain additional constraint at non-linear level?


Vainshtien:
add non-linearities
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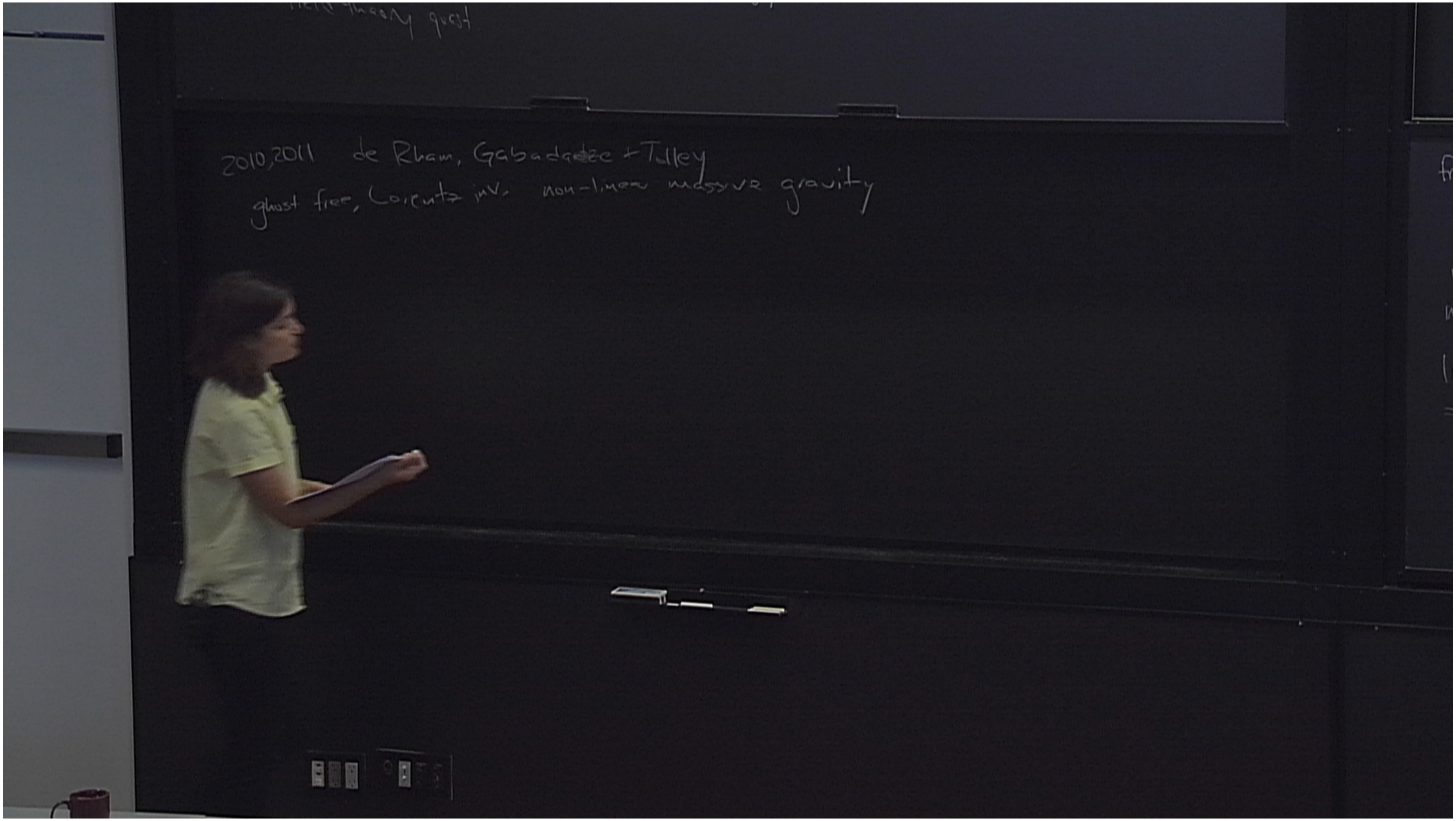
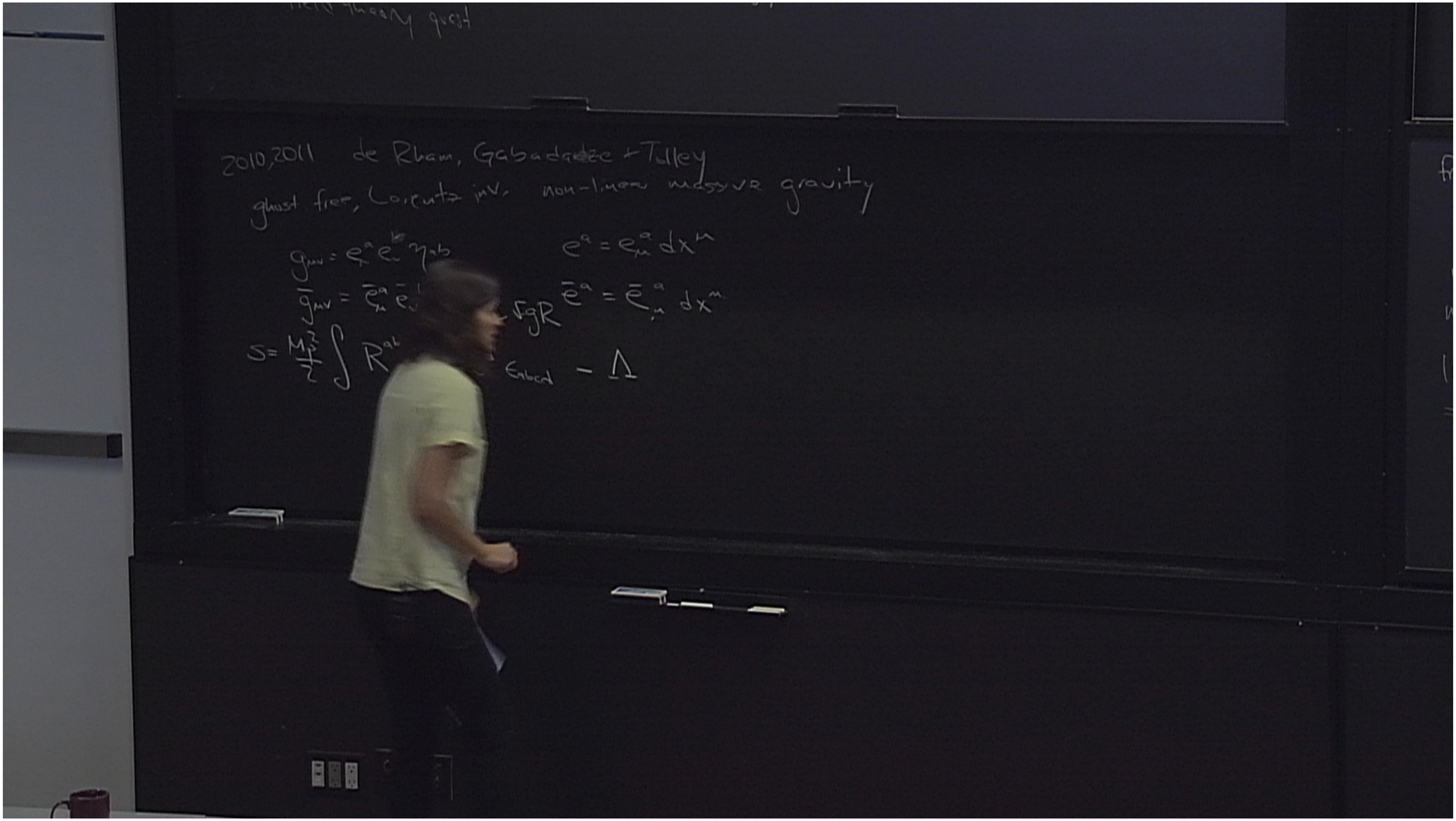
non-linearities become important
r~10¹⁸ km
is there a non-linear theory of massive gravity that exhibits vainshtein mech?
does it maintain additional constraint at non-linear level?
"Boulware Deser ghost"


2010, 2011 de Rham, Gabadadze + Tolley
ghost free, Lorentz inv. non-linear massive gravity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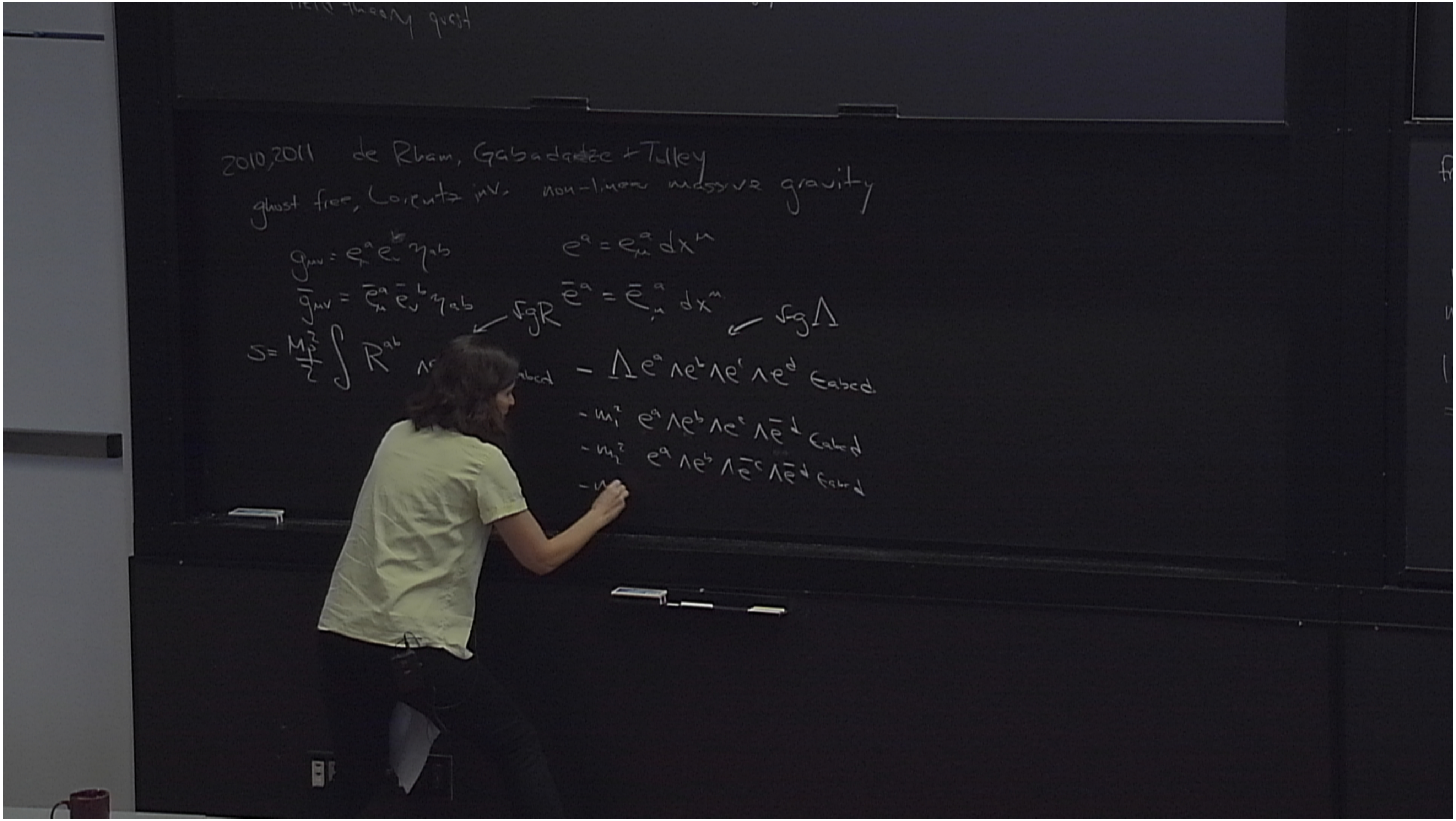
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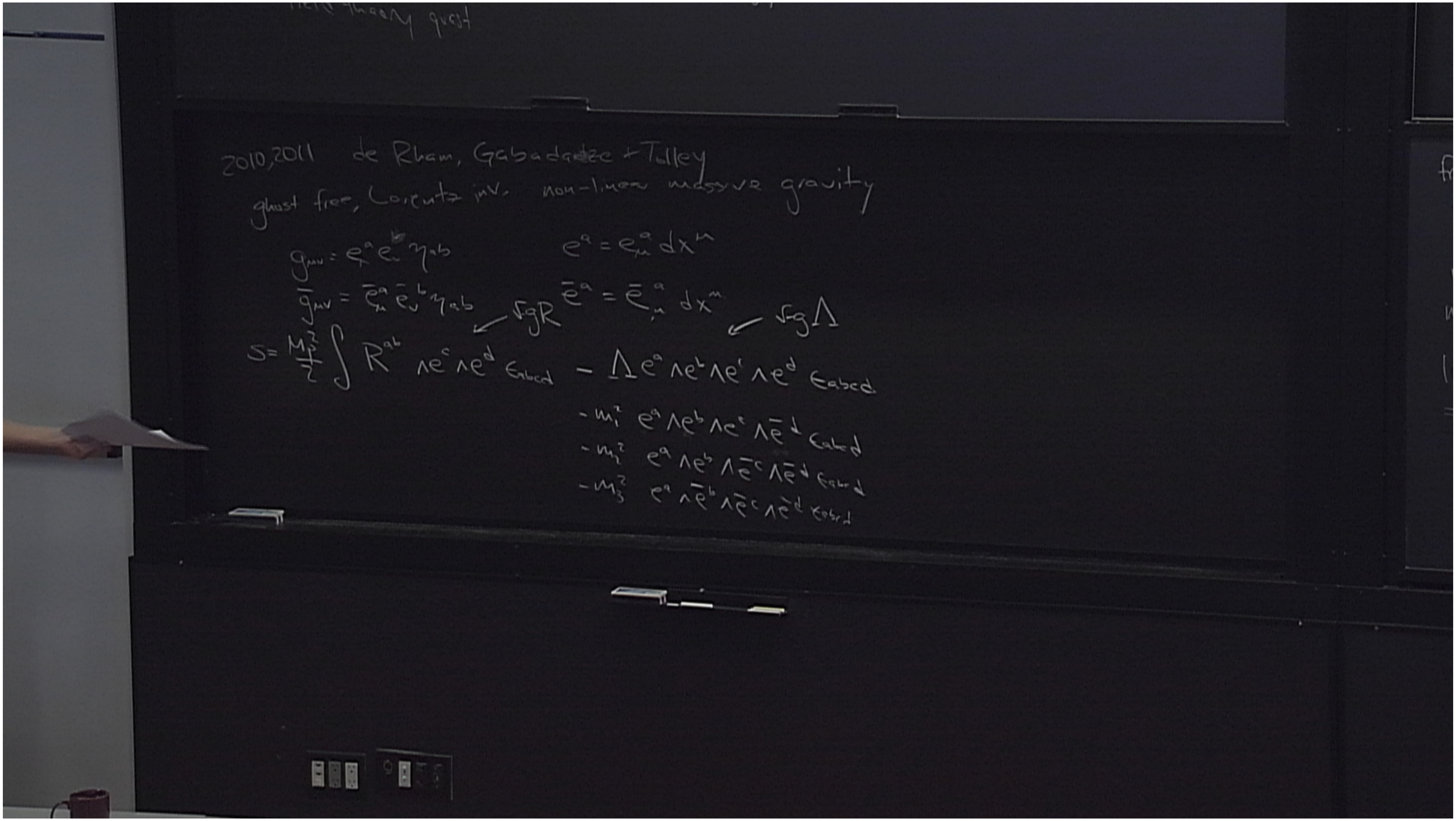
$\bar{g}_{\mu\nu} = \bar{e}^a_\mu \bar{e}^b_\nu \eta_{ab}$
$\bar{e}^a = \bar{e}^a_\mu dx^\mu$
$\sqrt{g} R$
$\sqrt{g} \Lambda$
$S = \frac{M_P^2}{2} \int R^{ab}$
$- \Lambda e^a \wedge e^b \wedge e^c \wedge e^d \epsilon_{abcd}$
$- m_1^2 e^a \wedge e^b \wedge e^c \wedge \bar{e}^d \epsilon_{abcd}$
$- m_2^2 e^a \wedge e^b \wedge \bar{e}^c \wedge \bar{e}^d \epsilon_{abcd}$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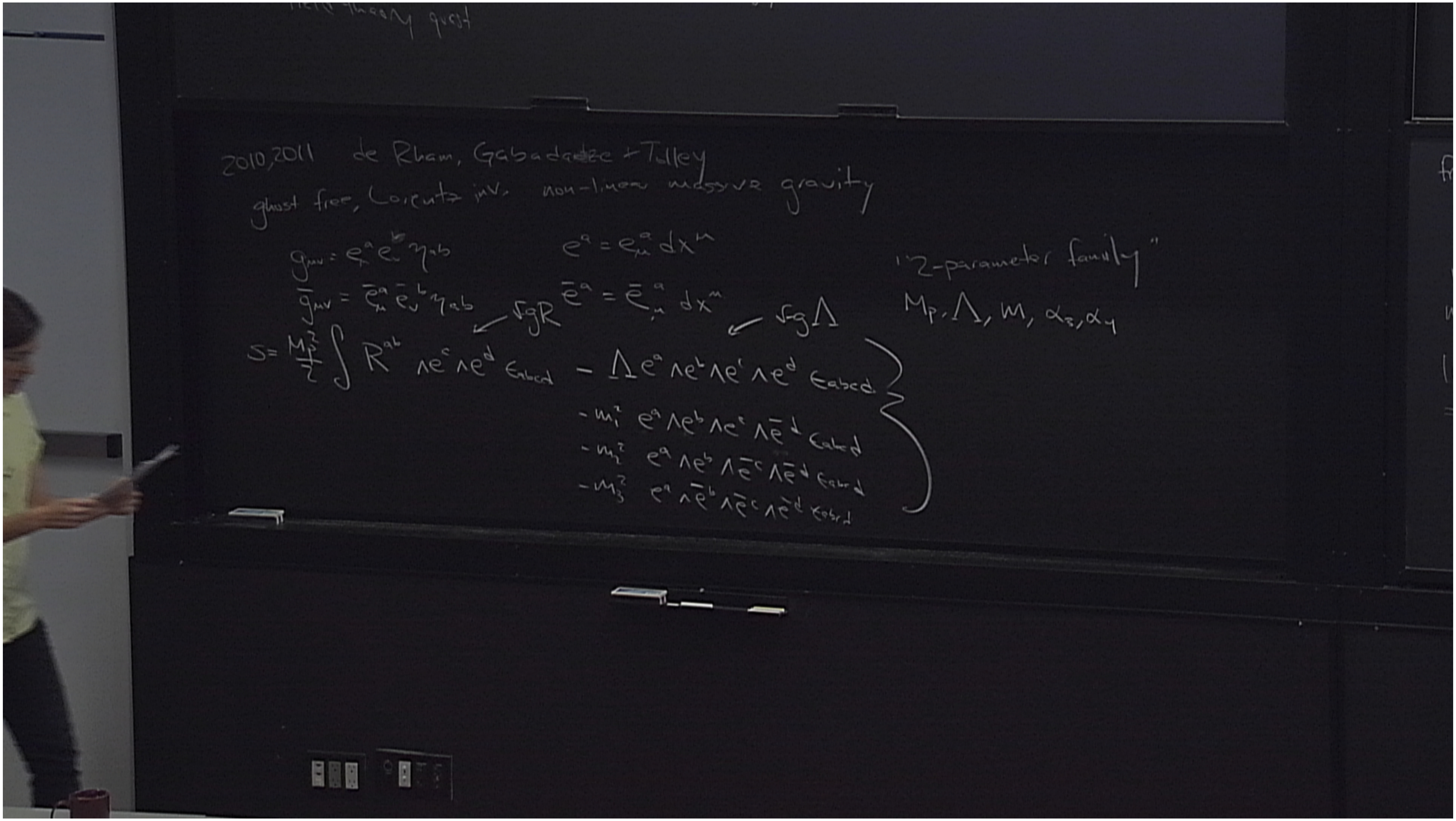
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"2-parameter family"
$M_p, \Lambda, m, \alpha_3, \alpha_4$
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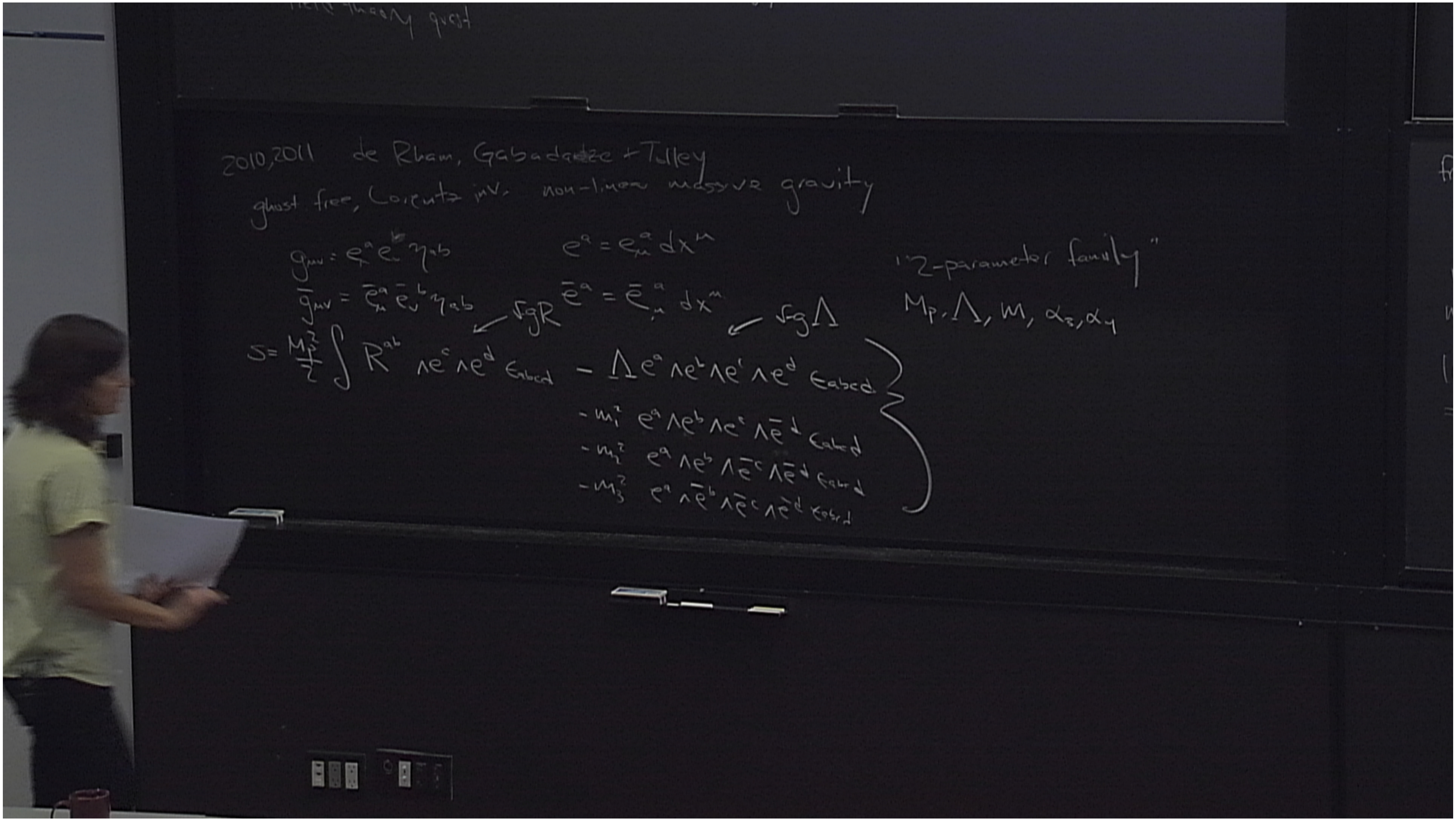
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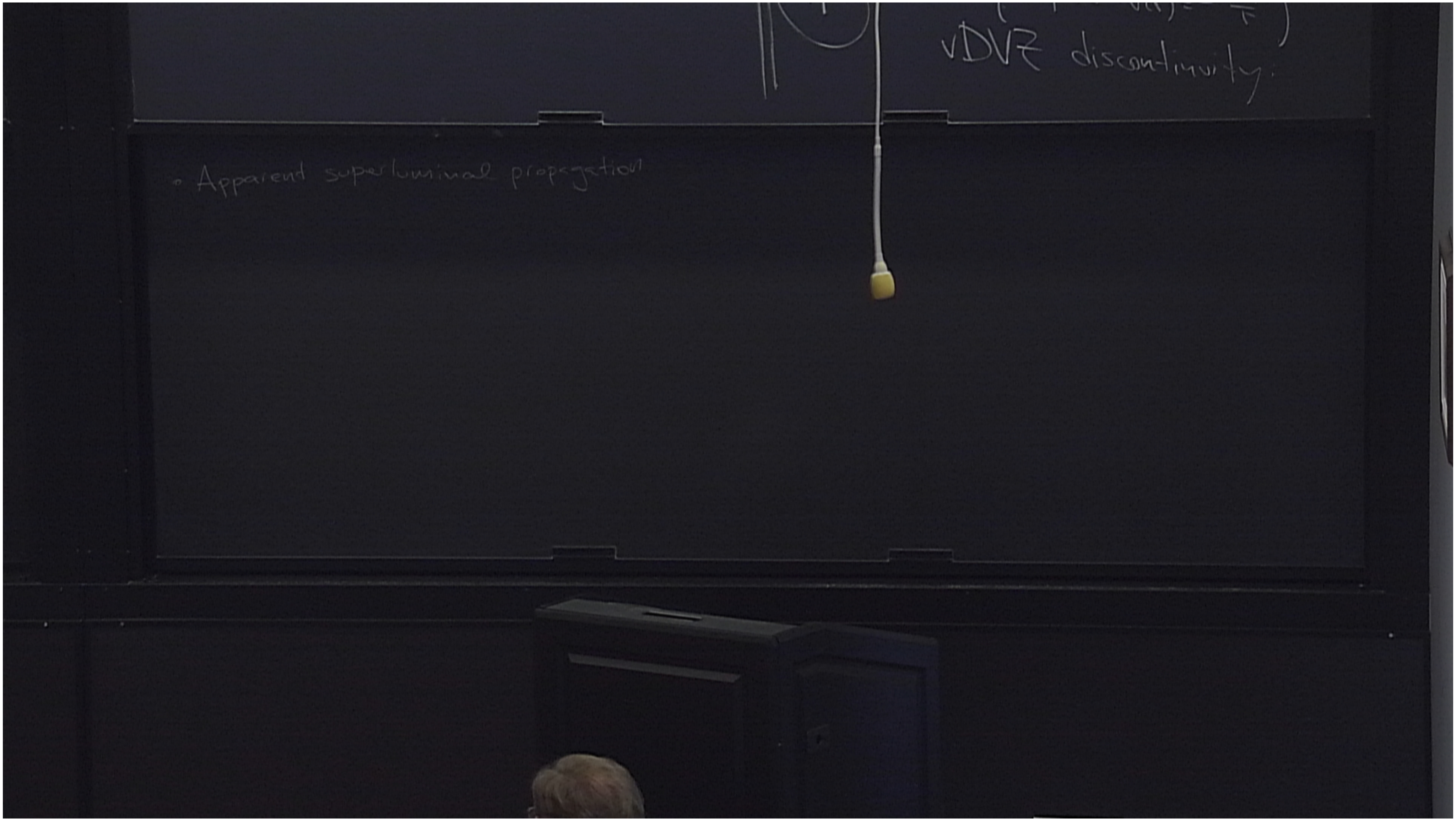
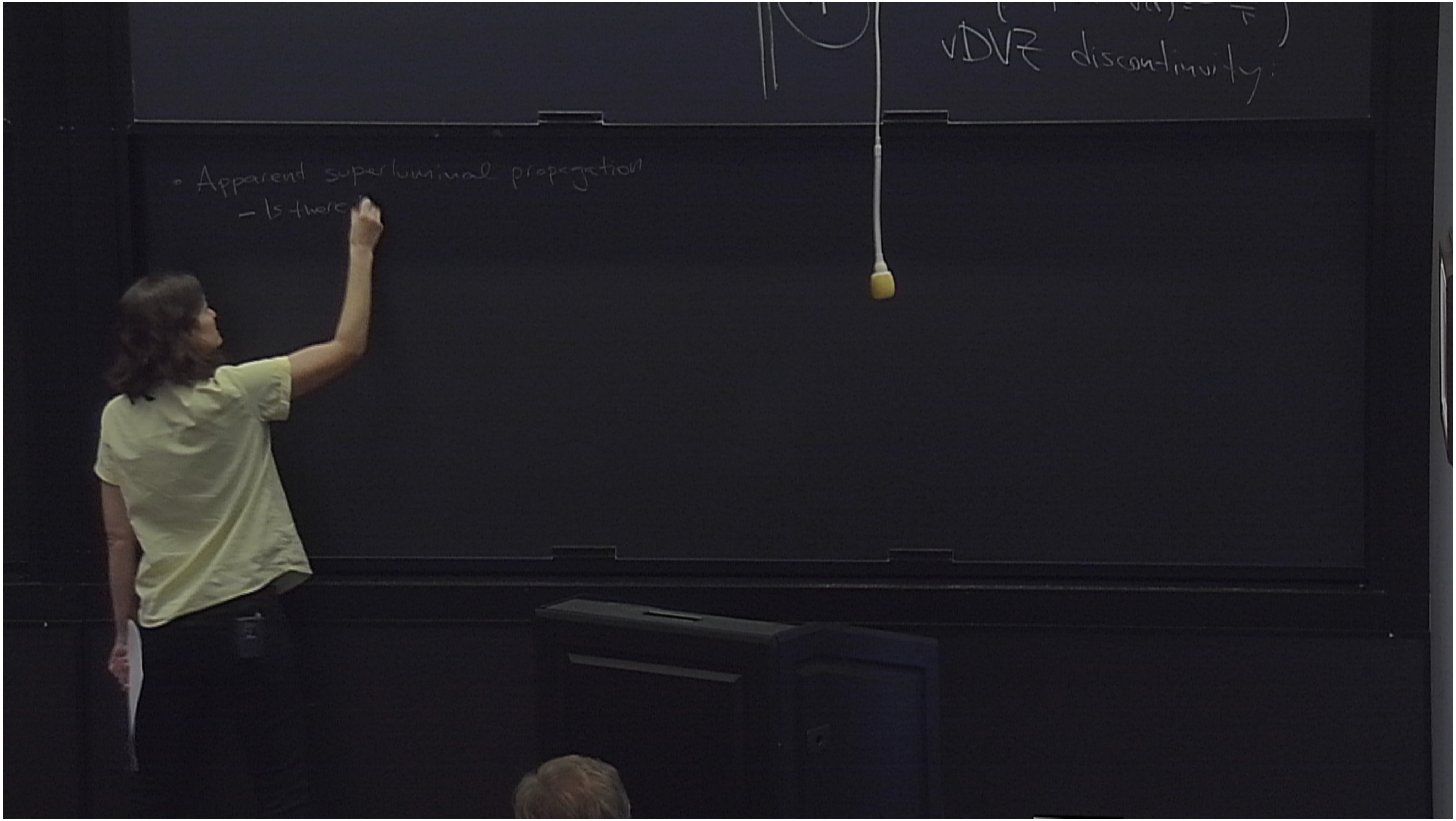
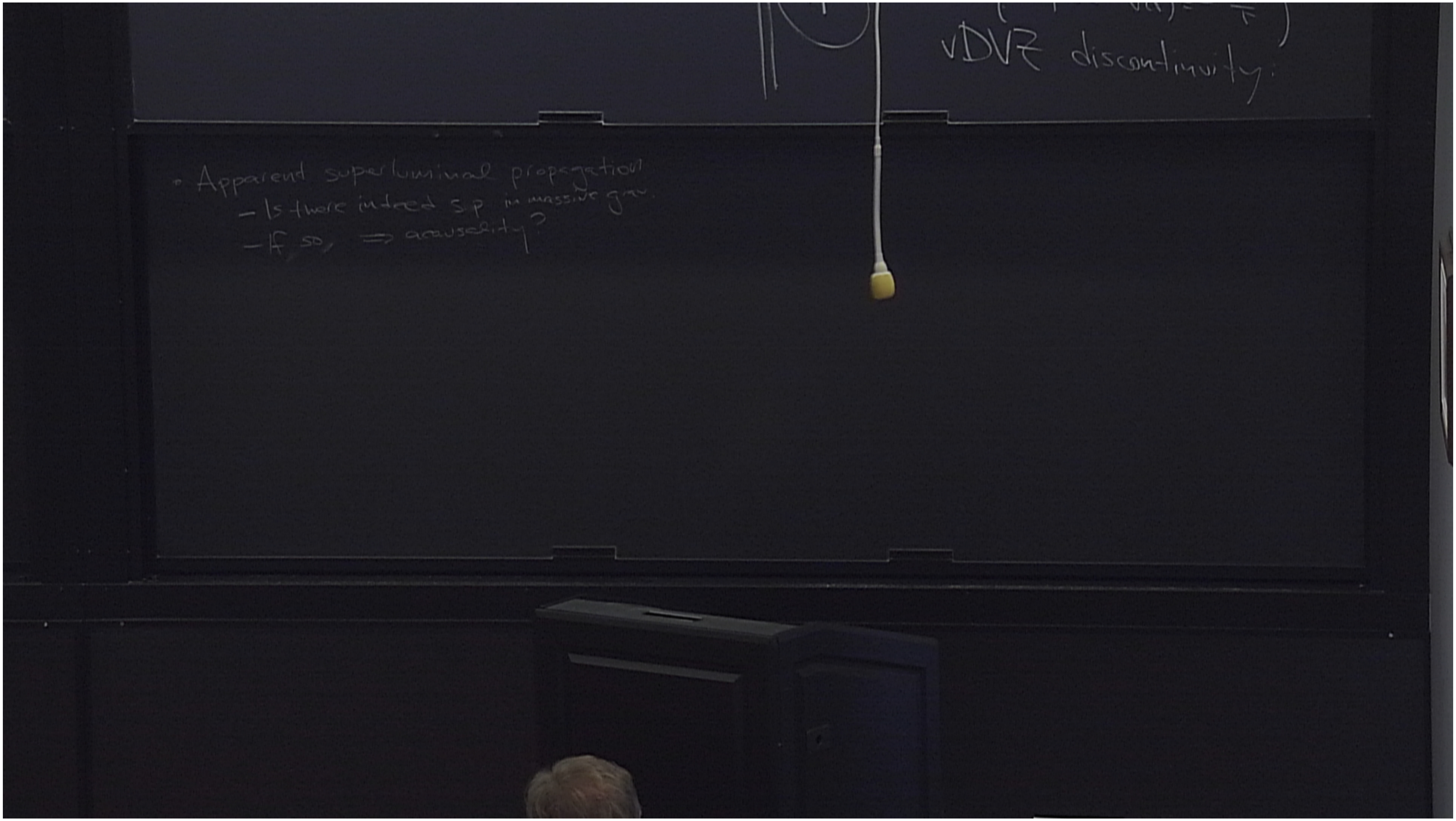
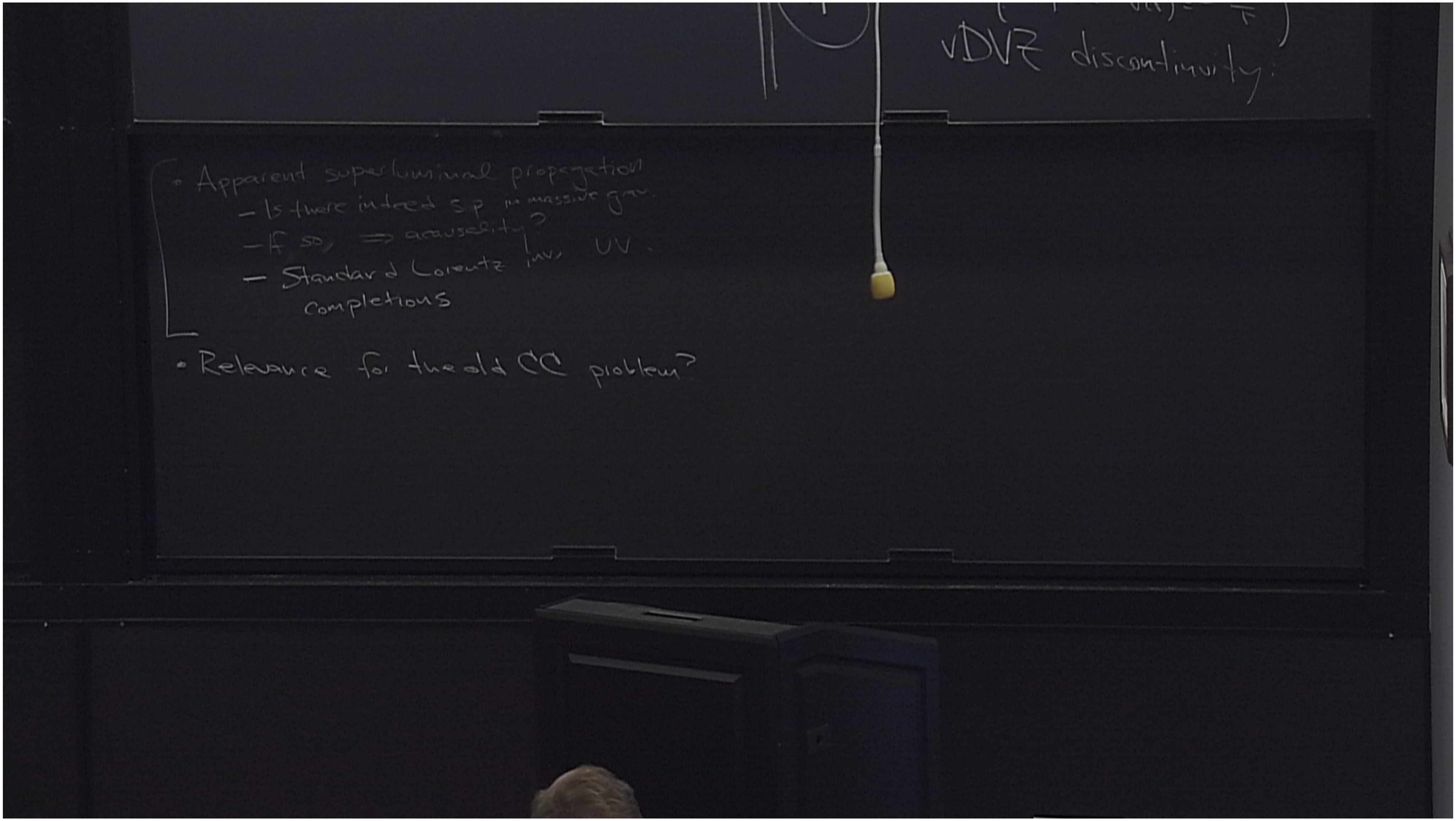

vDVZ discontinuity.
• Apparent superluminal propagation


vDVZ discontinuity.
• Apparent superluminal propagation
– Is there


vDVZ discontinuity:
• Apparent superluminal propagation
– Is there indeed s.p. in massive grav.
– If so, ⇒ acausality?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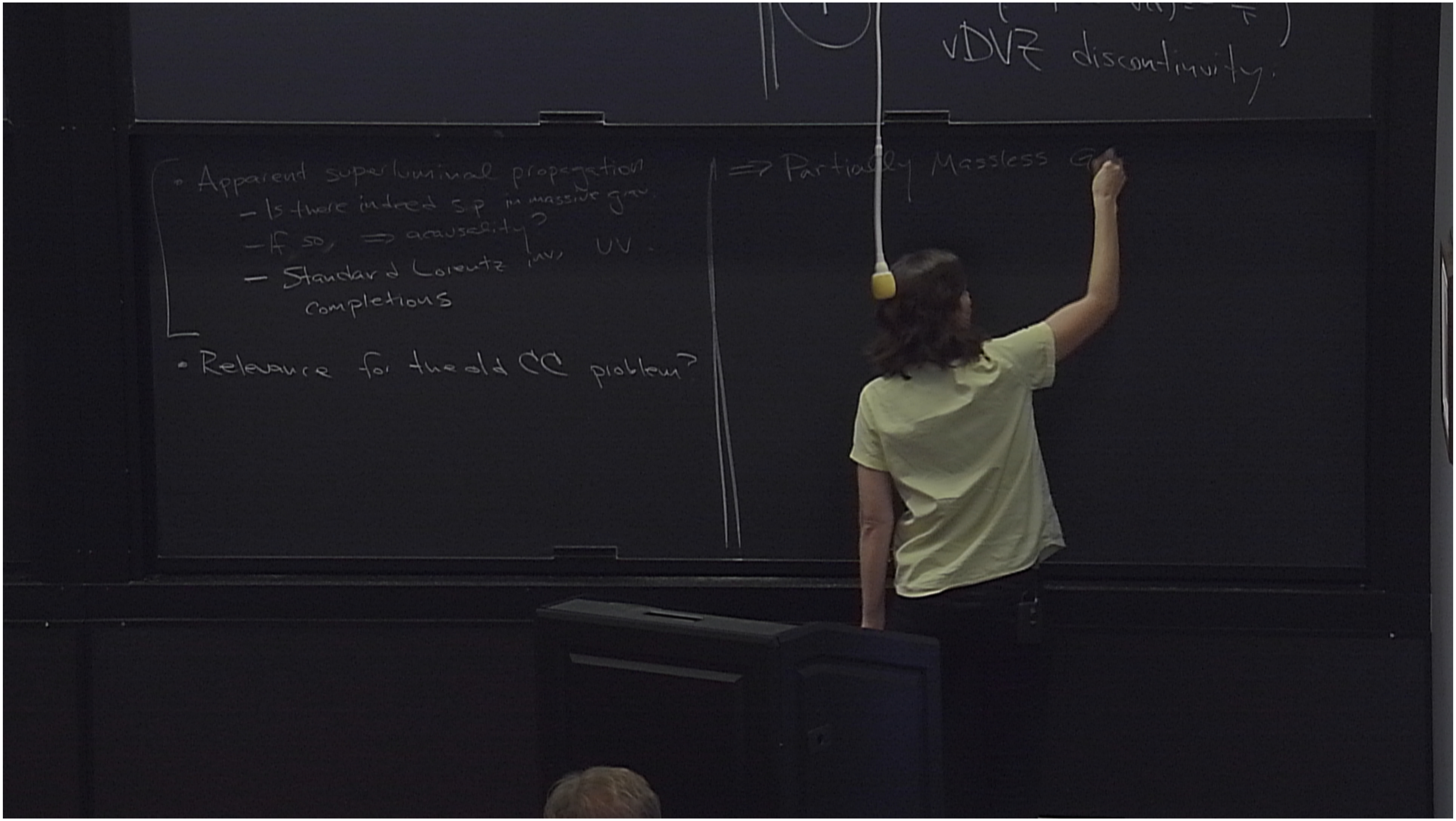
– Standard Lorentz inv. UV completions
• Relevance for the old CC problem?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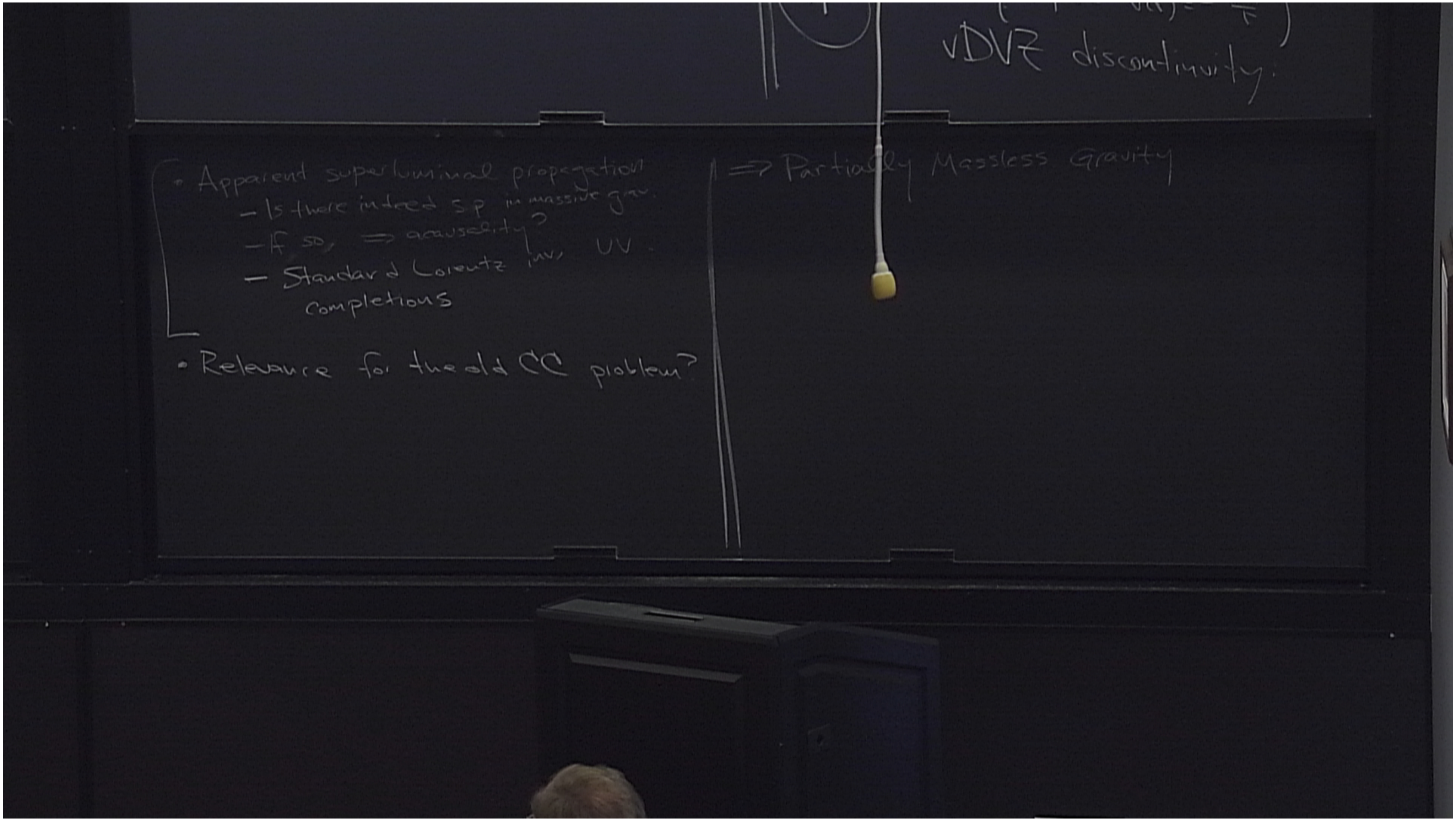
⇒ Partially Massless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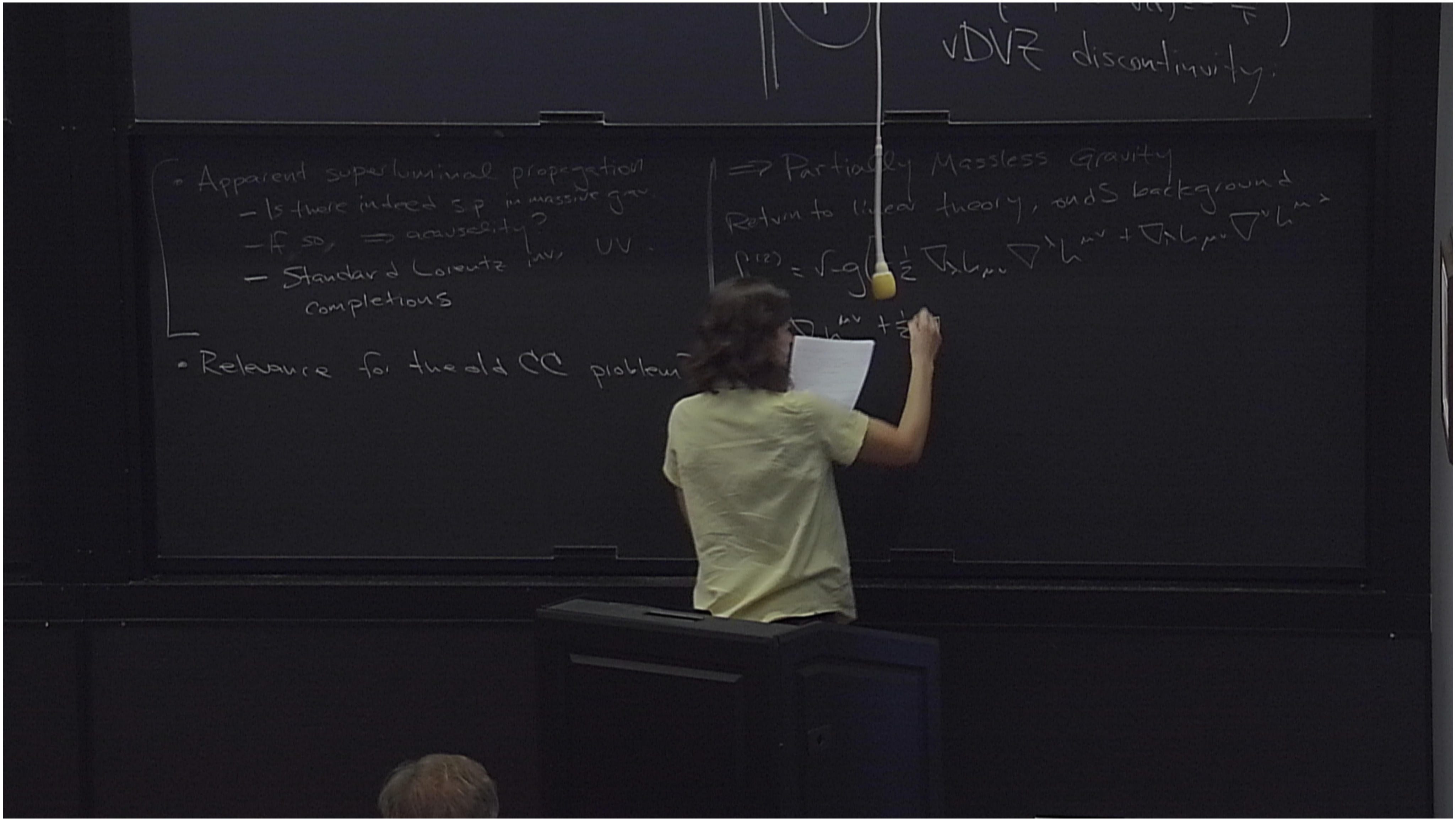
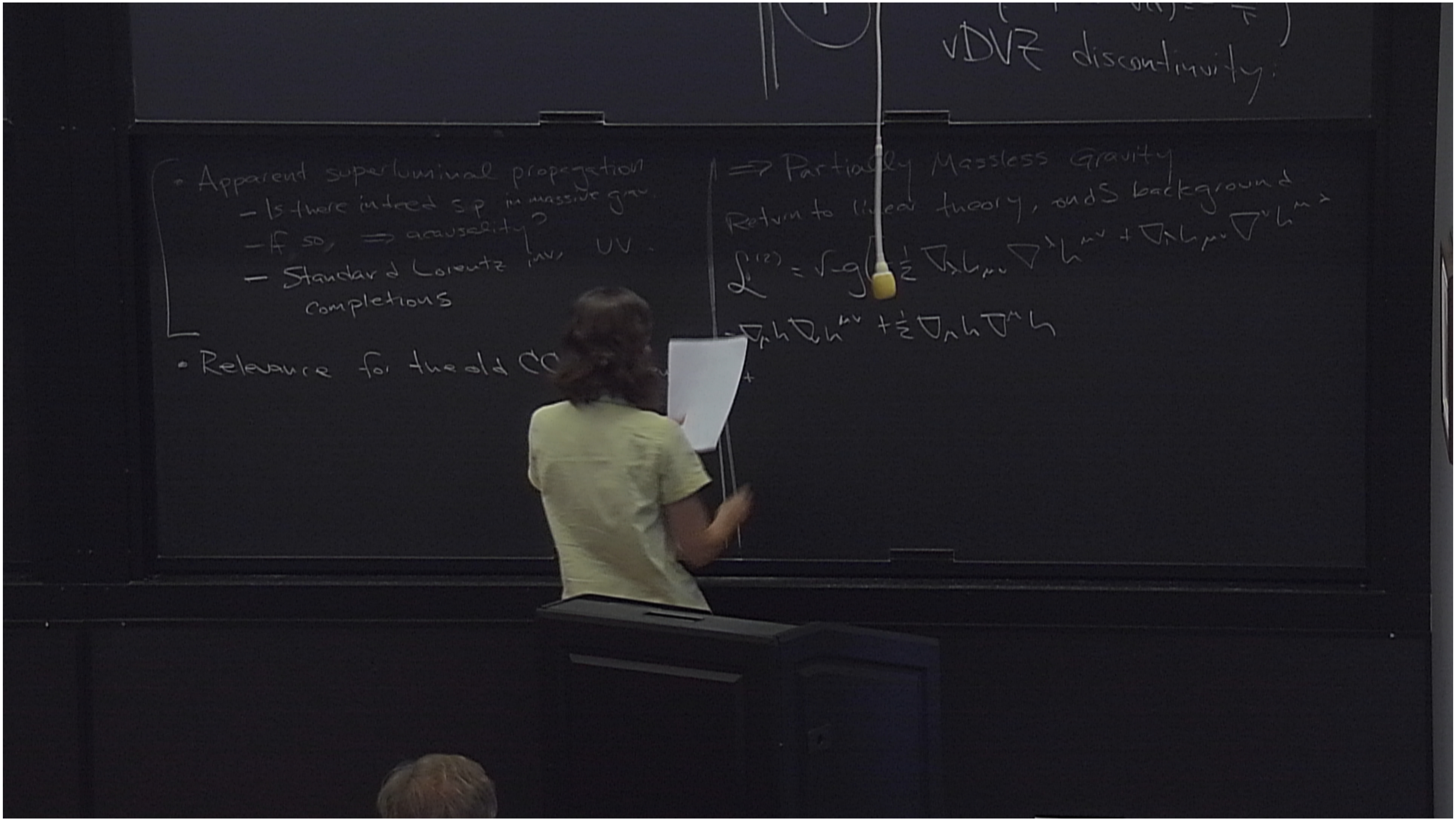
• Relevance for the old CC problem?
⇒ Partially Massless Gravity


vDVZ discontinuity
• Apparent superluminal propagation
– Is there indeed s.p. in massive grav.
– If so, ⇒ acausality?
– Standard Lorentz inv. UV completions
• Relevance for the old CC problem?
⇒ Partially Massless Gravity
Return to linear theory, on dS background


vDVZ discontinuity:
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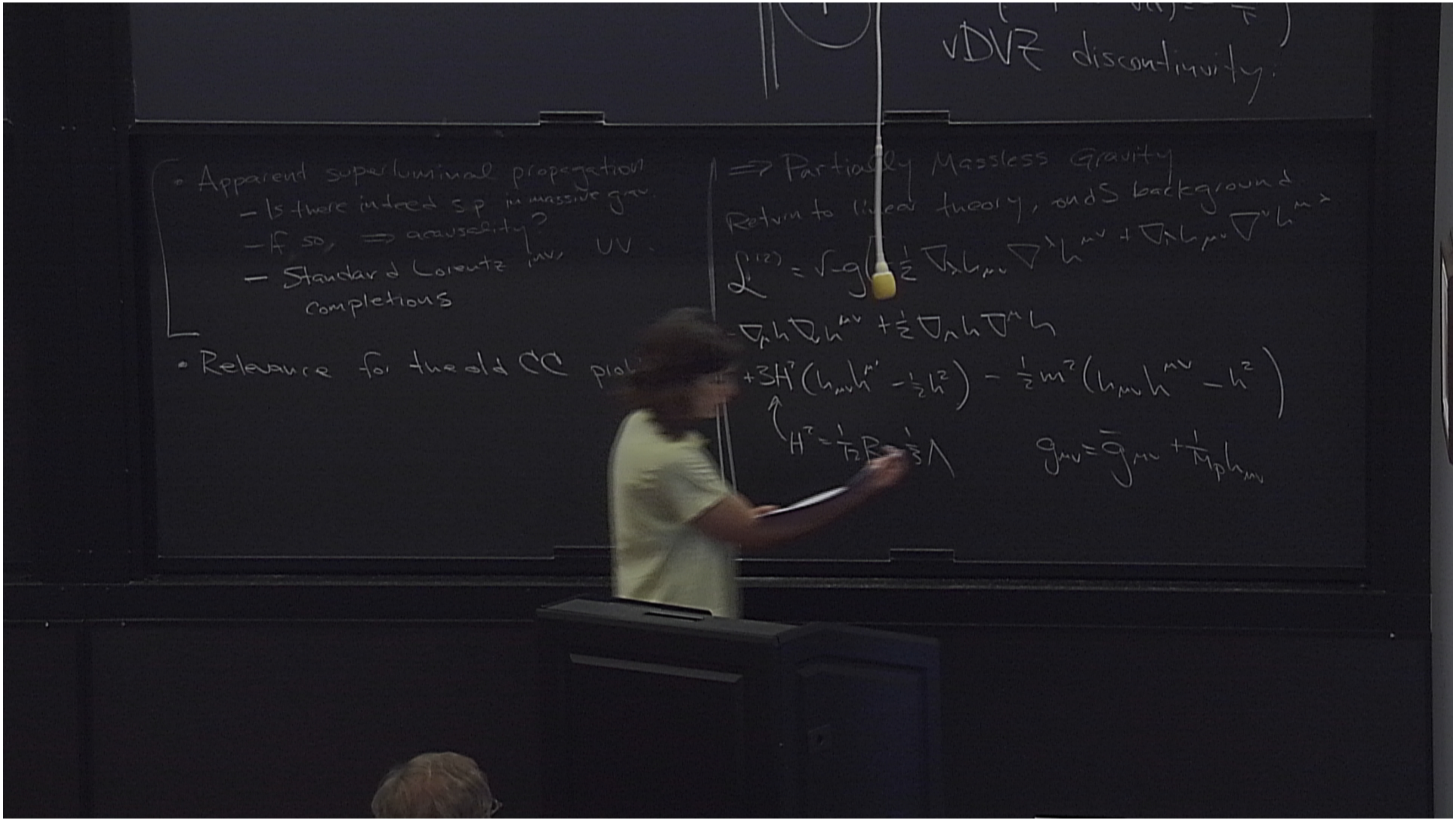
vDVZ discontinuity.
• Apparent superluminal propagation
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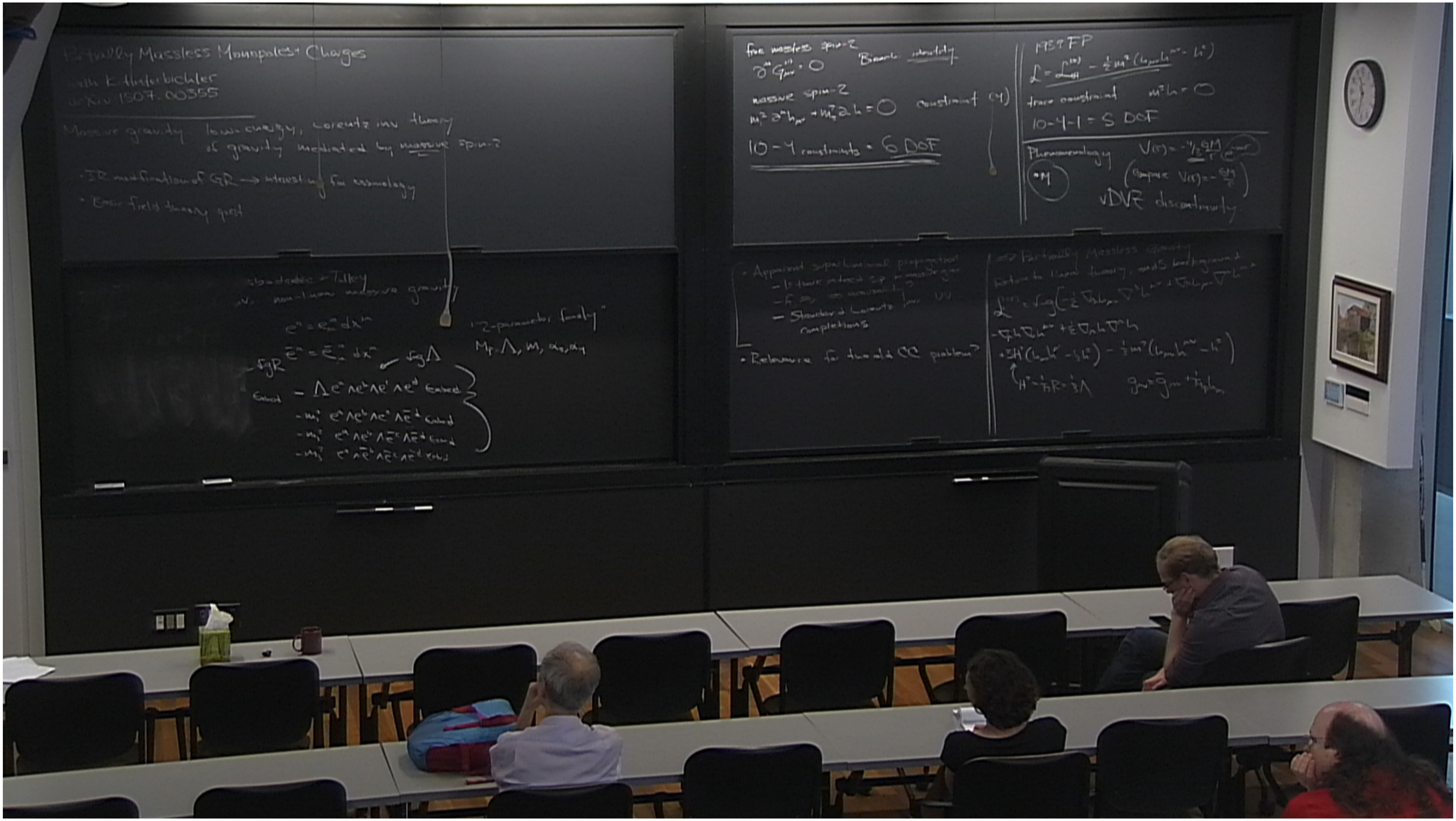
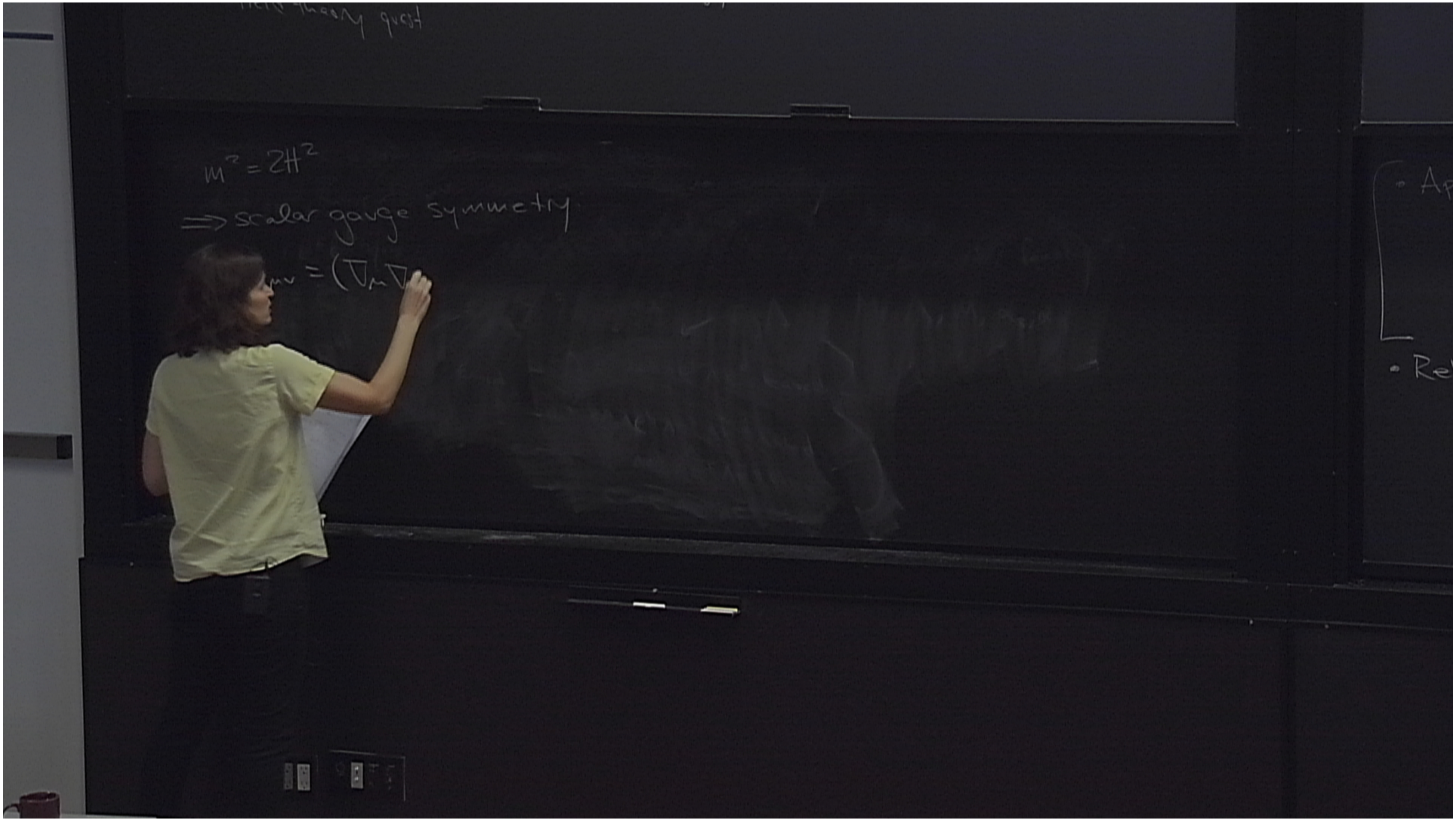
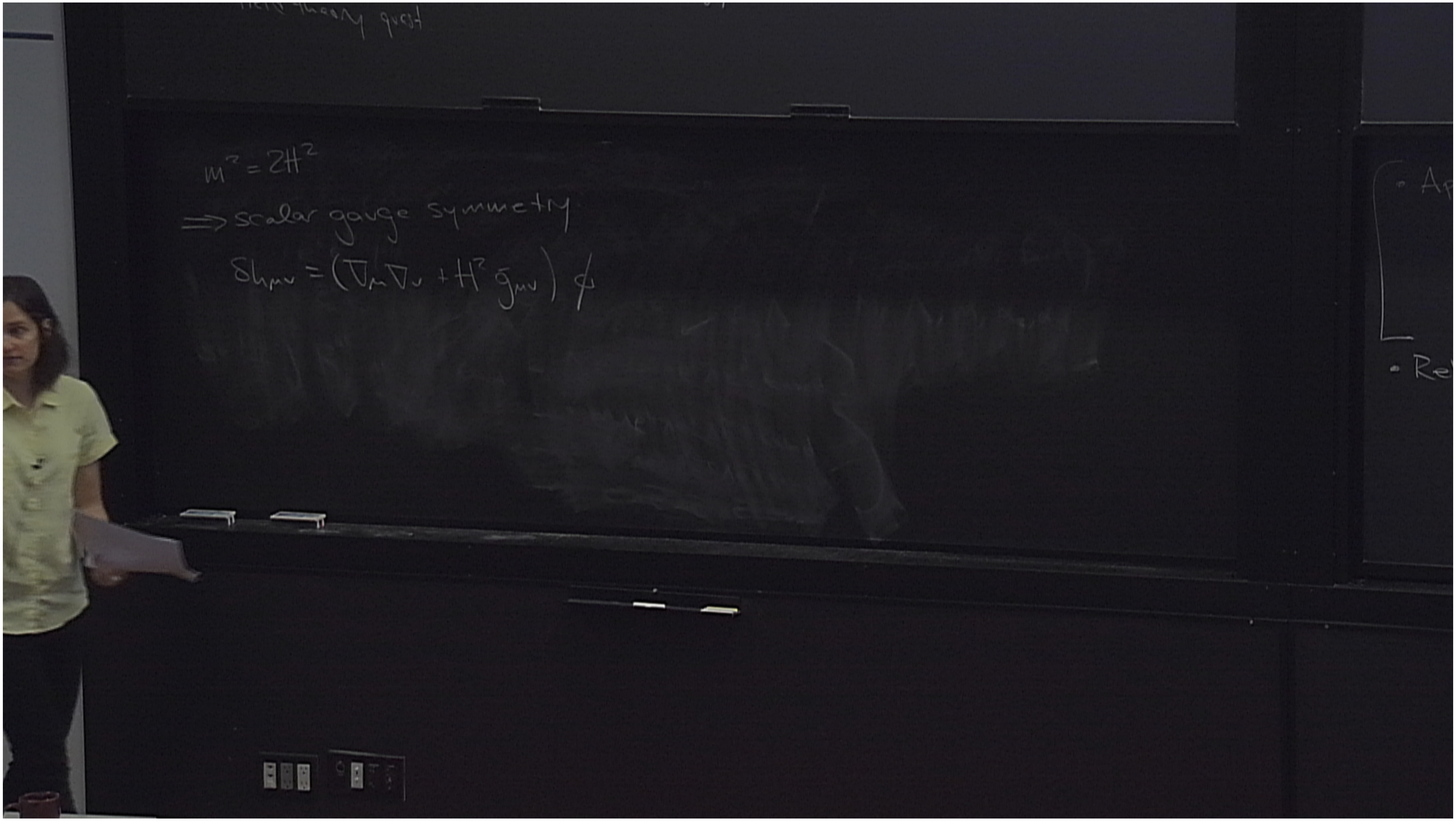
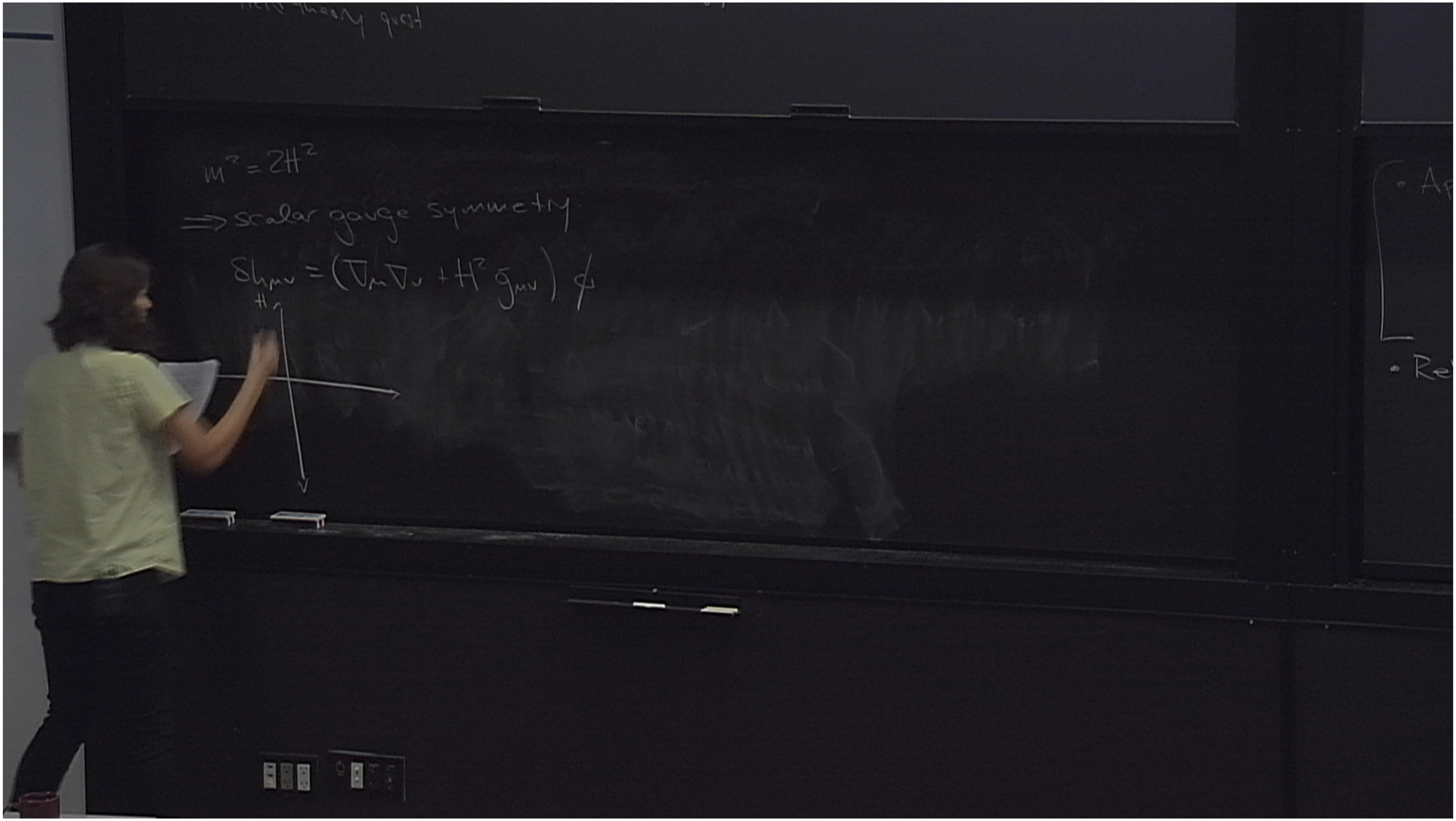
⇒ Partially Massless Gravity
Return to linear theory, on dS background
gμν = ḡμν + (1/Mp) hμν


Partially Massless Monopoles + Charges
arXiv 1507.00355
free massless spin-2
Bianchi identity
massive spin-2
constraint
10 - 4 constraints = 6 DOF
trace constraint
10-4-1 = 5 DOF
Phenomenology
vDVZ discontinuity
Relevance for the old CC problem?
Standard Lorentz inv UV completions


m² = 2H²
⟹ scalar gauge symmetry


m² = 2H²
⟹ scalar gauge symmetry
δh_μν = (∇_μ∇_ν + H² ḡ_μν) φ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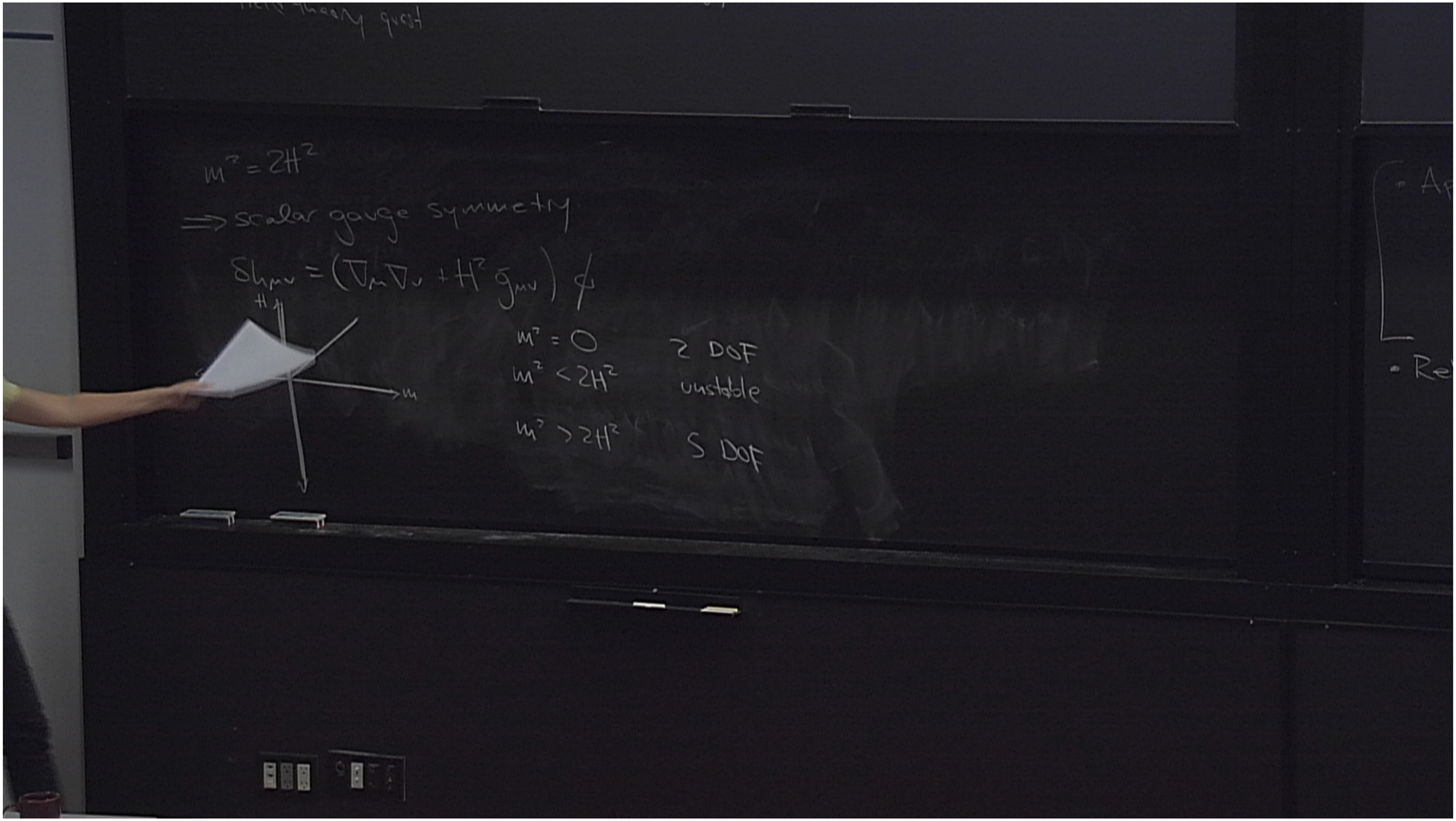
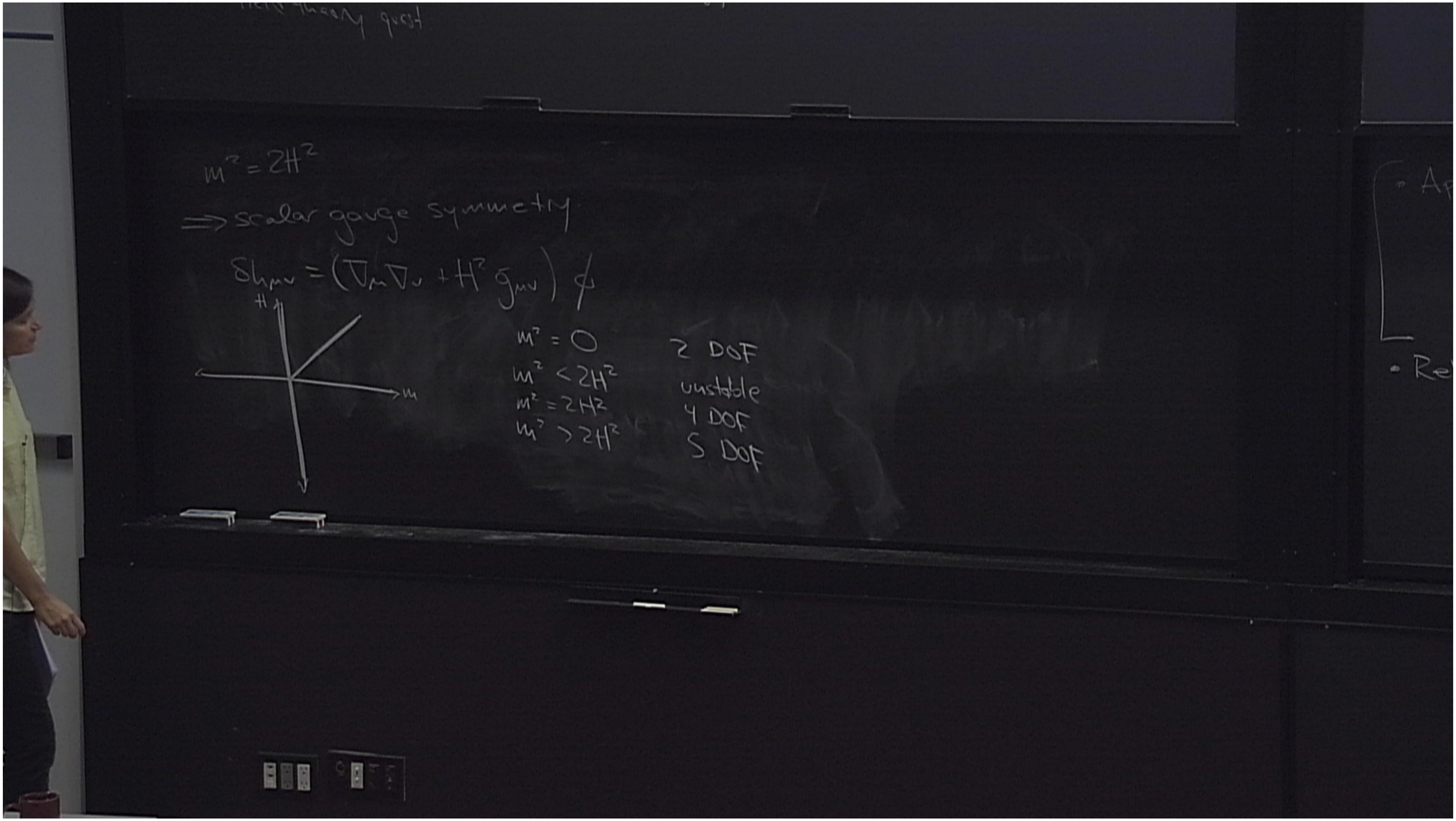
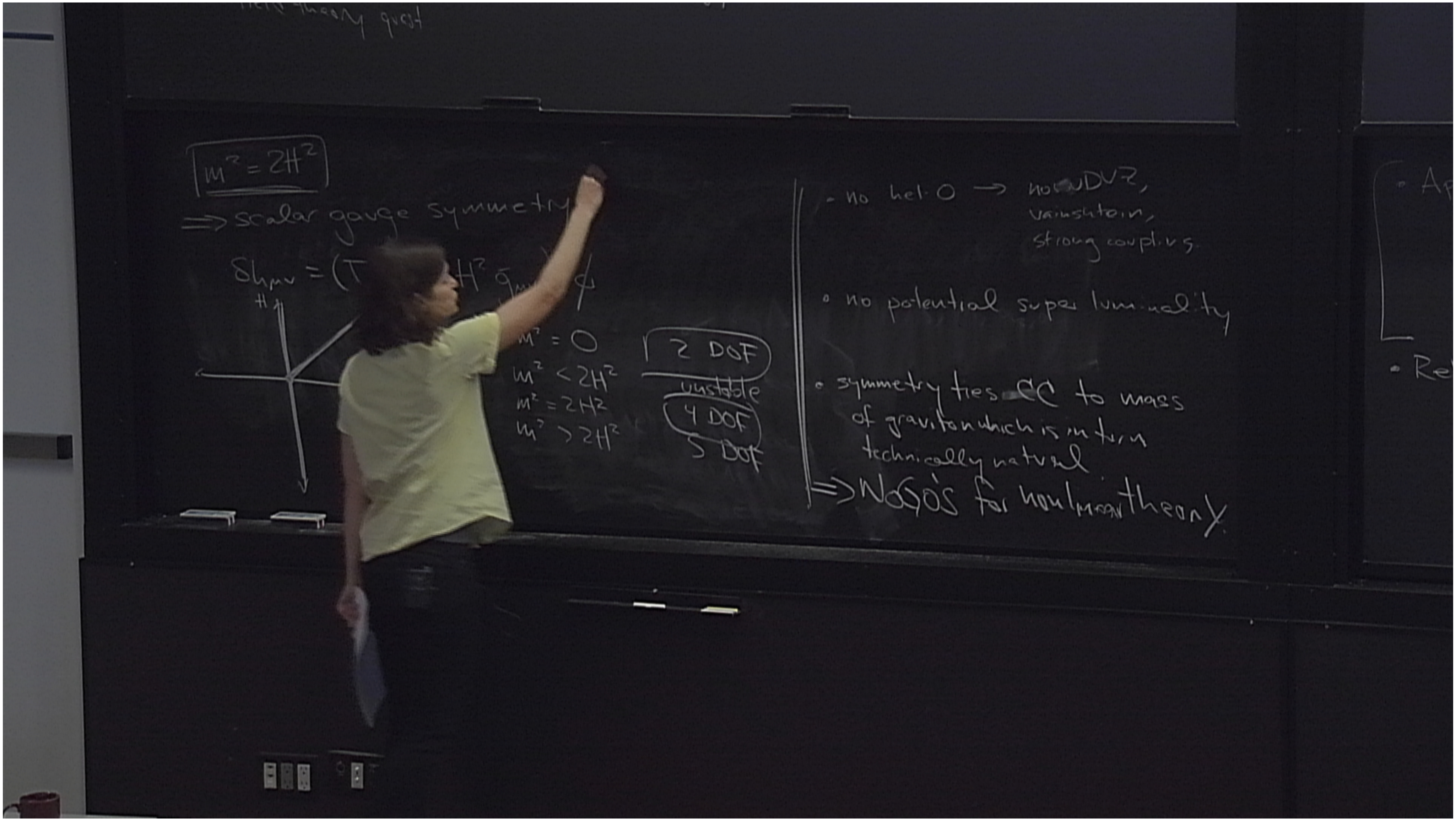
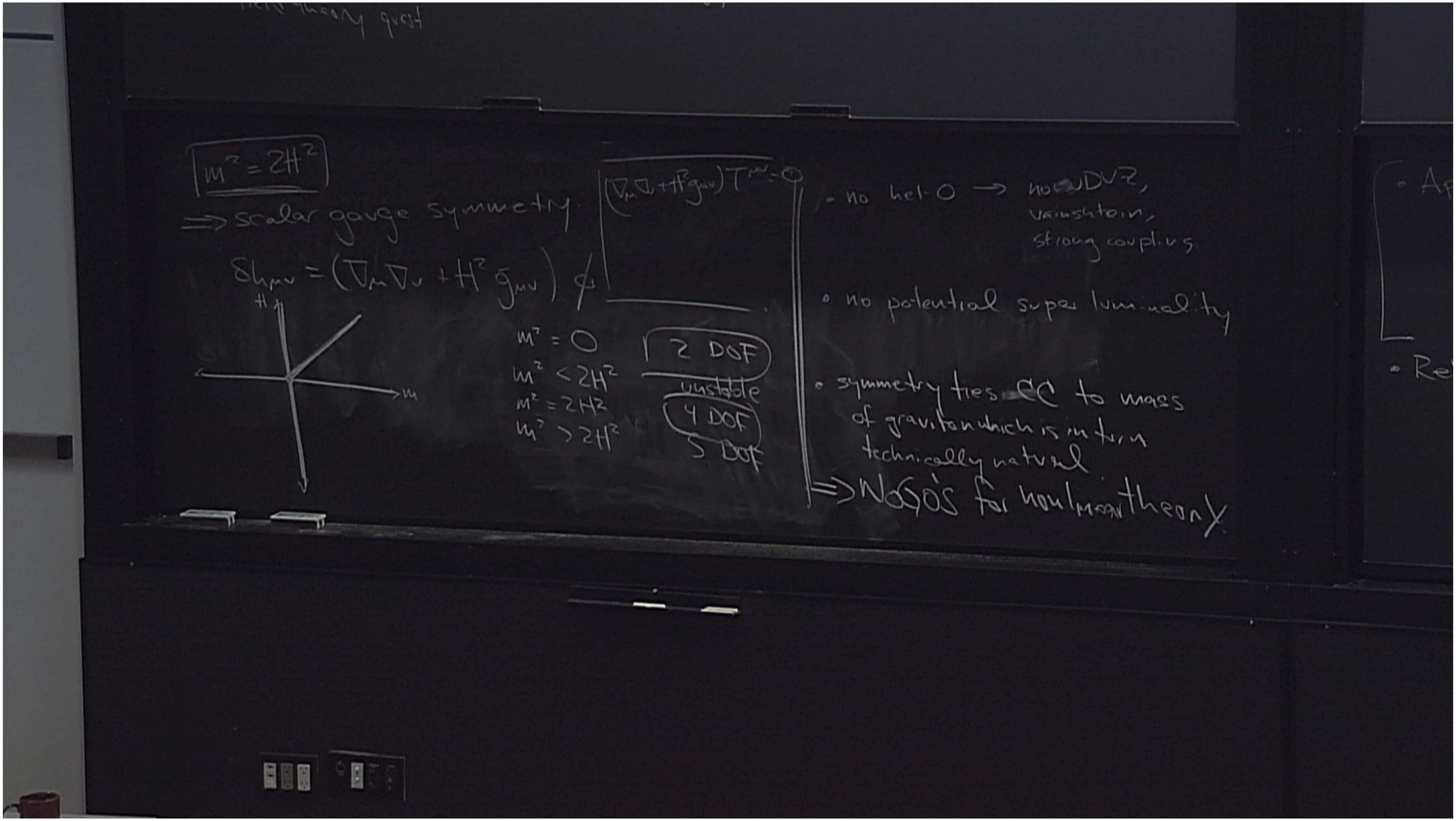

$m^2 = 2H^2$
$\Longrightarrow$ scalar gauge symmetry
$\delta h_{\mu\nu} = (\nabla_\mu \nabla_\nu + H^2 g_{\mu\nu})\,\phi$
$m^2 = 0$ 2 DOF
$m^2 < 2H^2$ unstable
$m^2 > 2H^2$ 5 DOF


m² = 2H²
⟹ scalar gauge symmetry
δh_μν = (∇_μ∇_ν + H² g_μν) φ
H
m
m² = 0
2 DOF
m² < 2H²
unstable
m² = 2H²
4 DOF
m² > 2H²
5 DOF


m² = 2H²
⟹ scalar gauge symmetry
m² = 0
m² < 2H²
m² = 2H²
m² > 2H²
2 DOF
unstable
4 DOF
5 DOF
• no hel·0 → no vDVZ, Vainshtein, strong coupling.
• no potential superluminality
• symmetry ties CC to mass of graviton which is in turn technically natural
⟹ NOGO'S for nonlinear theory.



m² = 2H²
⟹ scalar gauge symmetry
δh_μν = (∇_μ∇_ν + H² g_μν) φ
(∇_μ∇_ν + H² g_μν) T^μν = 0
H
m
m² = 0
2 DOF
m² < 2H²
unstable
m² = 2H²
4 DOF
m² > 2H²
5 DOF
• no hel-0 → no vDVZ, Vainshtein, strong coupling
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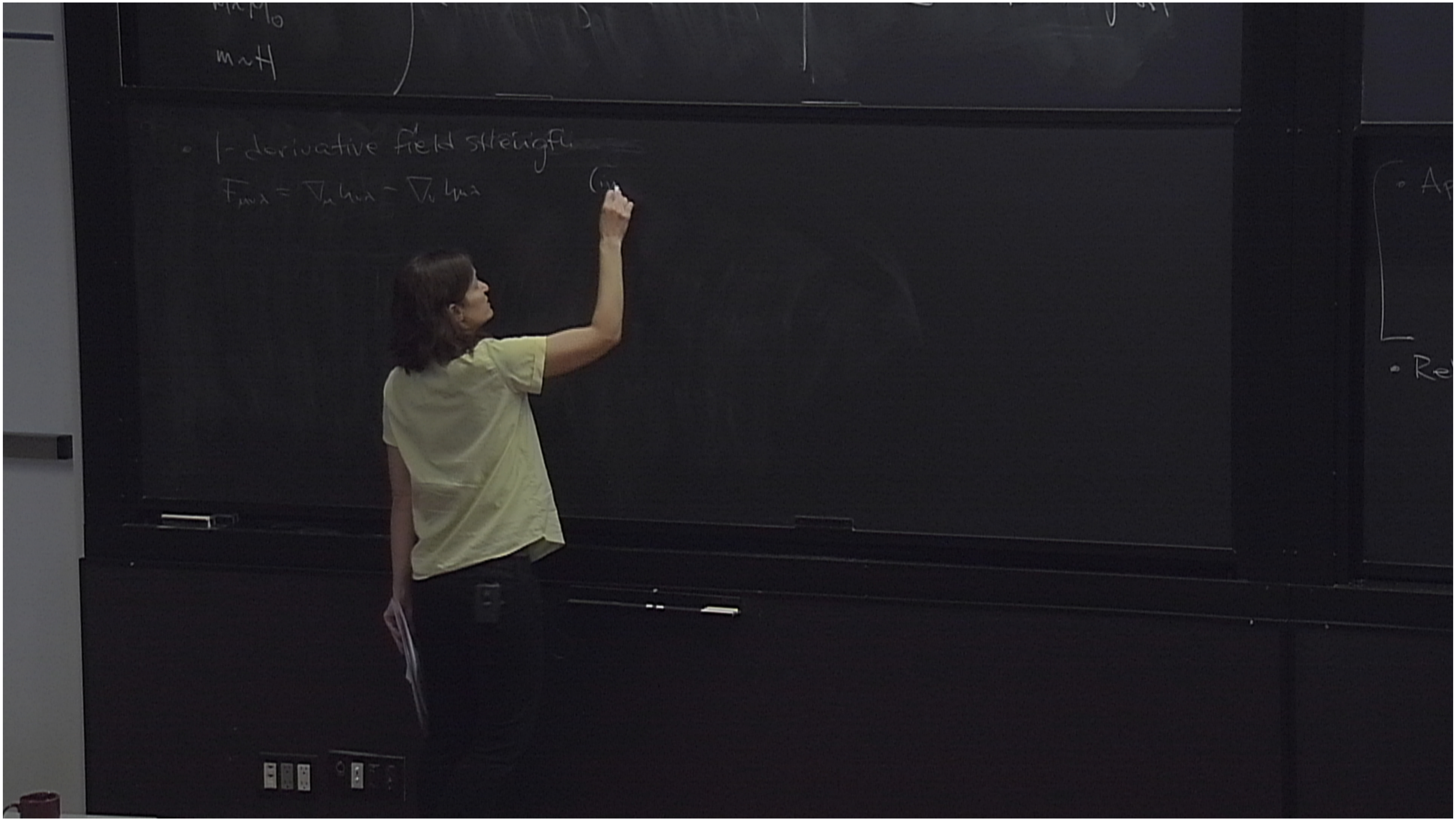
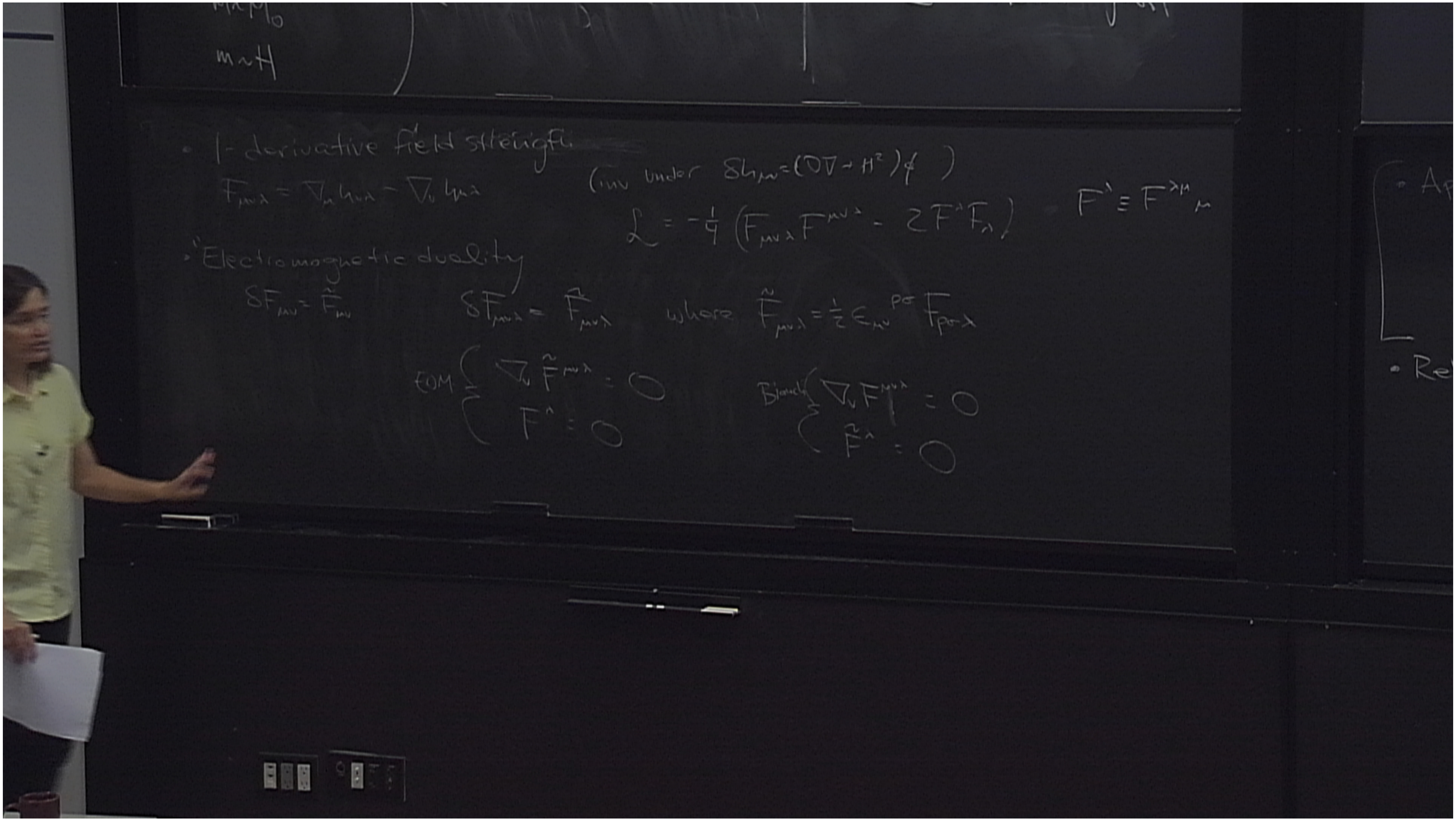
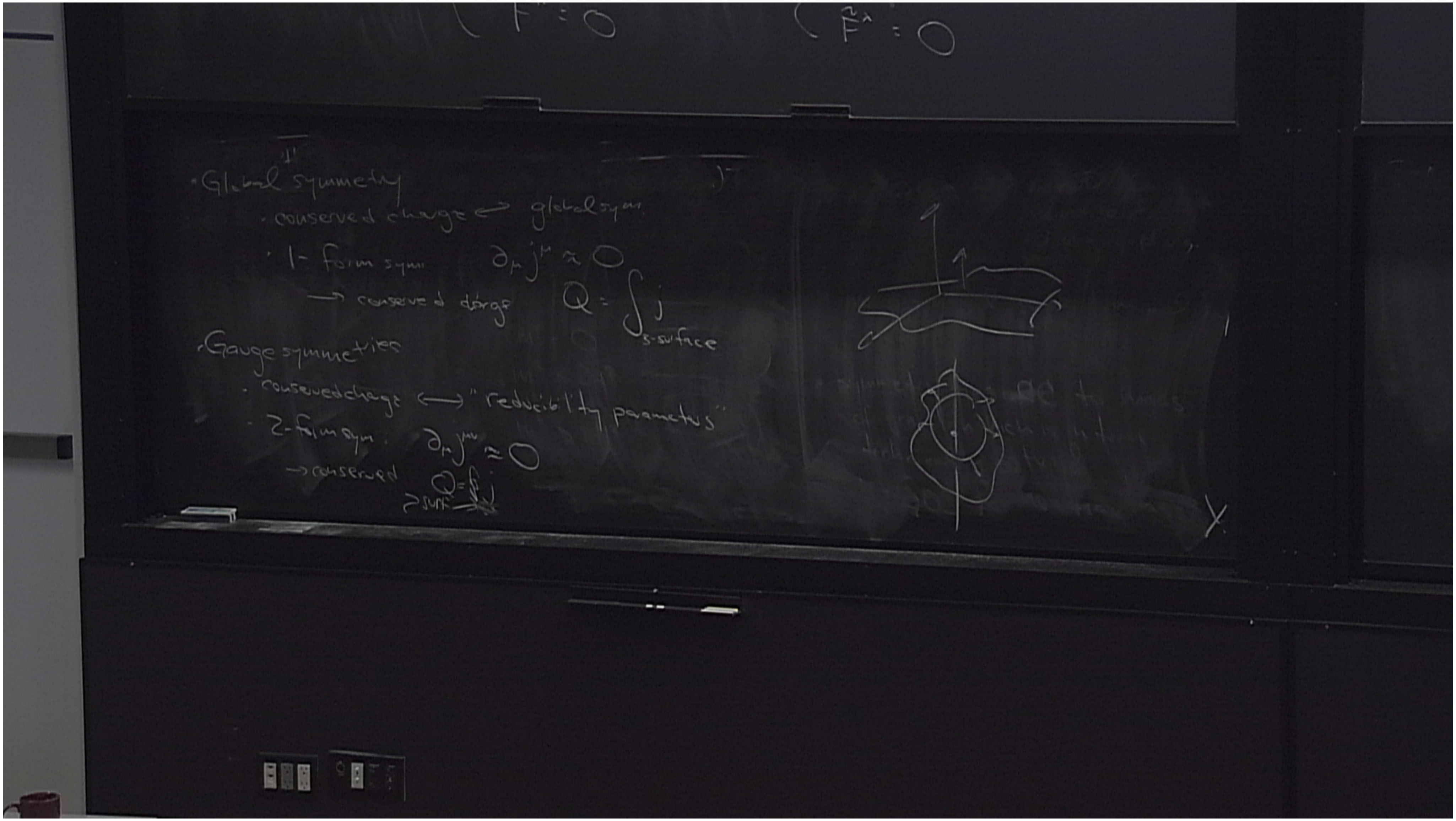


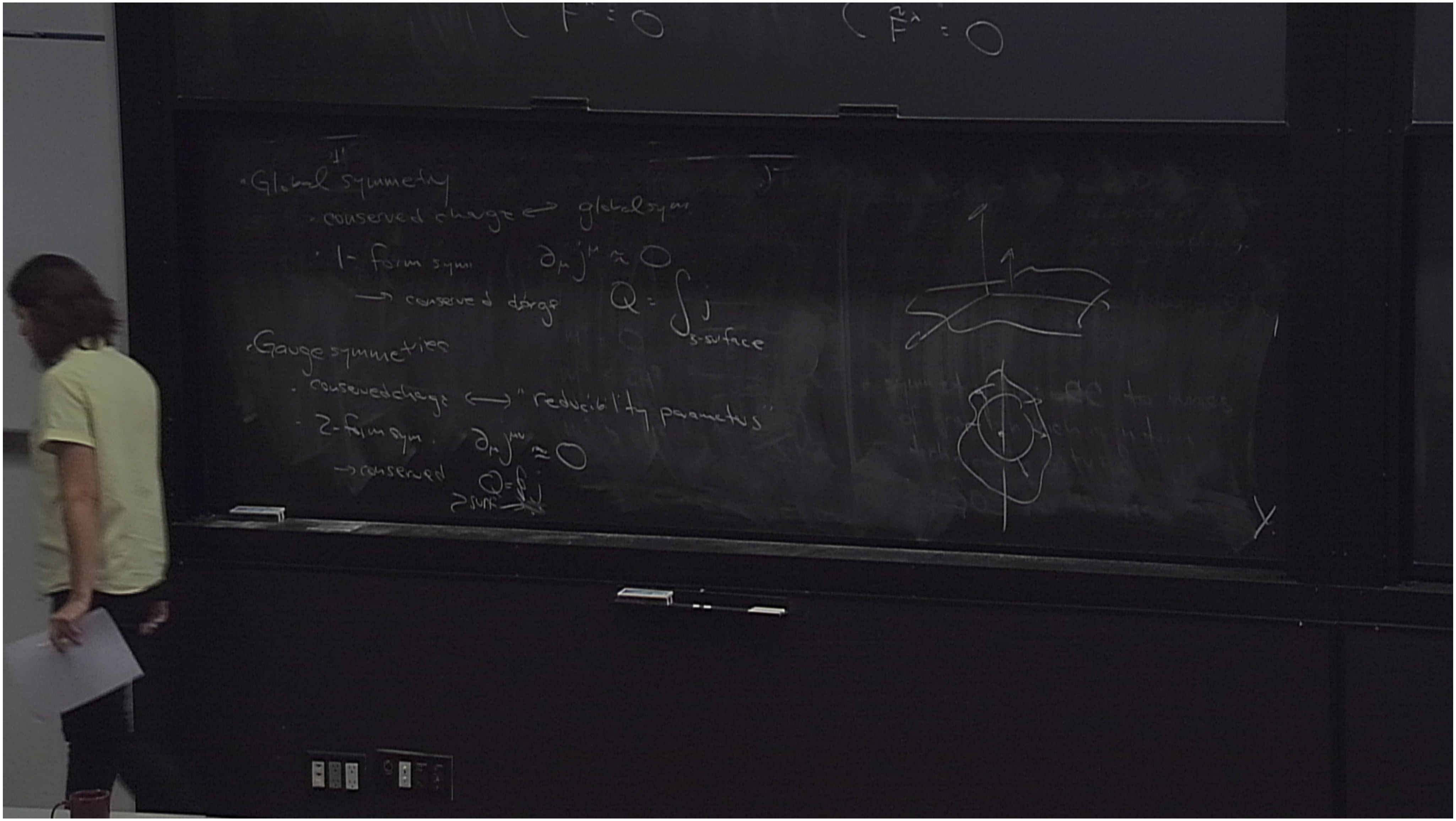
• 1-derivative field strength
$F_{\mu\nu\lambda} = \nabla_\mu h_{\nu\lambda} - \nabla_\nu h_{\mu\lambda}$



m ~ H
• 1-derivative field strength
$F_{\mu\nu\lambda} = \nabla_\mu h_{\nu\lambda} - \nabla_\nu h_{\mu\lambda}$
(inv under $\delta h_{\mu\nu} = (\nabla\nabla + H^2)\phi$)
$F^\lambda \equiv F^{\lambda\mu}{}_\mu$
$\mathcal{L} = -\frac{1}{4}\left(F_{\mu\nu\lambda}F^{\mu\nu\lambda} - 2F^\lambda F_\lambda\right)$
• "Electromagnetic duality"
$\delta F_{\mu\nu} = \tilde{F}_{\mu\nu}$
$\delta F_{\mu\nu\lambda} = \tilde{F}_{\mu\nu\lambda}$ where $\tilde{F}_{\mu\nu\lambda} = \frac{1}{2}\epsilon_{\mu\nu}{}^{\rho\sigma}F_{\rho\sigma\lambda}$
EOM $\nabla_\nu \tilde{F}^{\mu\nu\lambda} = 0$, $F^\lambda = 0$
Bianchi $\nabla_\nu F^{\mu\nu\lambda} = 0$, $\tilde{F}^\lambda = 0$



· Global symmetry
· conserved charge ⟷ global sym
· 1-form sym ∂μ j^μ ≈ 0
⟶ conserved charge Q = ∫ j
3-surface
· Gauge symmetries
· conserved charge ⟷ "reducibility parameters"
· 2-form sym ∂μ j^μν ≈ 0
⟶ conserved Q = ∫ j
2 surf


Global symmetry
conserved charge ⟷ global sym
1-form sym ∂μ j^μ ≈ 0
→ conserved charge Q = ∫ j
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Gauge symmetries
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→ conserved Q = ∮ j
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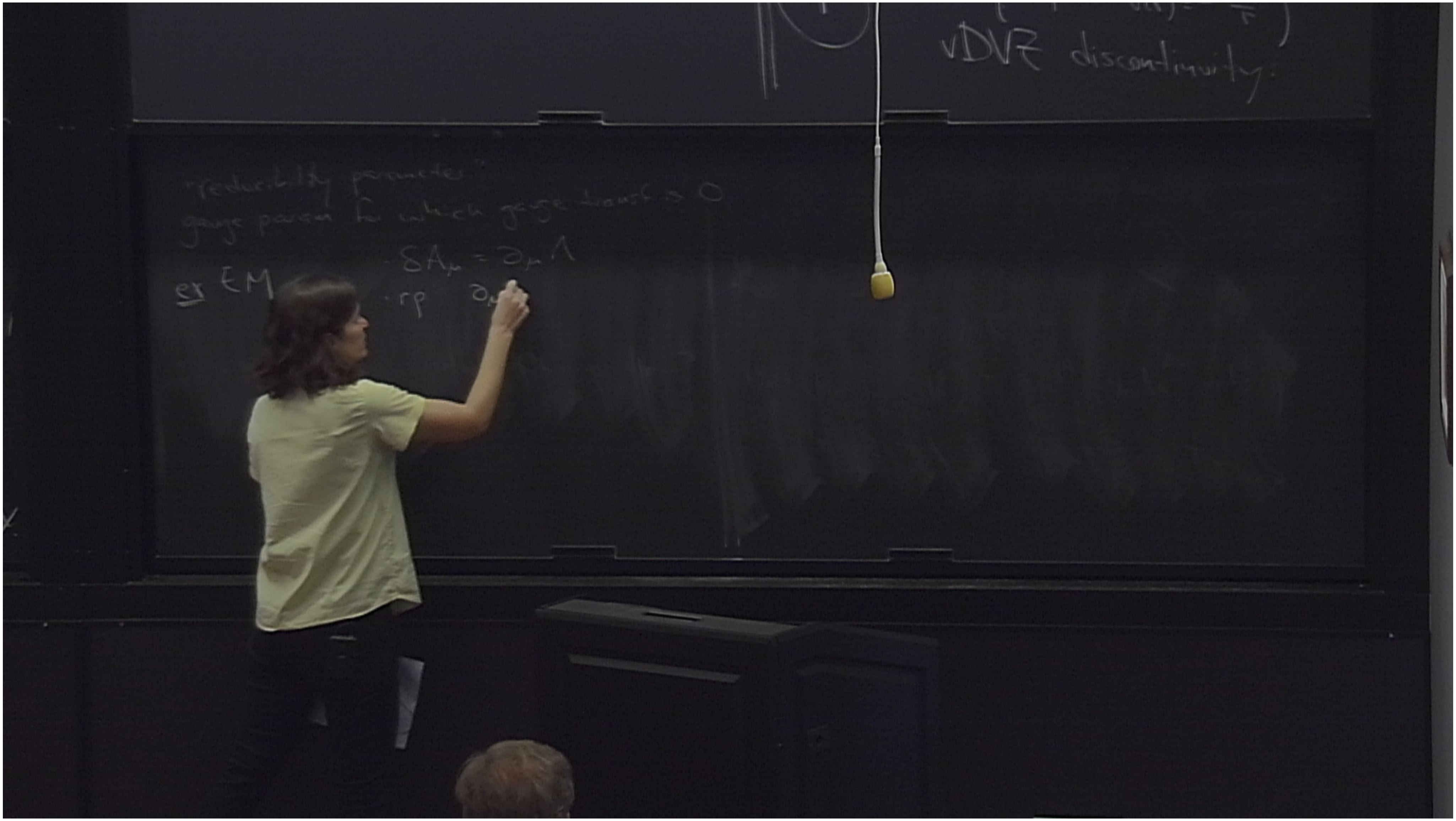
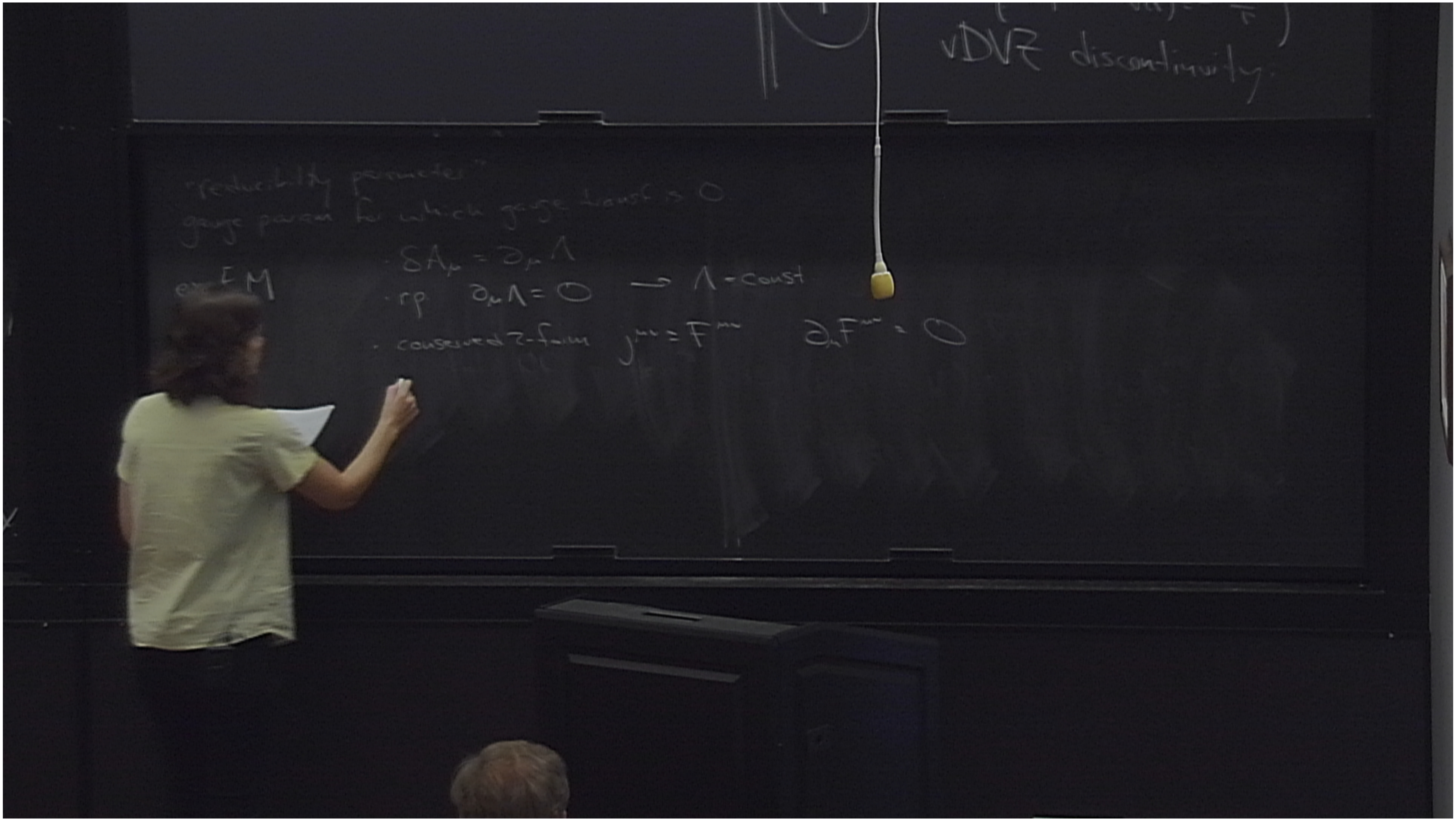
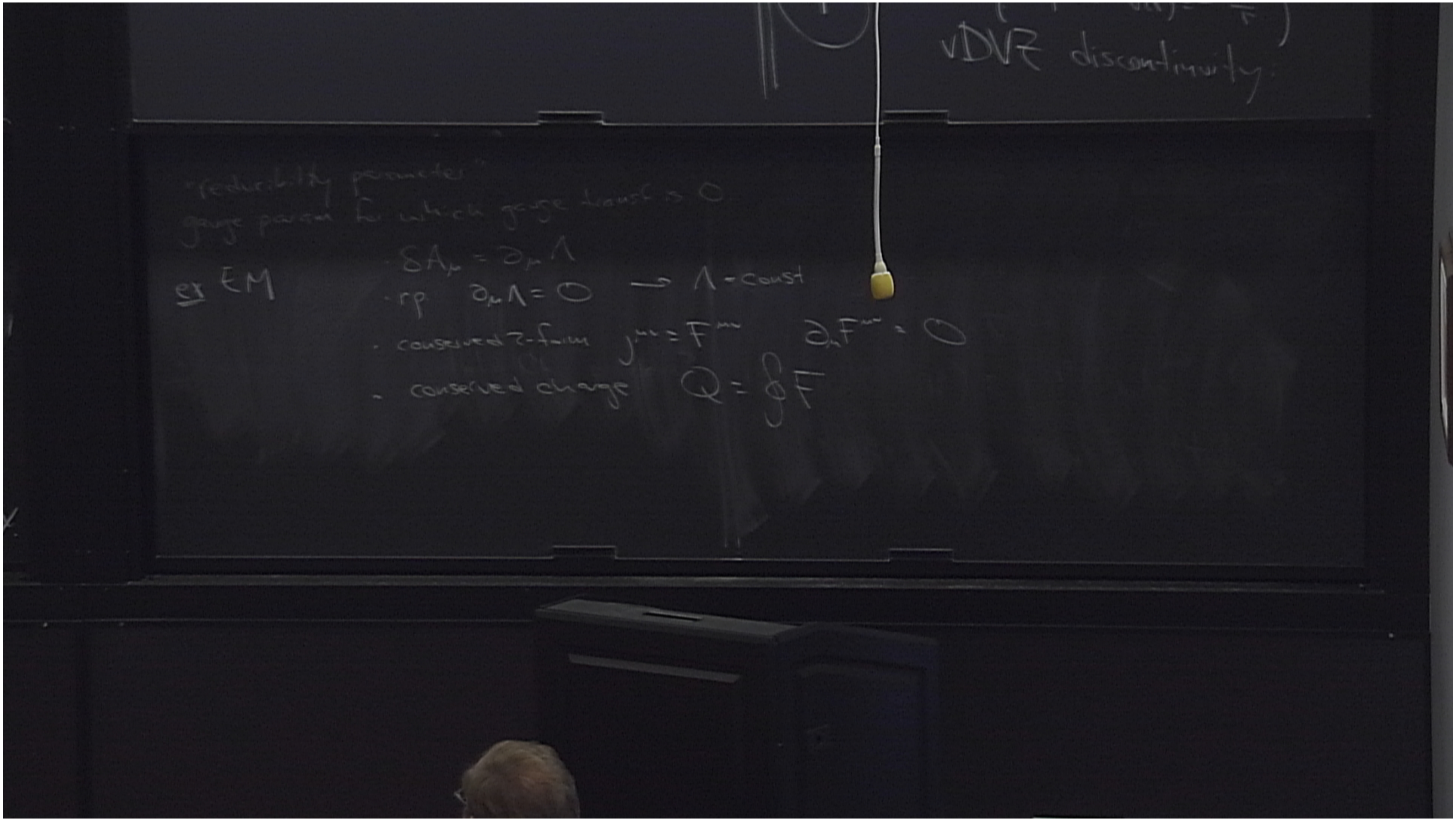

vDVZ discontinuity.
"reducibility parameter"
gauge param for which gauge transf is 0
δA_μ = ∂_μ Λ
ex EM


vDVZ discontinuity.
"reducibility parameter"
gauge param for which gauge transf is 0
ex: EM
· δA_μ = ∂_μ Λ
· rp ∂_μ Λ = 0 → Λ = const
· conserved 2-form j^μν = F^μν ∂_μ F^μν = 0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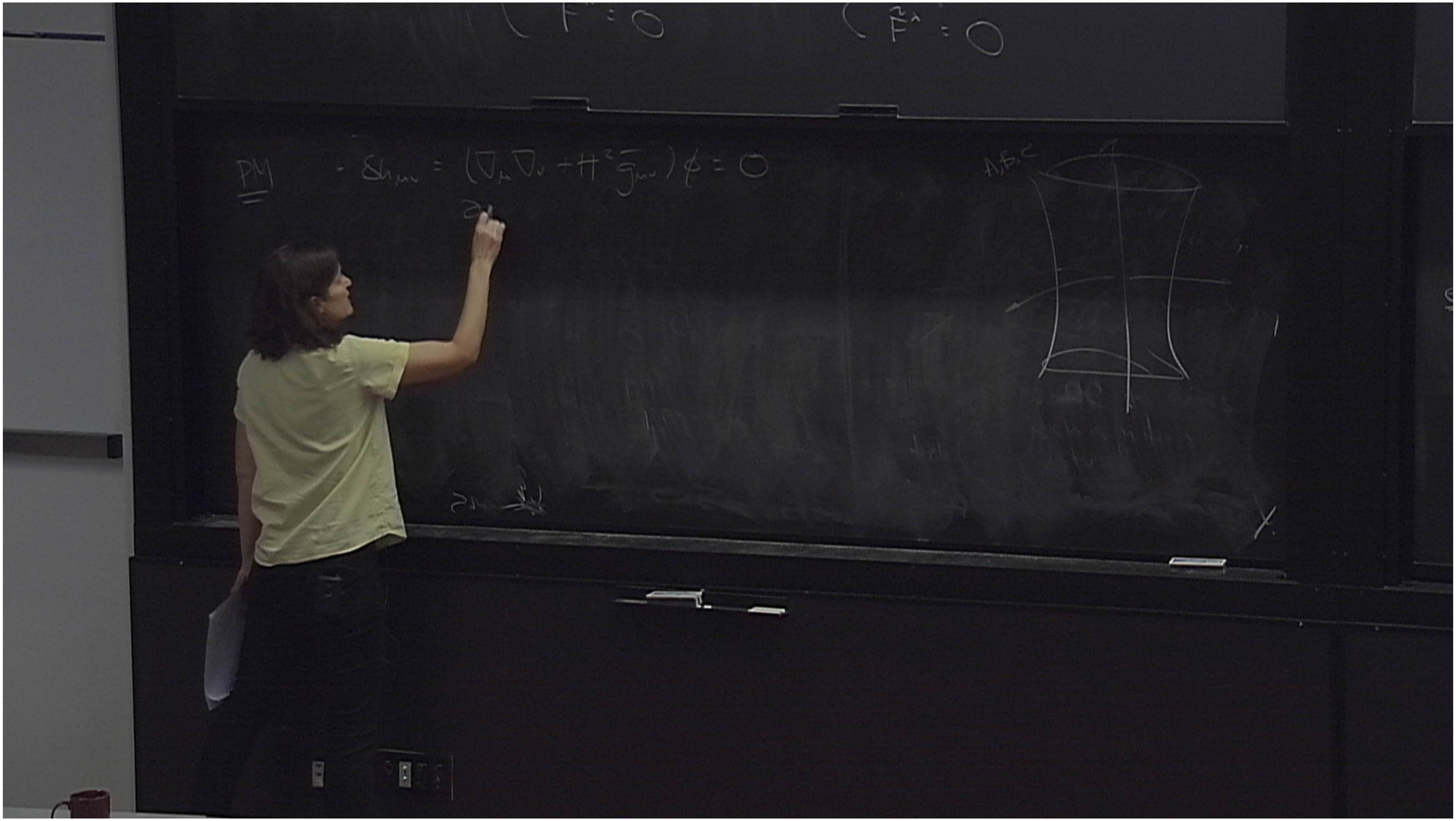
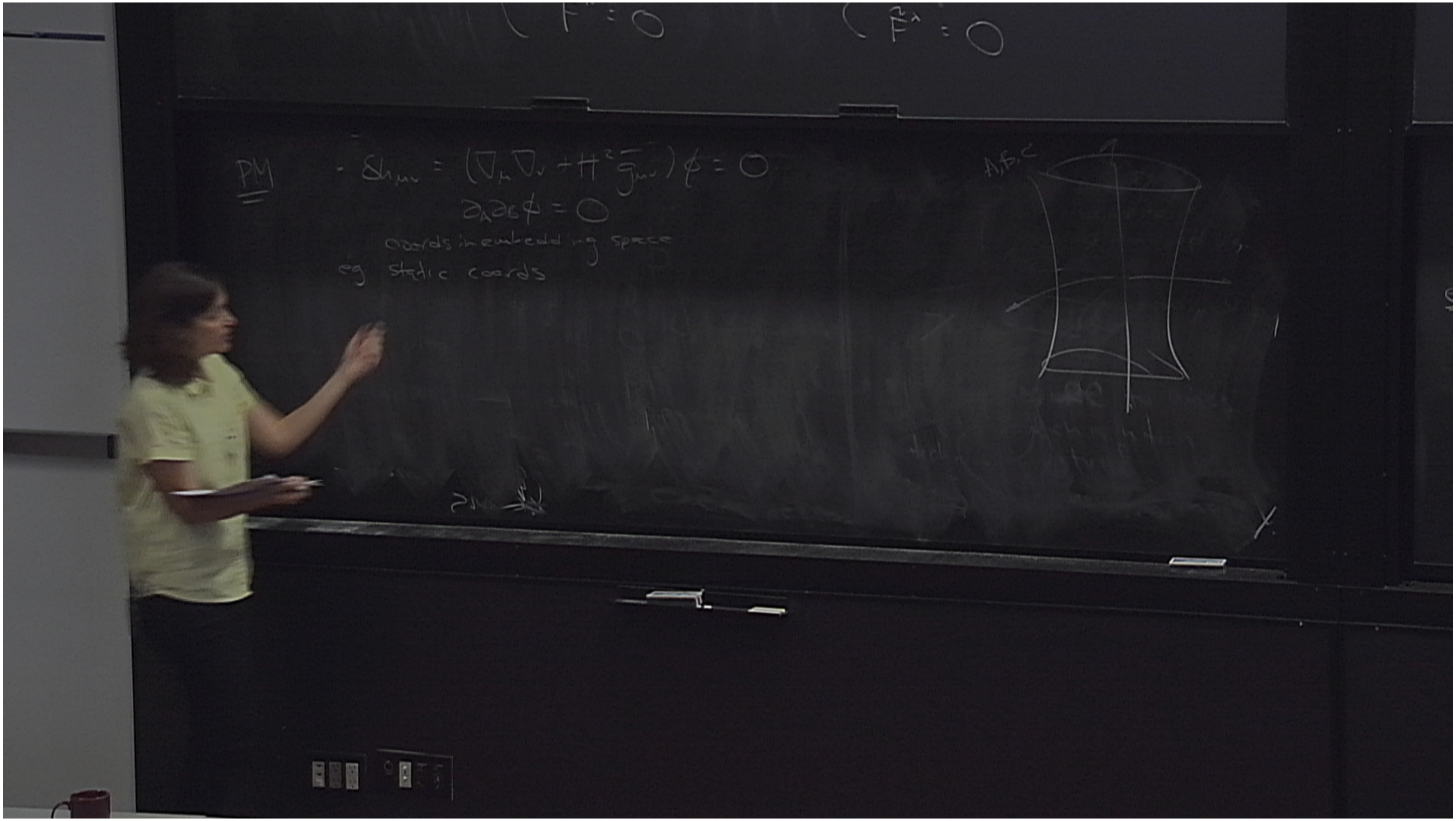
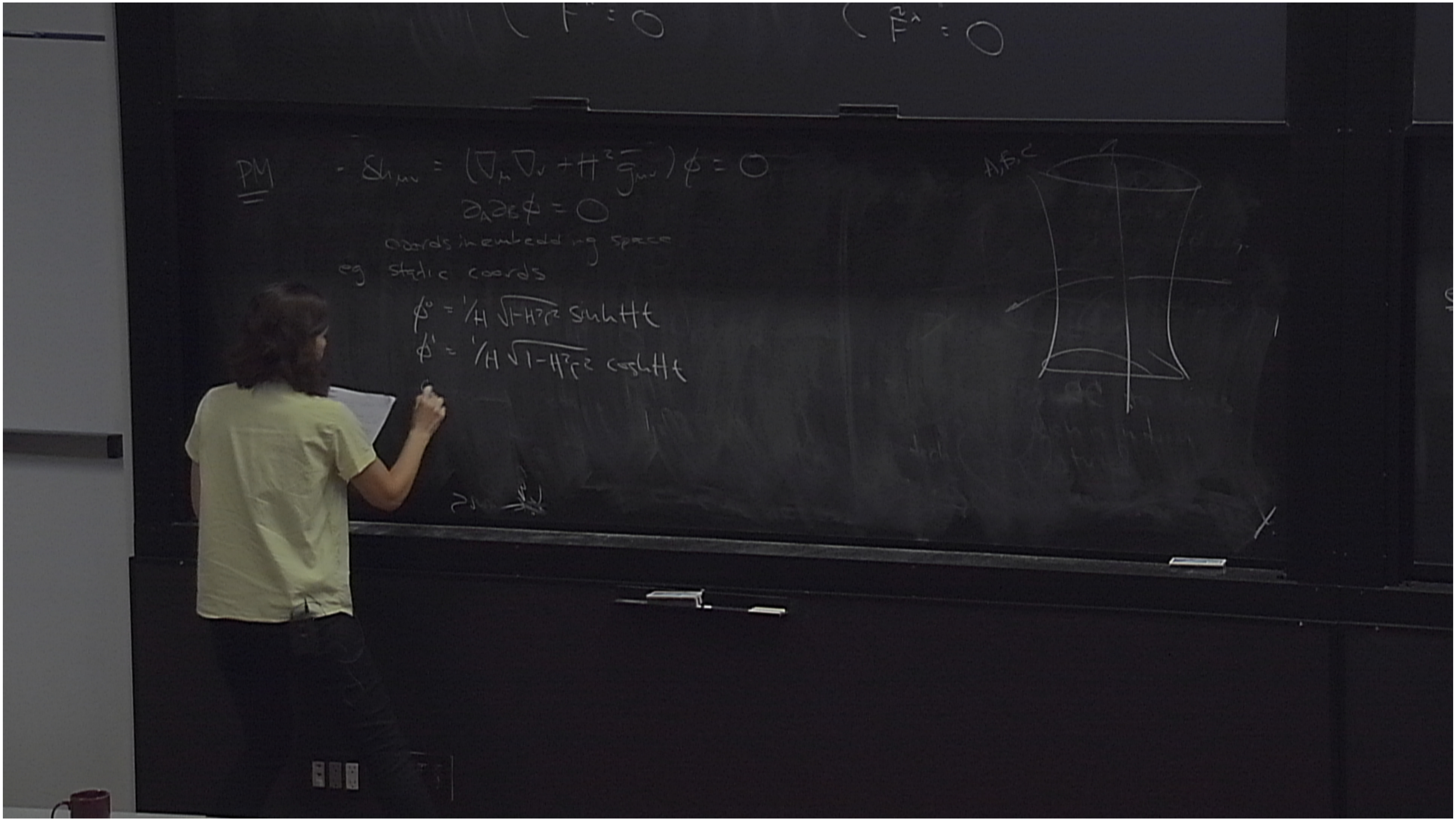
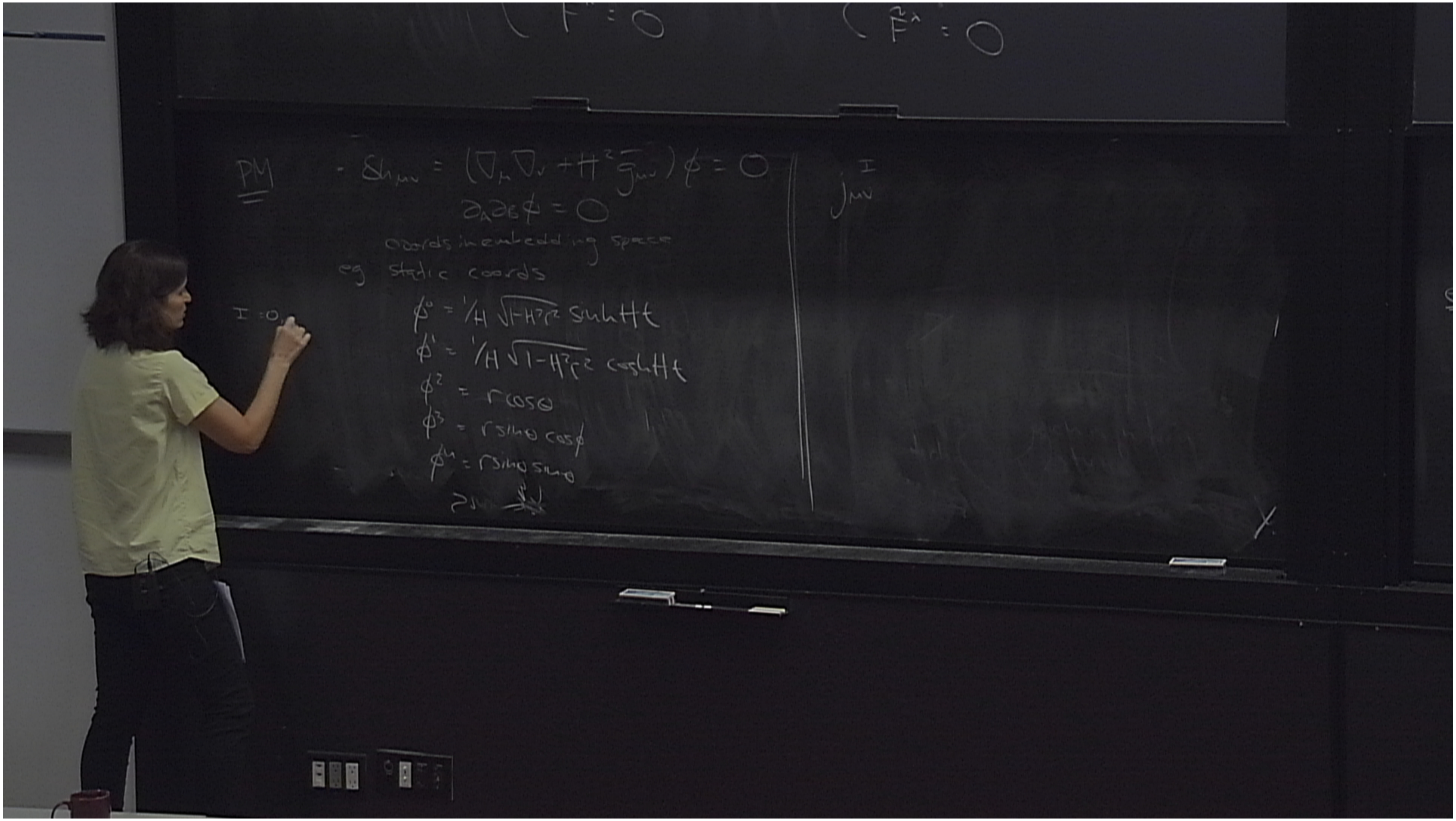
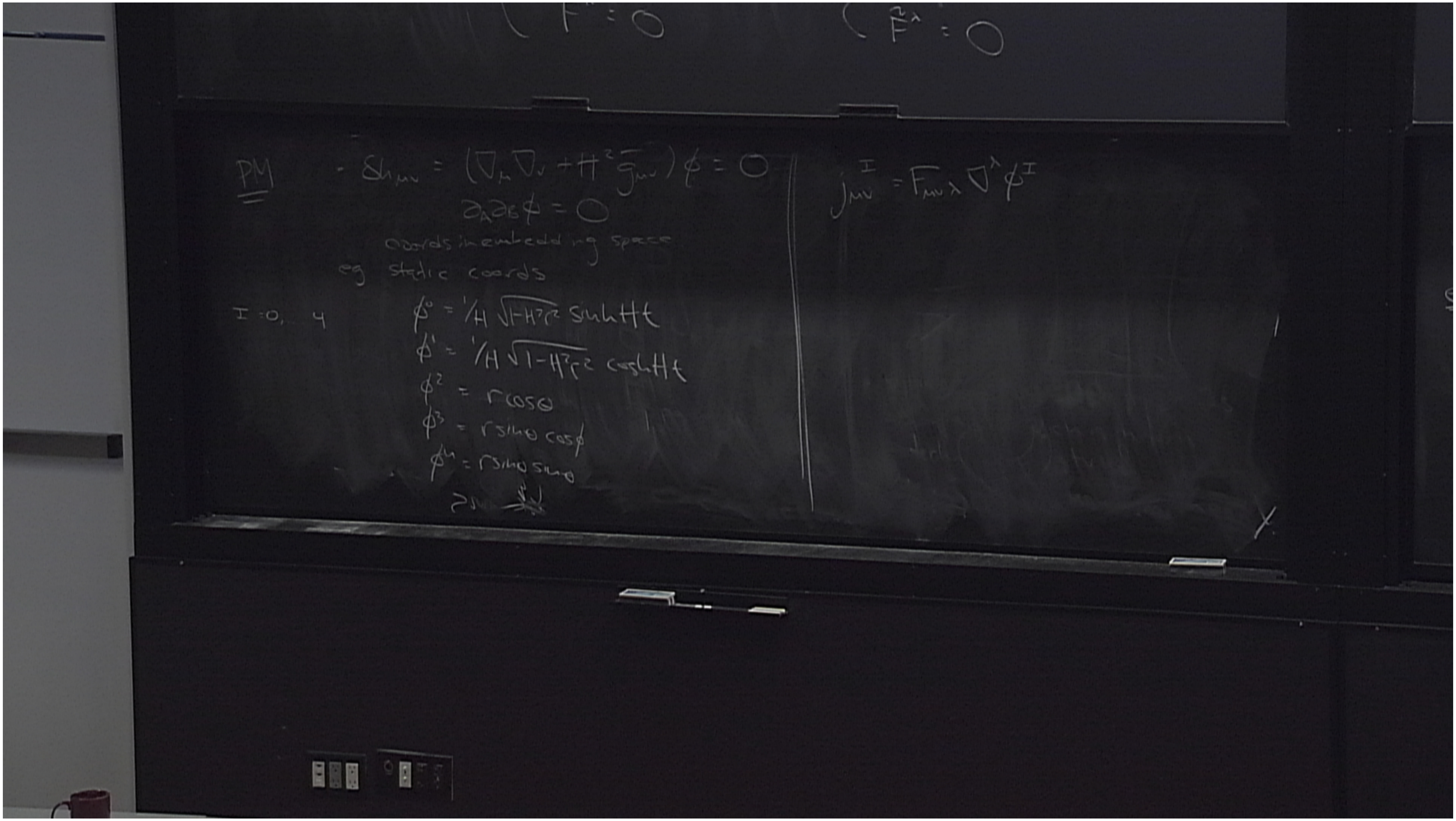
· conserved charge Q = ∮F

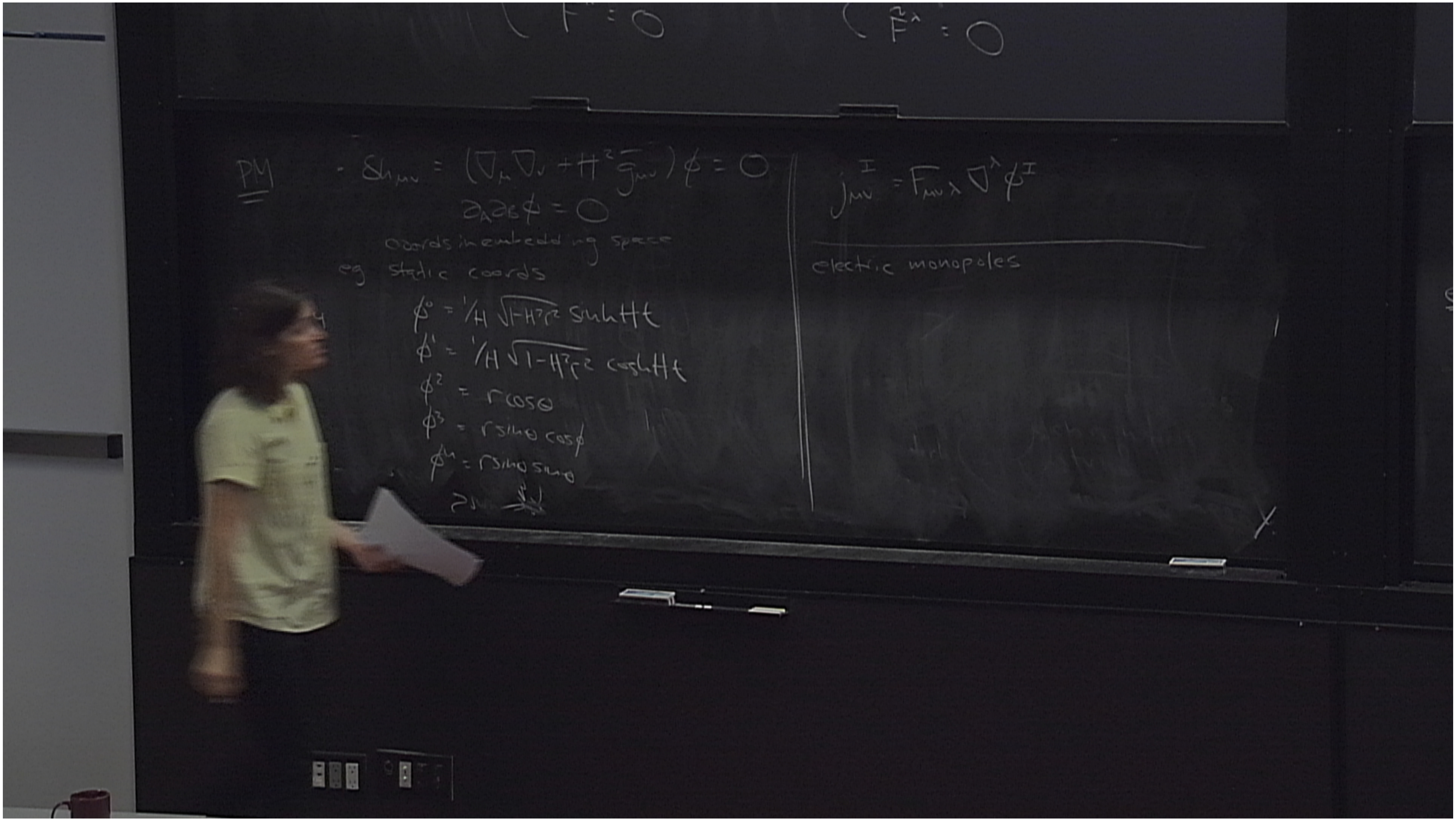



PM
$\delta h_{\mu\nu} = (\nabla_\mu \nabla_\nu + H^2 \bar{g}_{\mu\nu})\phi = 0$
$\partial_A \partial_B \phi = 0$
coords in embedding space
eg static coords
A, B, C


PM
- δh_μν = (∇_μ ∇_ν + H² g_μν) φ = 0
∂_A ∂_B φ = 0
coords in embedding space
eg static coords
φ⁰ = 1/H √(1-H²r²) sinh Ht
φ¹ = 1/H √(1-H²r²) cosh Ht


PM
$-\delta h_{\mu\nu} = (\nabla_\mu \nabla_\nu + H^2 \bar{g}_{\mu\nu})\phi = 0$
$\partial_A \partial_B \phi = 0$
coords in embedding space
eg static coords
$\phi^0 = \frac{1}{H}\sqrt{1-H^2r^2}\sinh Ht$
$\phi^1 = \frac{1}{H}\sqrt{1-H^2r^2}\cosh Ht$
$\phi^2 = r\cos\theta$
$\phi^3 = r\sin\theta\cos\phi$
$\phi^4 = r\sin\theta\sin\phi$
$j_{\mu\nu}^I$


PM
- δh_μν = (∇_μ ∇_ν + H² g_μν) φ = 0
∂_A ∂_B φ = 0
coords in embedding space
eg static coords
I = 0, ... 4
φ⁰ = 1/H √(1-H²r²) sinh Ht
φ¹ = 1/H √(1-H²r²) cosh Ht
φ² = r cos θ
φ³ = r sin θ cos φ
φ⁴ = r sin θ sin φ
j_μν^I = F_μνλ ∇^λ φ^I


PM
electric monopoles
eg static coords
coords in embedding space