Title: Mass and Tension (momentum) Sum Rules in AdS (dS)

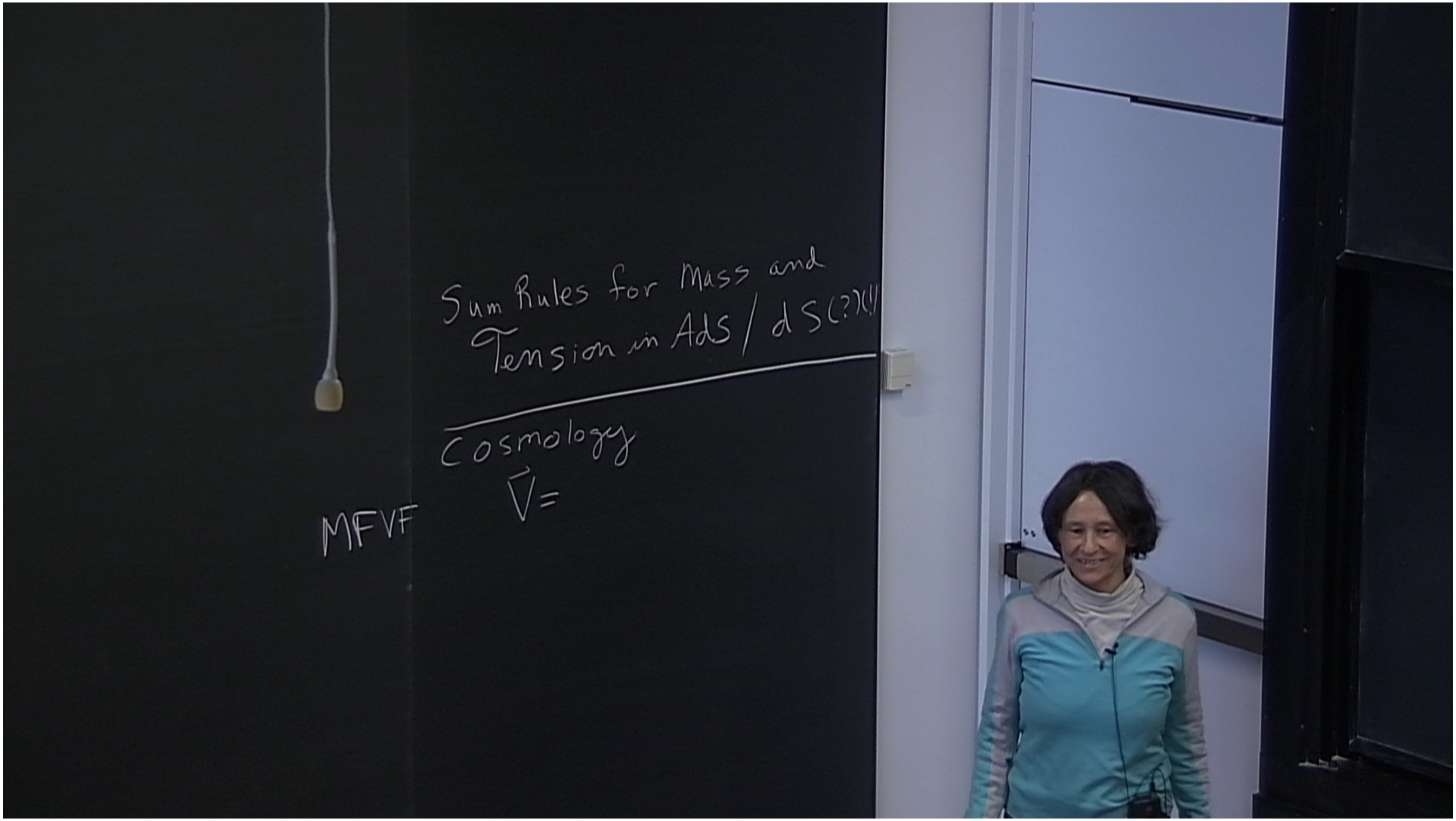
Date: Nov 27, 2012 11:00 AM

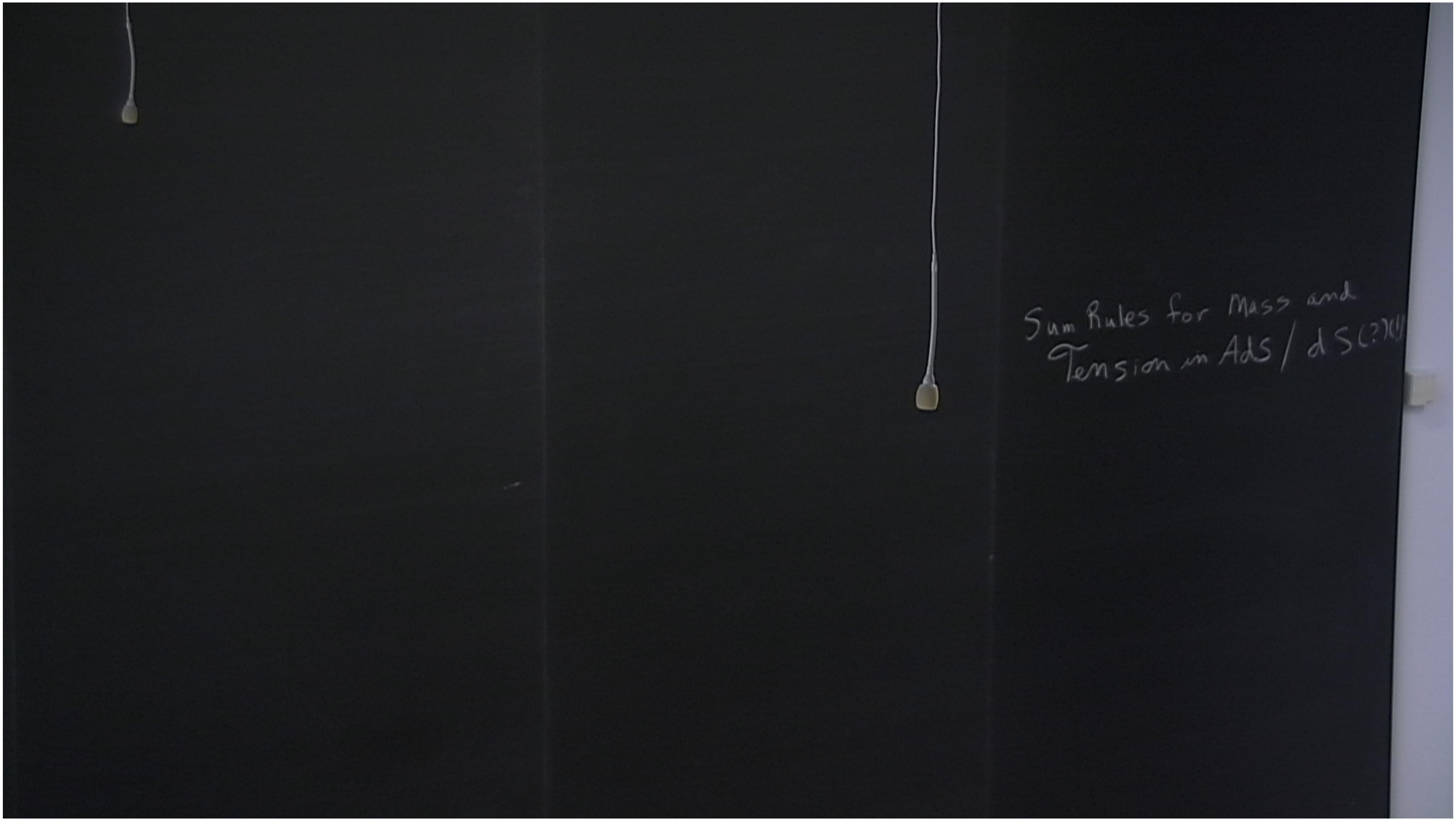
URL: http://www.pirsa.org/12110042

Abstract: The stress-energy tensor in a conformal field theory has zero trace.

Hence AdS boundary stress-tensors are traceless by construction, to match this property of the dual CFT. An elegant (aka nifty) construction based on the conformal isometry of AdS will be presented which shows that in an asymptotically AdS spacetime, the sum of the ADM mass and the ADM tensions is zero. This result follows strictly from the gravitational point of view- that is, the Einstein equations and the definitions of the ADM charges. Further, it turns out that perturbative stress-energy sources in an asymptotically AdS spacetime must satisfy a local version of this constraint, namely that the sum of the energy density minus the pressures equals zero. The situation with positive cosmological constant is both similar and distinct in interesting ways, which will be briefly discussed. The analogous (analytically continued) conformal isometry in dS is the root of the

``k^4 â€œ power spectrum for causal cosmological perturbations. Work in progress (speculations) will be presented about a corresponding sum-rule for gravitational charges defined at future infinity in a spacetime that approaches dS at late times.


Sum Rules for Mass and
Tension in AdS / dS(?)(!)
Cosmology
$\vec{V} =$
MFVF


Sum Rules for Mass and
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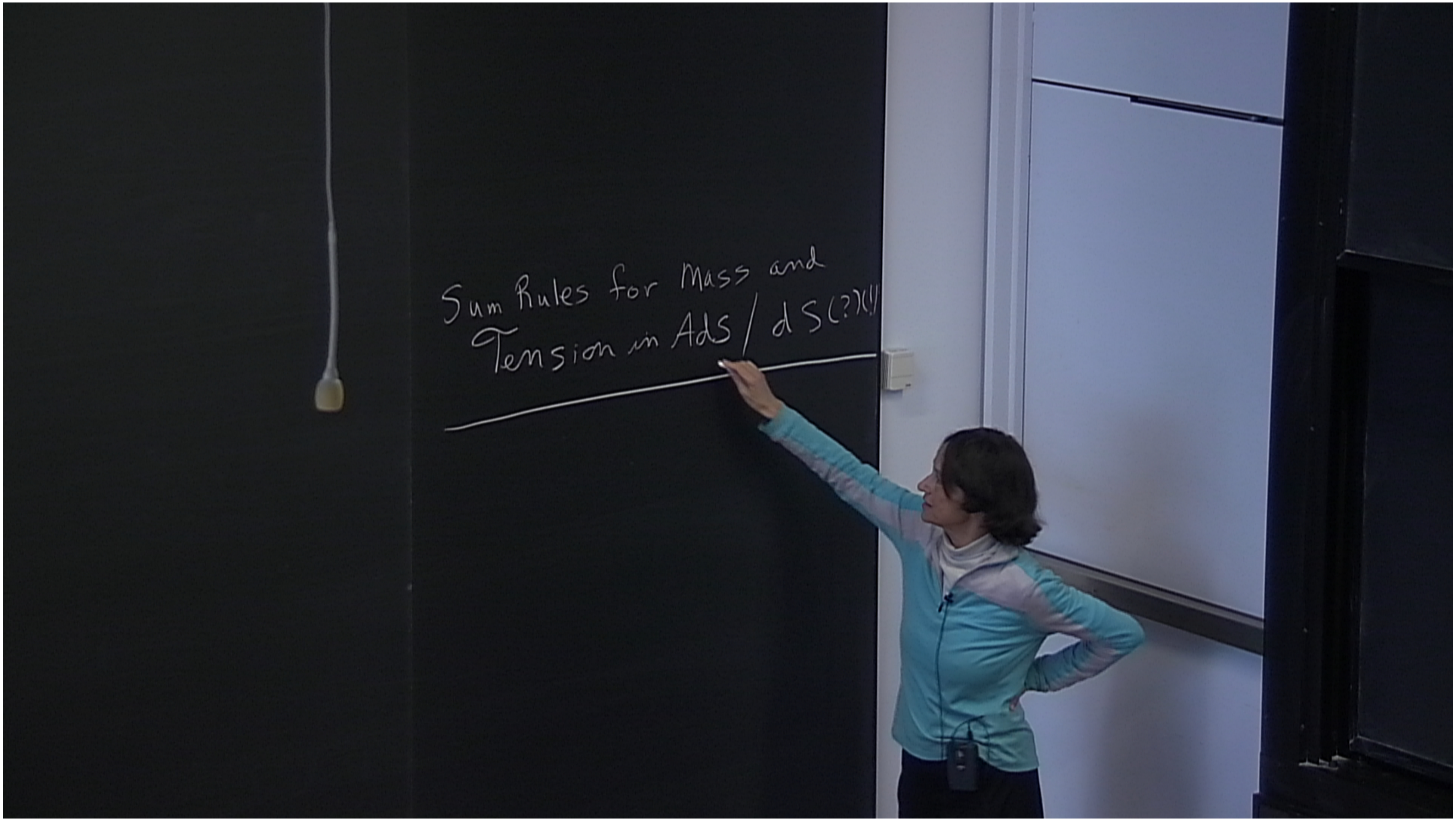
Sum Rules for Mass and
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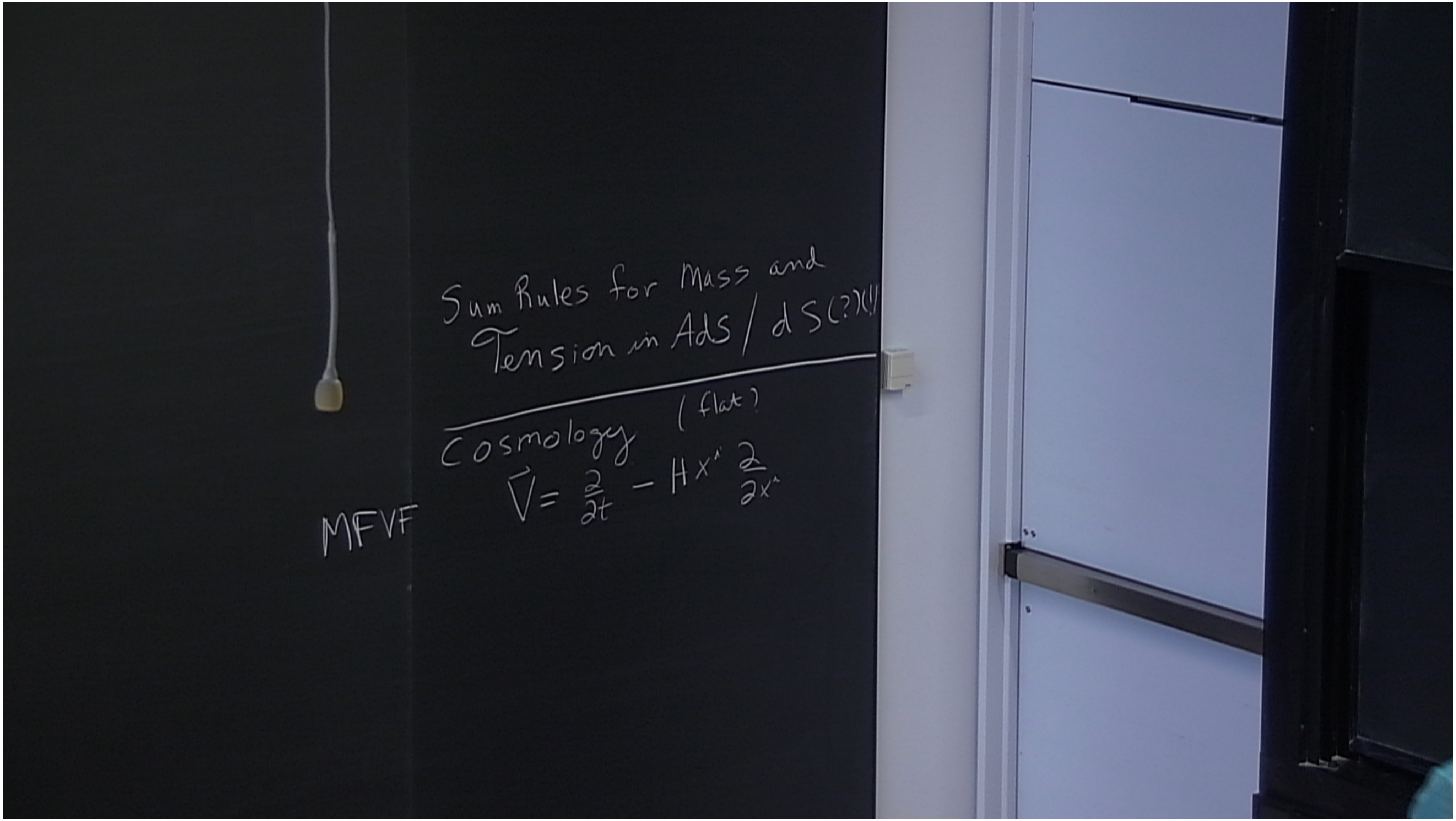
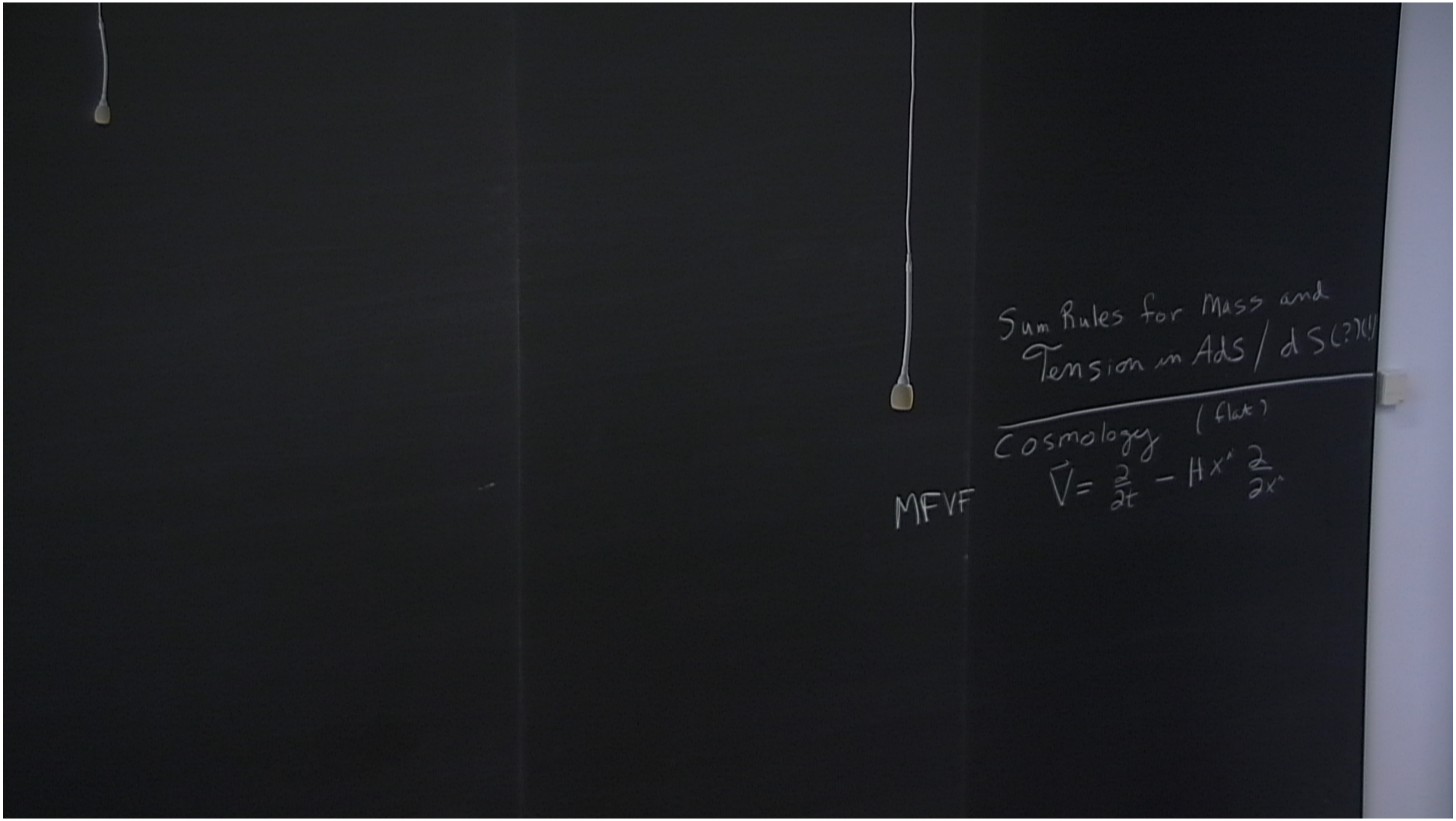

Sum Rules for Mass and
Tension in AdS / dS (?)(!)
Cosmology (flat)
$\vec{\nabla} = \frac{\partial}{\partial t} - H x^i \frac{\partial}{\partial x^i}$
MFVF


Sum Rules for Mass and
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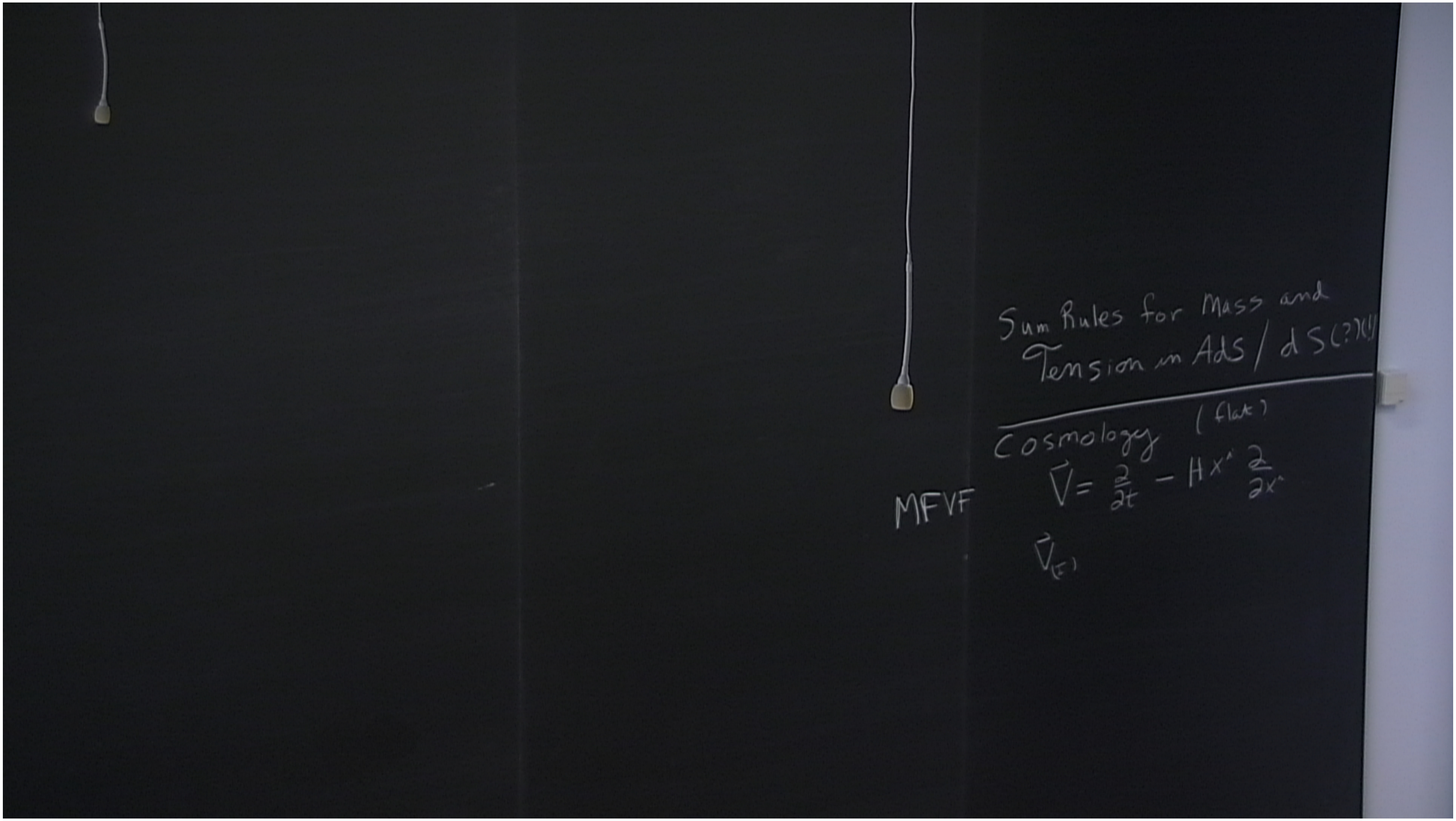
Cosmology (flat)
$\vec{V} = \frac{\partial}{\partial t} - H x^i \frac{\partial}{\partial x^i}$
MFVF


Sum Rules for Mass and
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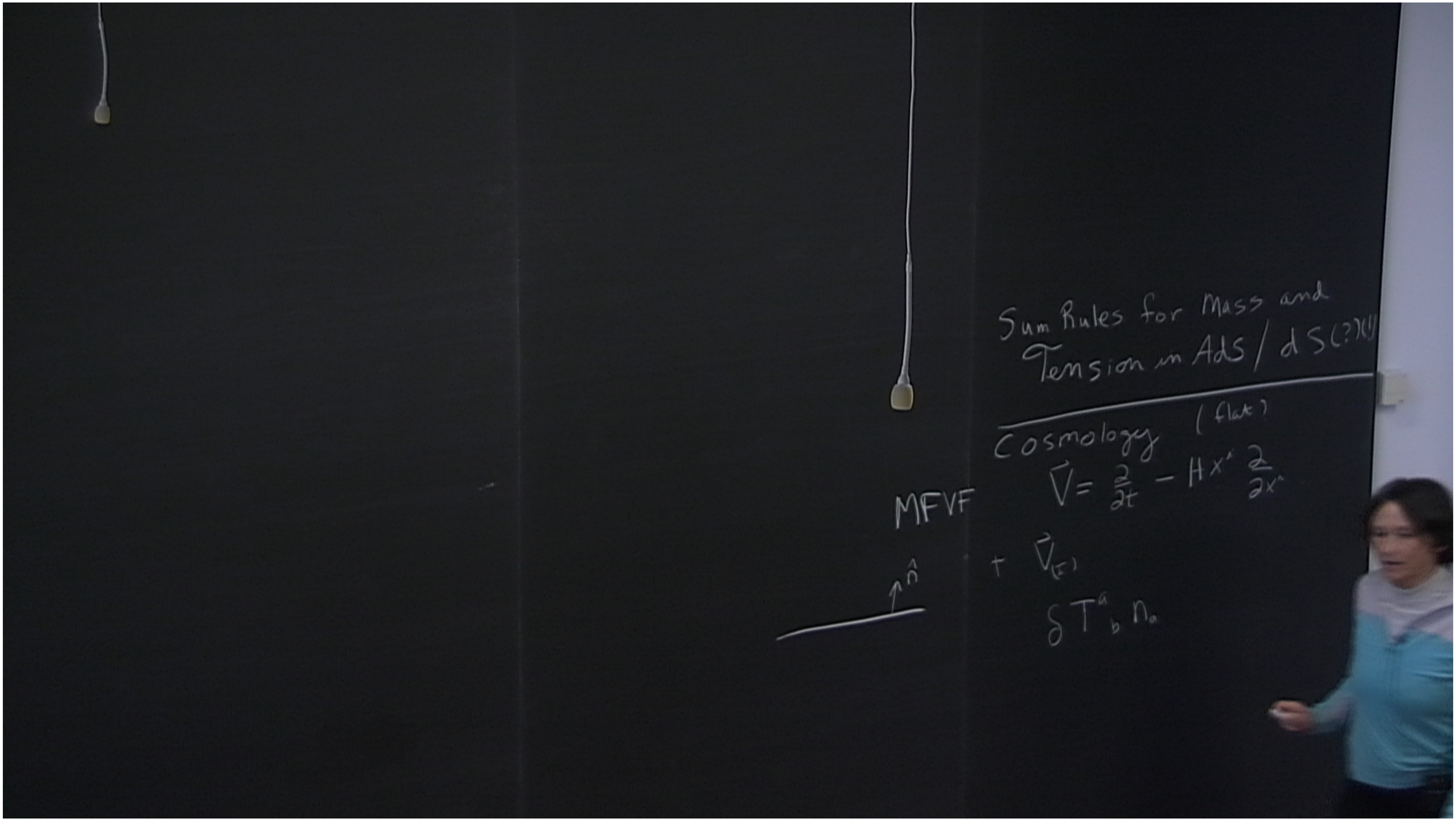
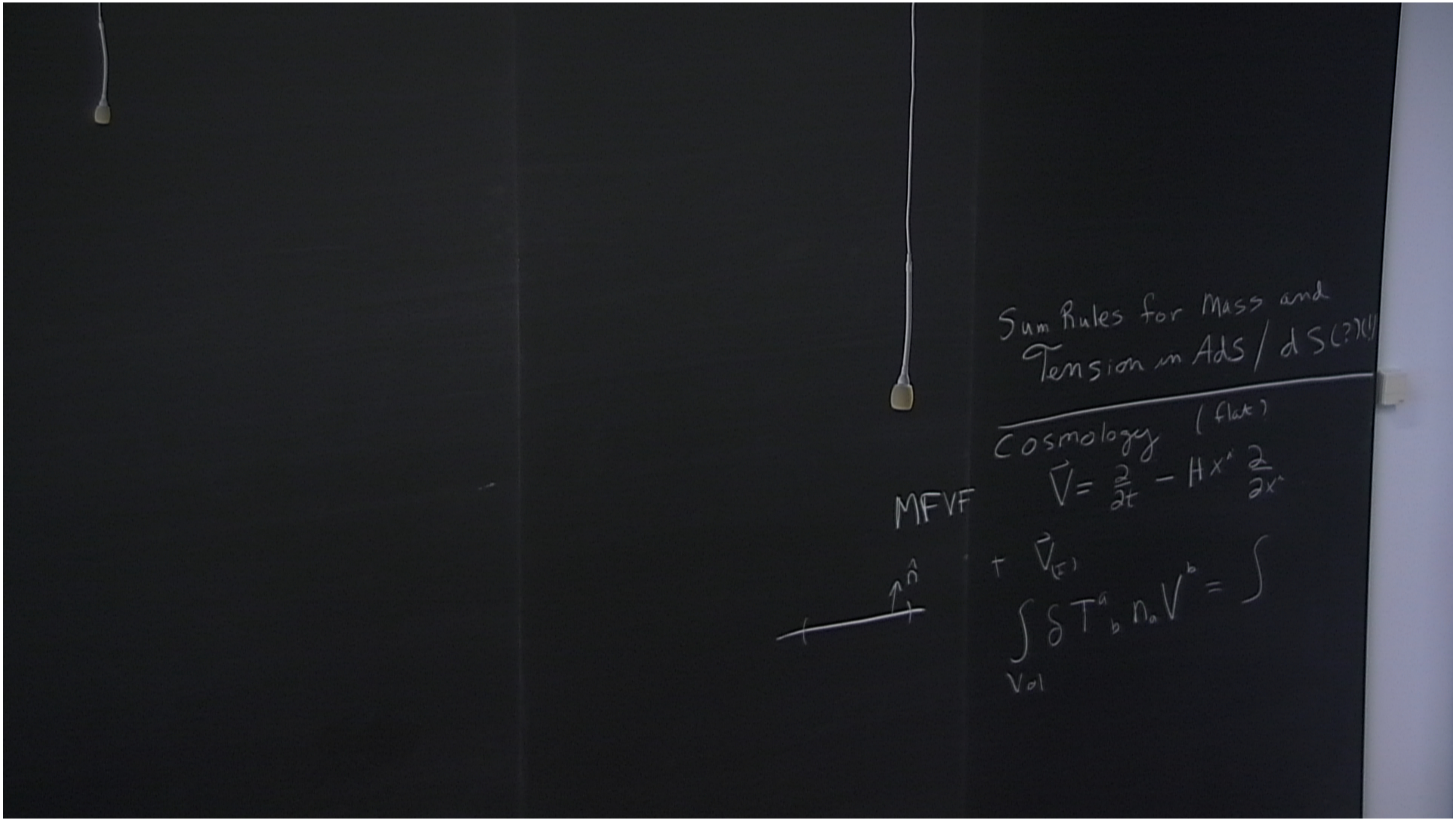
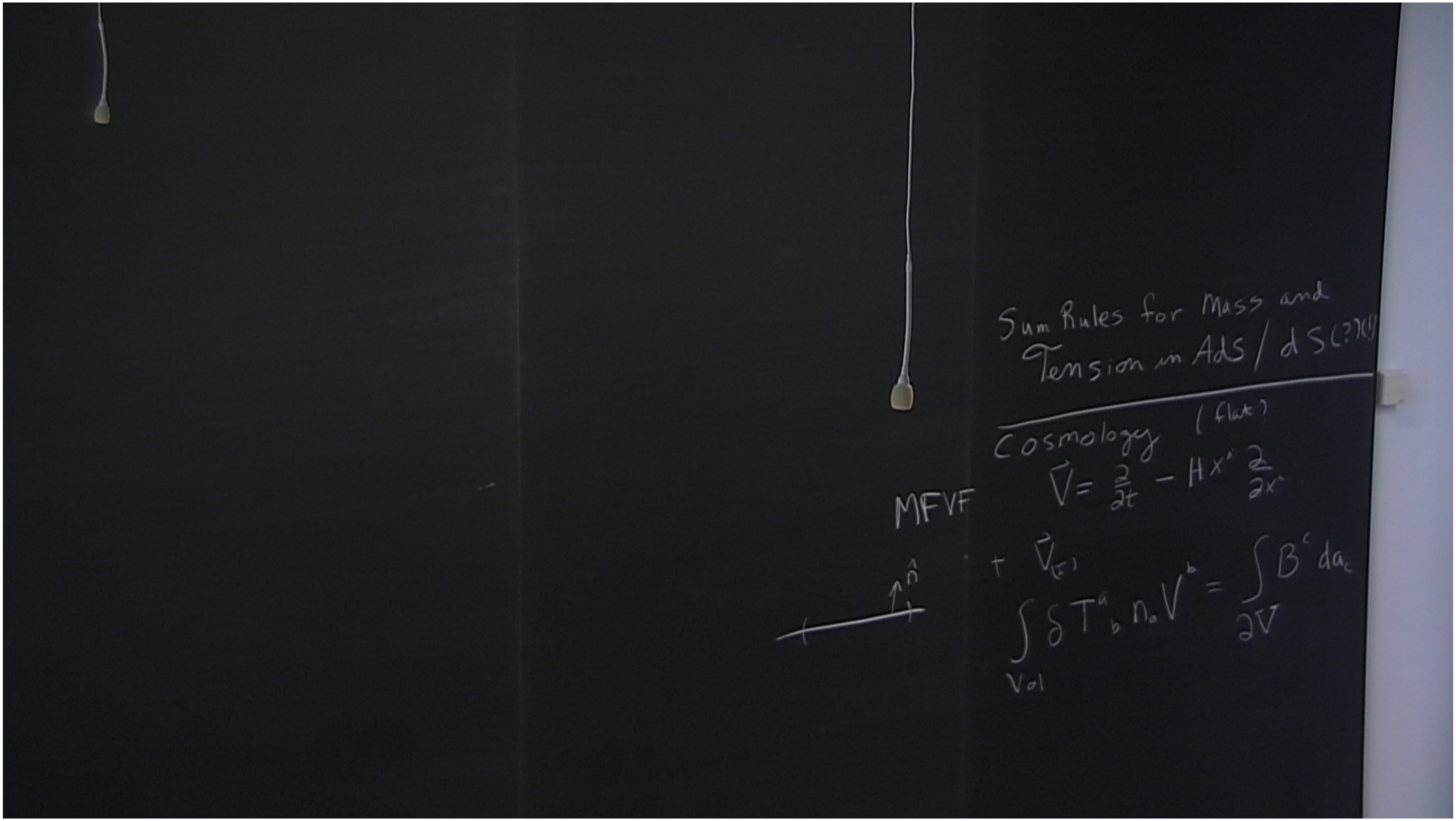
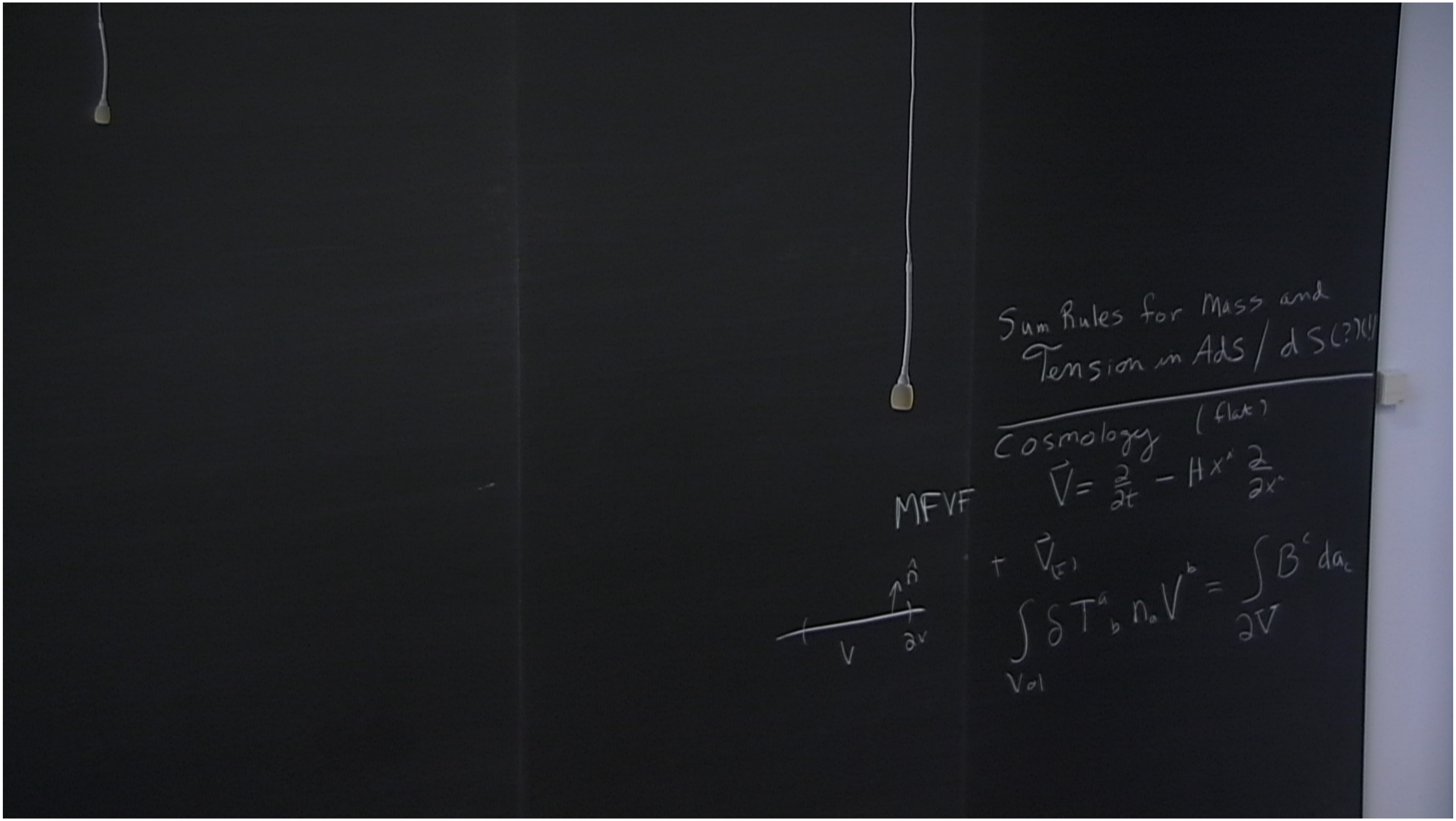
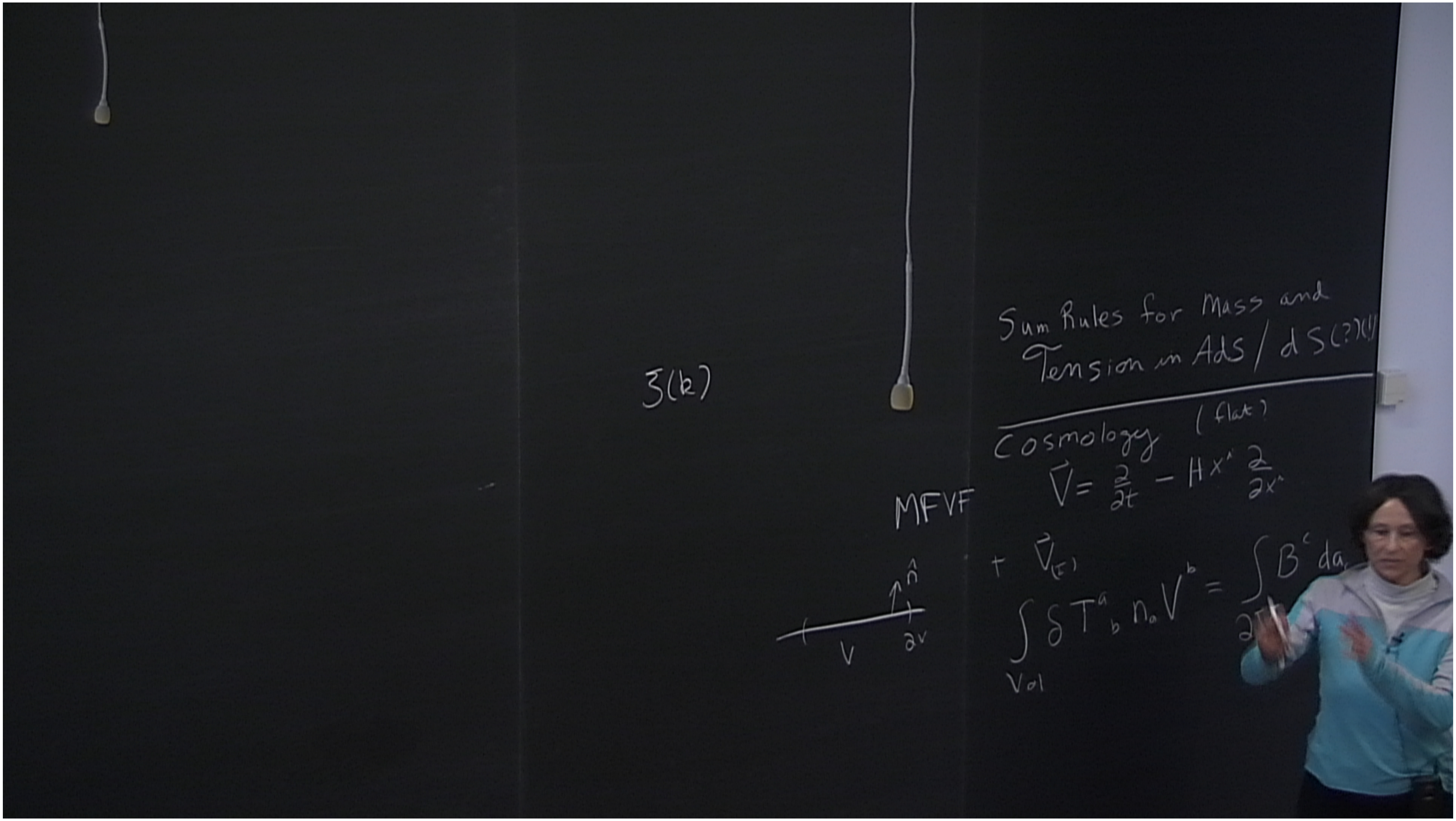
Cosmology (flat)
MFVF
$\vec{V} = \frac{\partial}{\partial t} - H x^i \frac{\partial}{\partial x^i}$

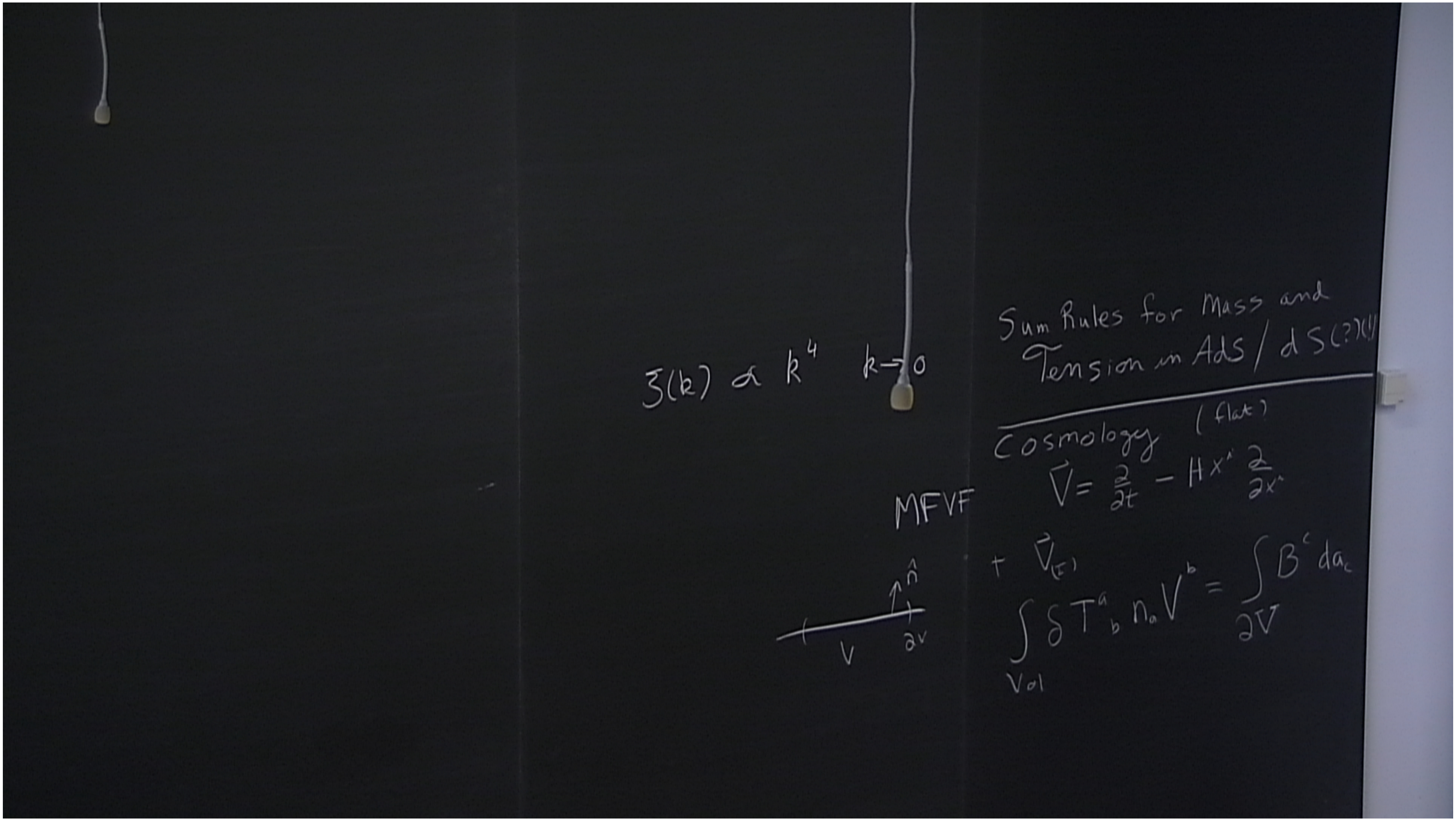

Sum Rules for Mass and
Tension in AdS / dS (?)(!)
Cosmology (flat)
MFVF
$\vec{V} = \frac{\partial}{\partial t} - H x^i \frac{\partial}{\partial x^i}$
$+ \vec{V}_{(\Sigma)}$
$\hat{n}$
$\delta T^a{}_b n_a$

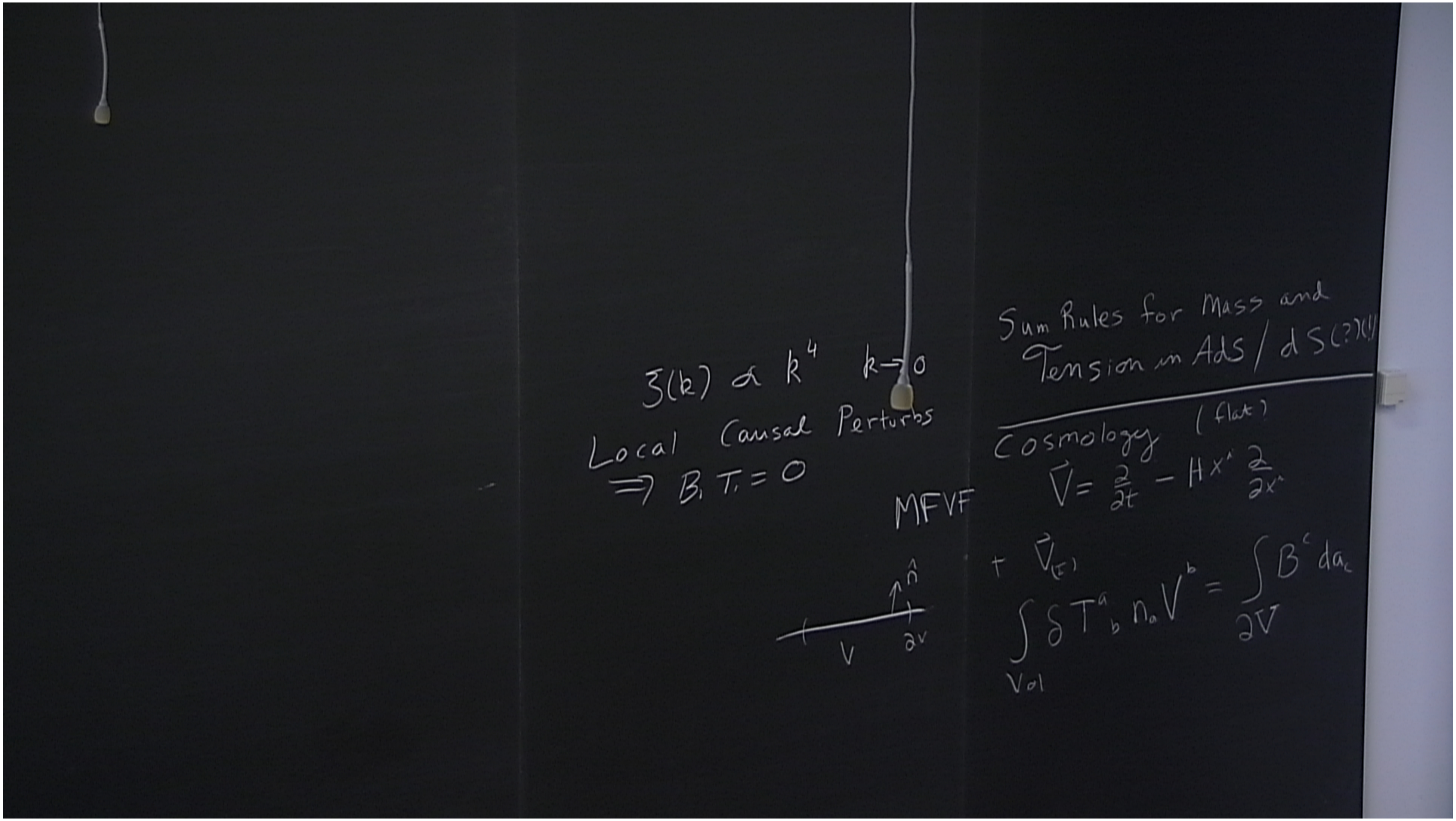

Sum Rules for Mass and
Tension in AdS / dS (?)(!)
Cosmology (flat)
V = ∂/∂t − H x^i ∂/∂x^i
MFVF
+ V(ε)
∫ δ T^a_b n_a V^b = ∫
Vol

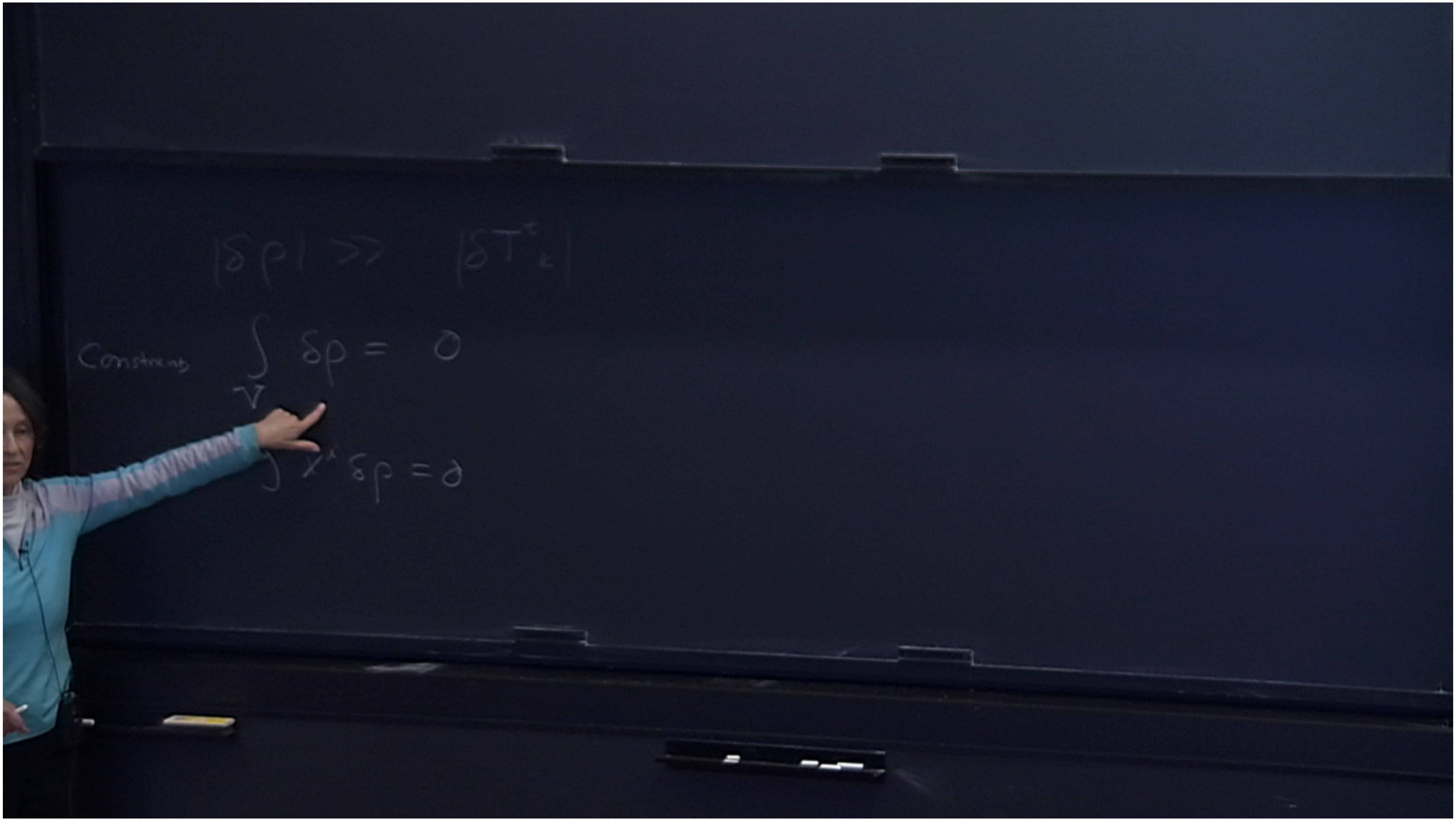

Sum Rules for Mass and
Tension in AdS / dS (?)(!)
Cosmology (flat)
$\vec{V} = \frac{\partial}{\partial t} - H x^i \frac{\partial}{\partial x^i}$
MFVF
$+ \vec{V}_{(\varepsilon)}$
$\hat{n}$
$\int_{Vol} \delta T^a{}_b n_a V^b = \int_{\partial V} B^c da_c$

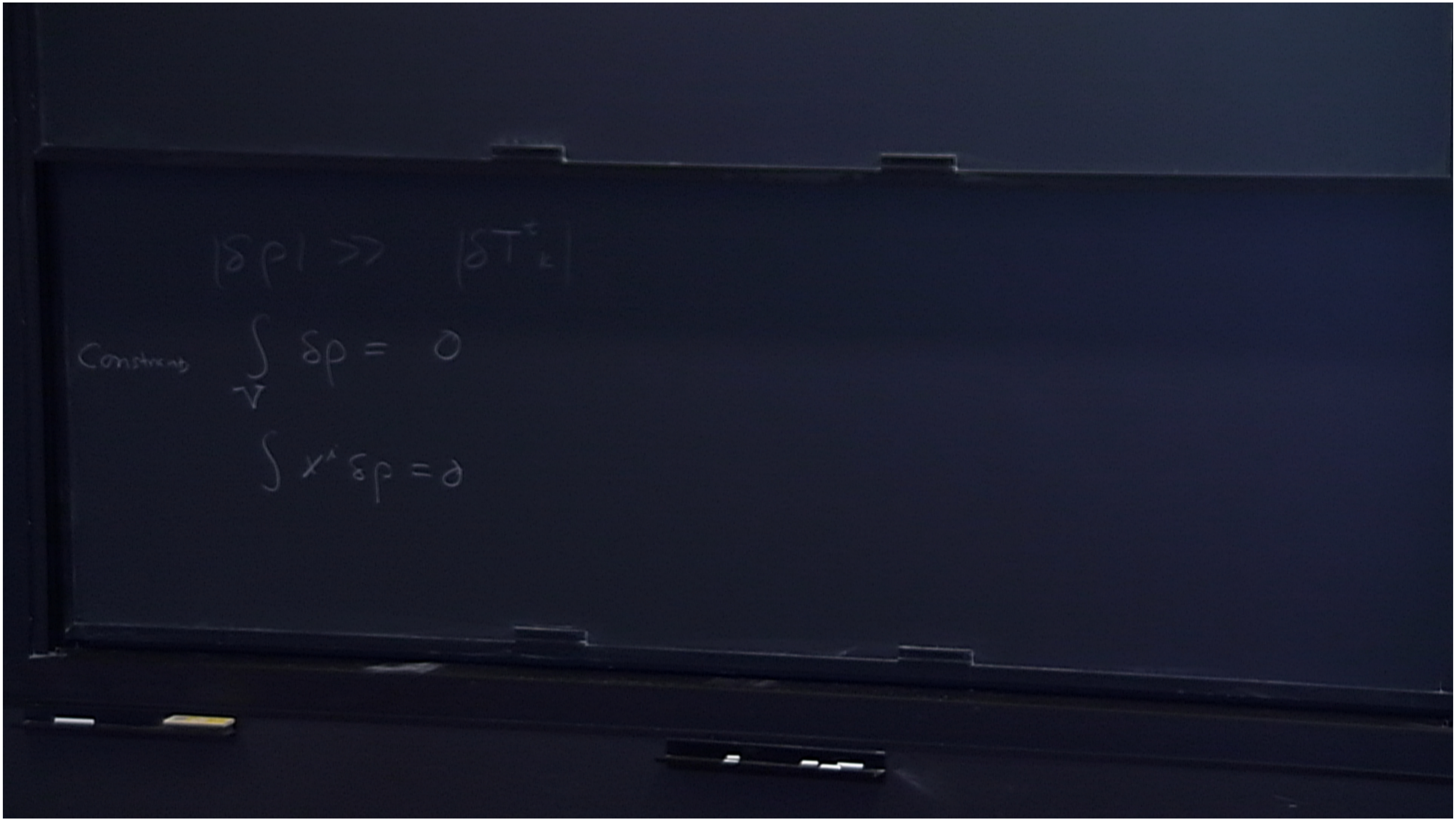

Sum Rules for Mass and
Tension in AdS / dS (?)(!)
Cosmology (flat)
MFVF
V = ∂/∂t − H x^i ∂/∂x^i
+ V(ε)
∫ δT^a_b n_a V^b = ∫ B^c da_c
Vol
∂V
n̂
V
∂V

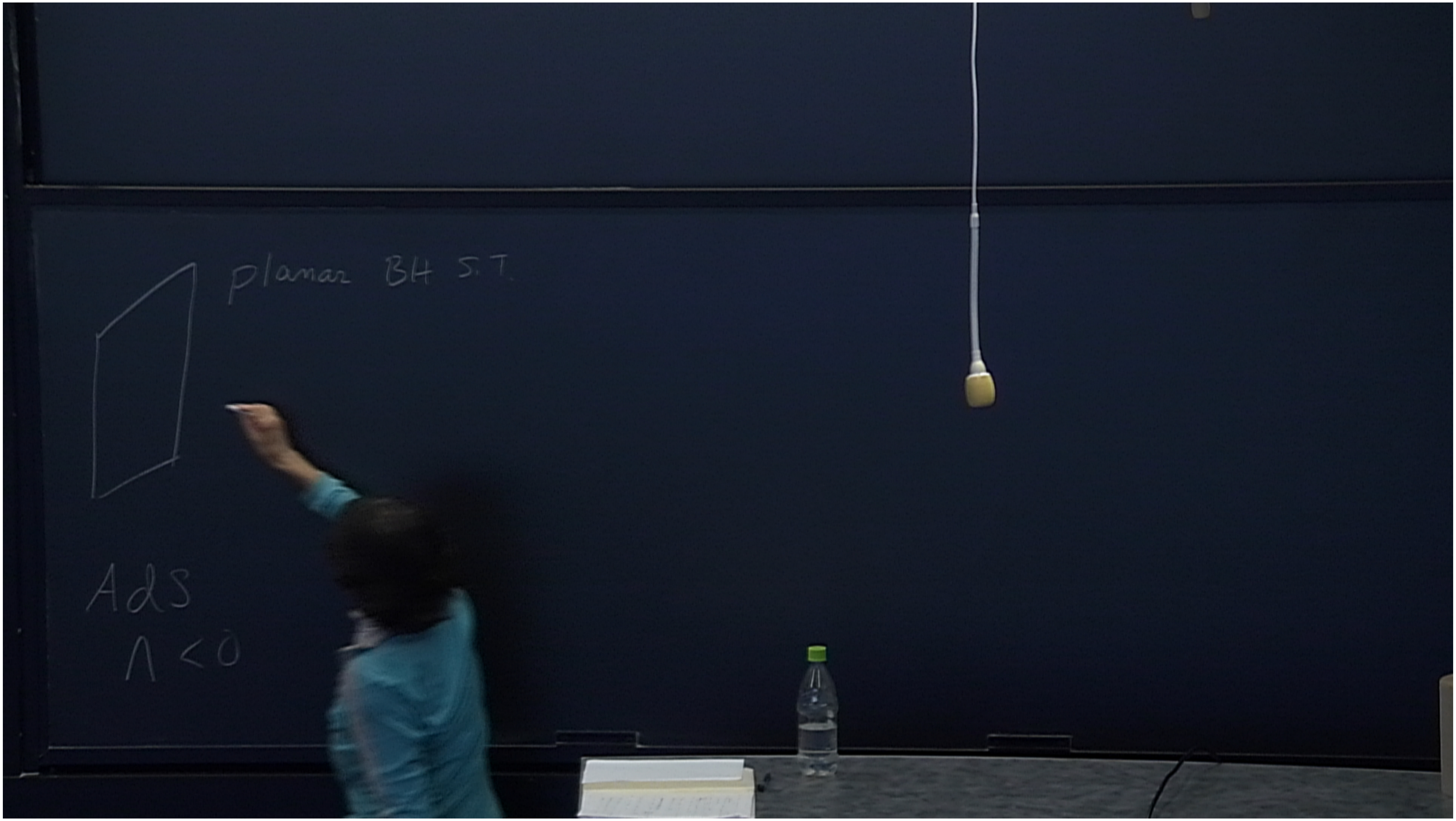

Sum Rules for Mass and
Tension in AdS / dS (?)(!)
Cosmology
(flat)
MFVF
ξ(k)
V
∂V
Vol

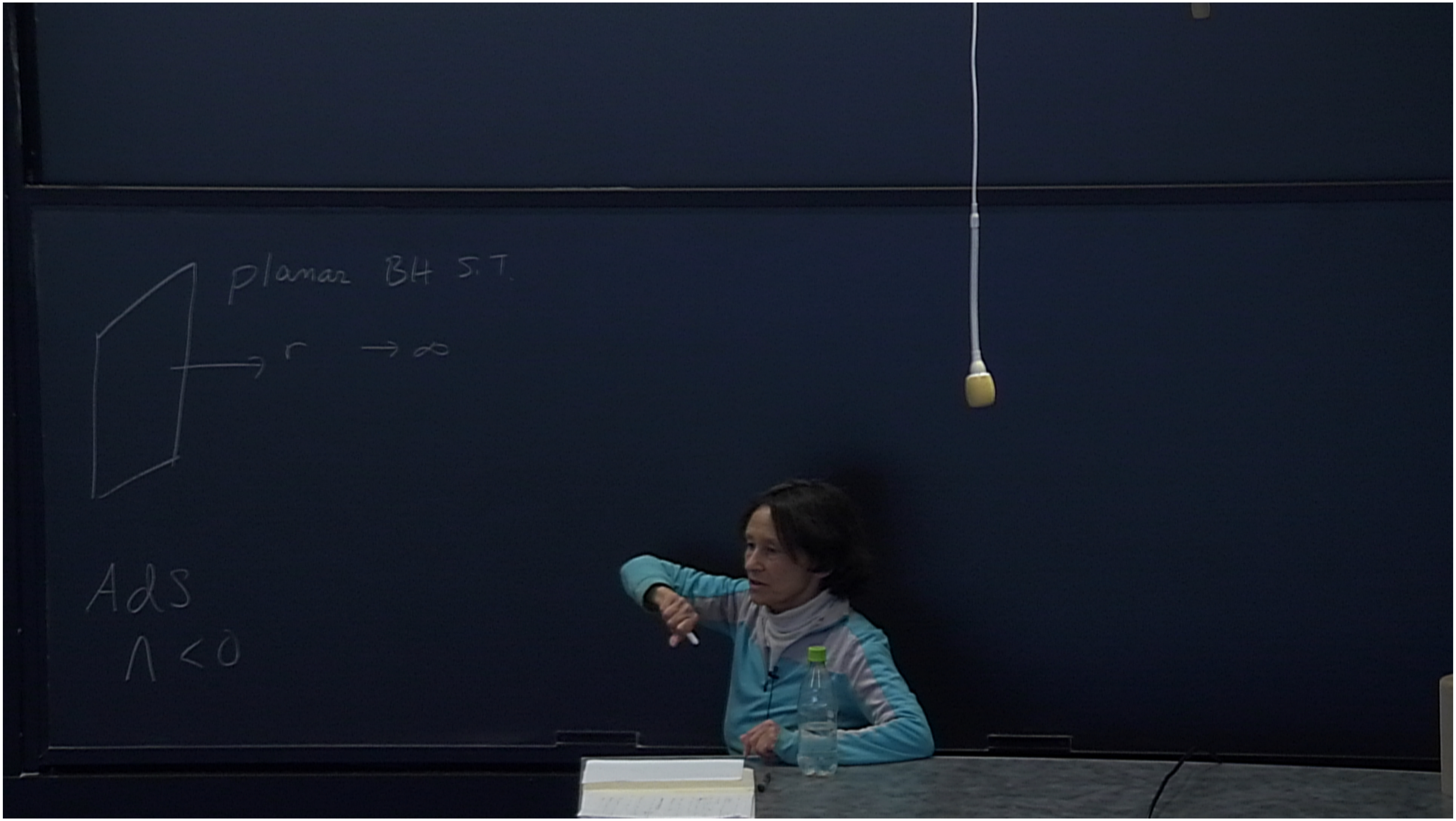

Sum Rules for Mass and
Tension in AdS / dS (?)(!)
Cosmology (flat)
MFVF
V

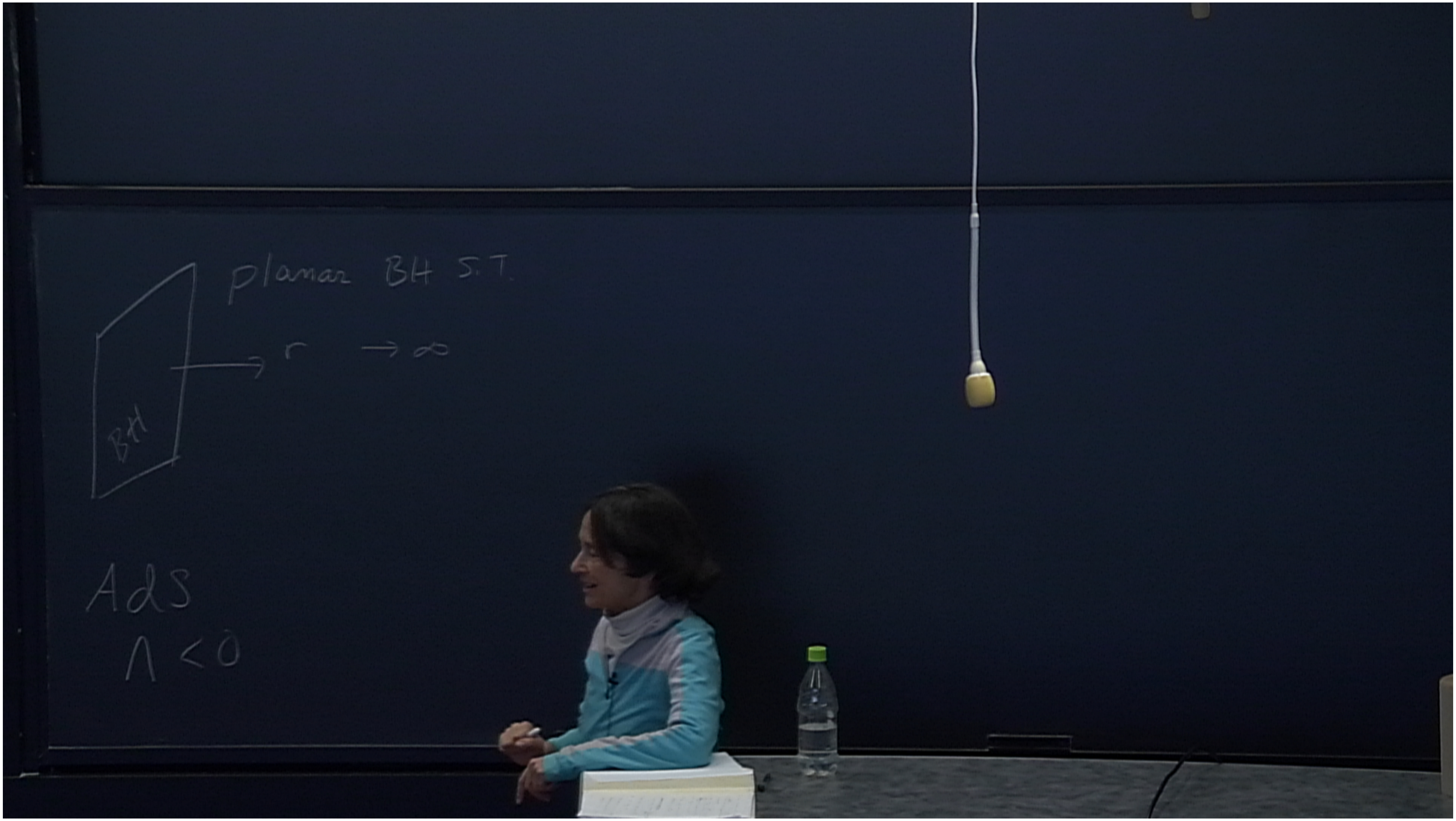

Sum Rules for Mass and
Tension in AdS / dS (?)(!)
Cosmology (flat)
V = ∂/∂t − H x^i ∂/∂x^i
MFVF
+ V(t)
∫ δT^a_b n_a V^b = ∫ B^c da_c
Vol
∂V
ξ(k) ∝ k^4   k → 0
Local Causal Perturbs
⇒ B. T. = 0
n̂
V
∂V

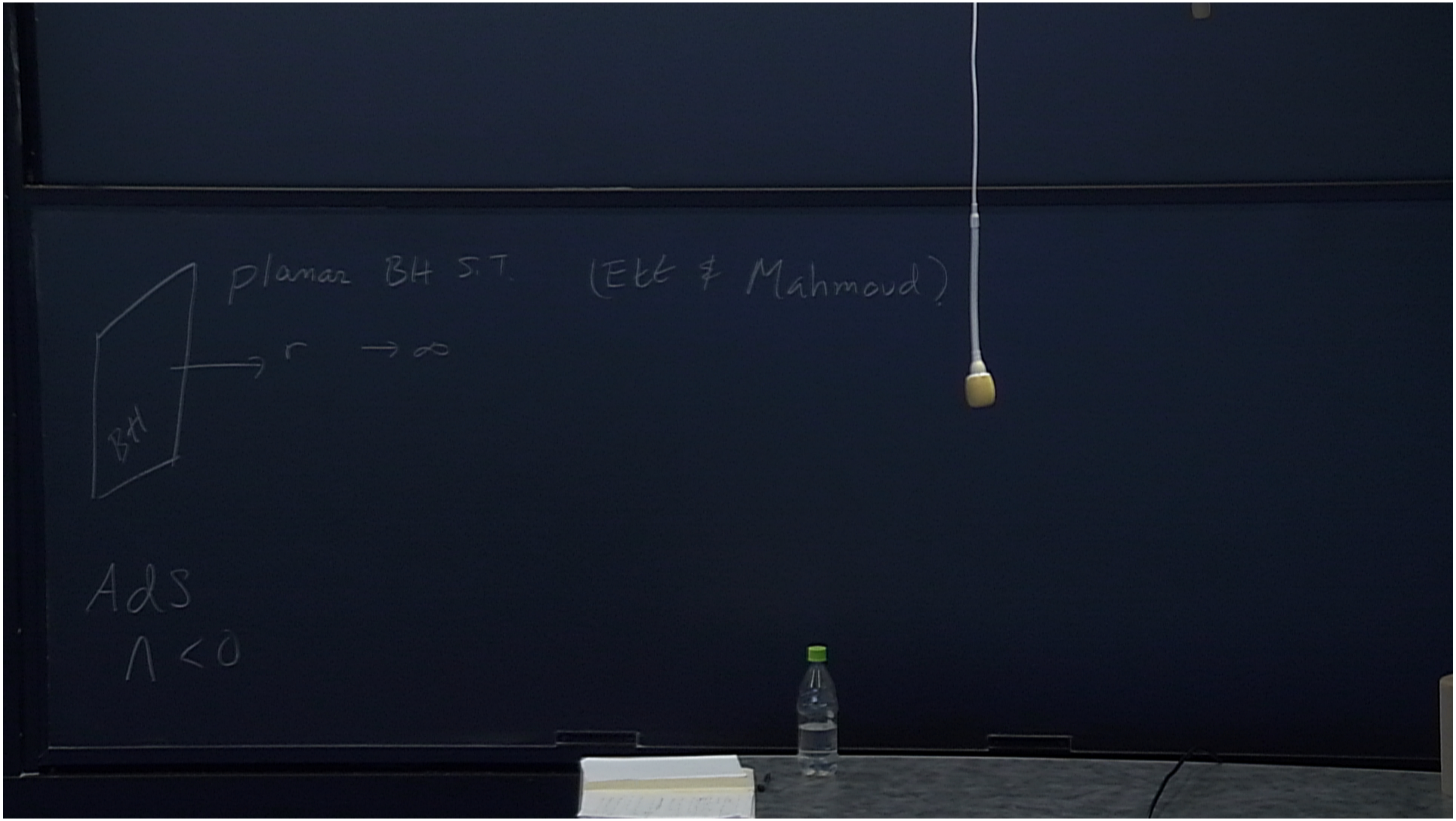

|δρ| >> |δT^i_k|
Constraints
∫_V δρ = 0
∫ x^α δρ = 0

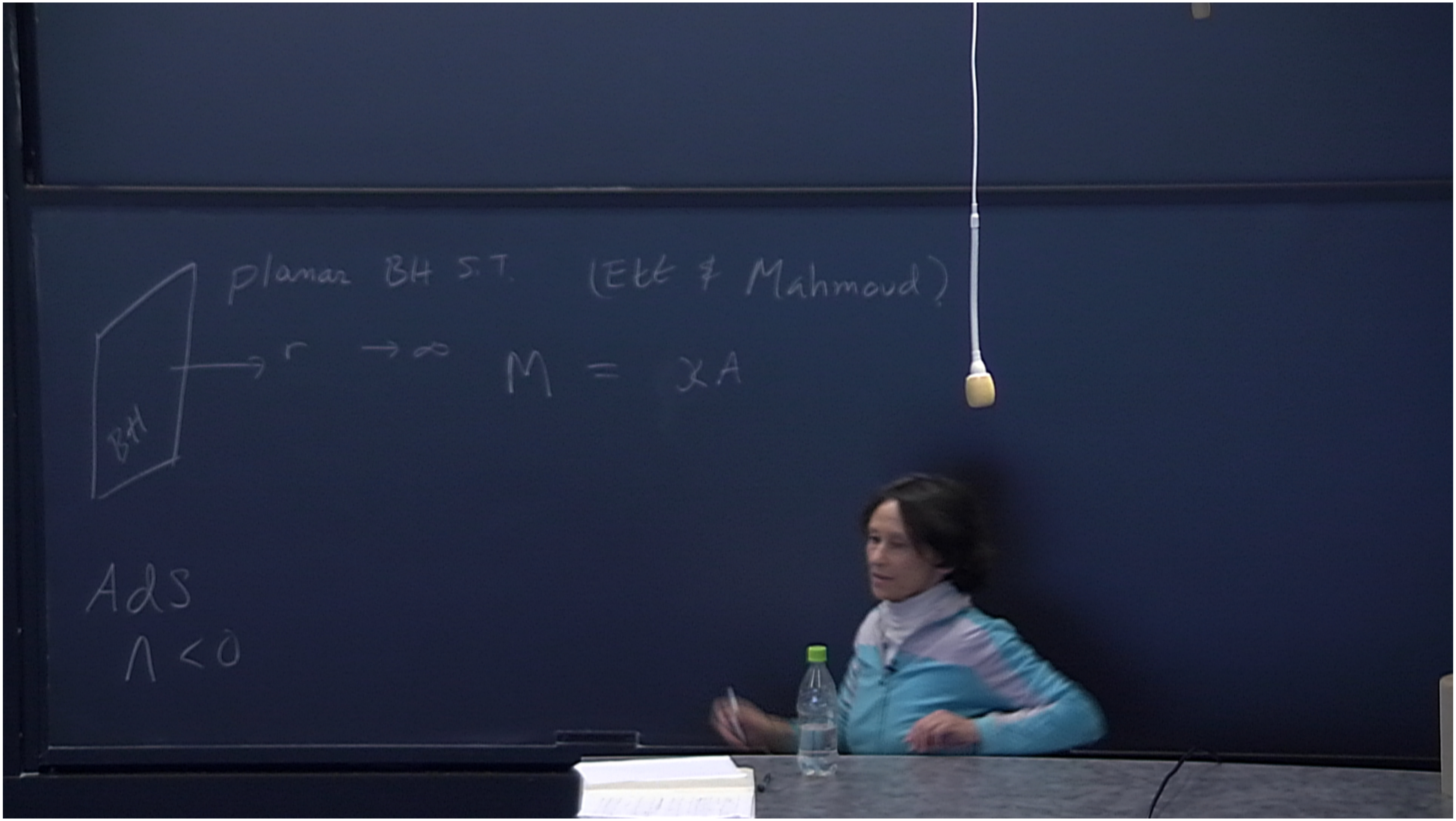

$|\delta\rho| \gg |\delta T^i_k|$
Constraints $\int_V \delta\rho = 0$
$\int x^i \delta\rho = 0$

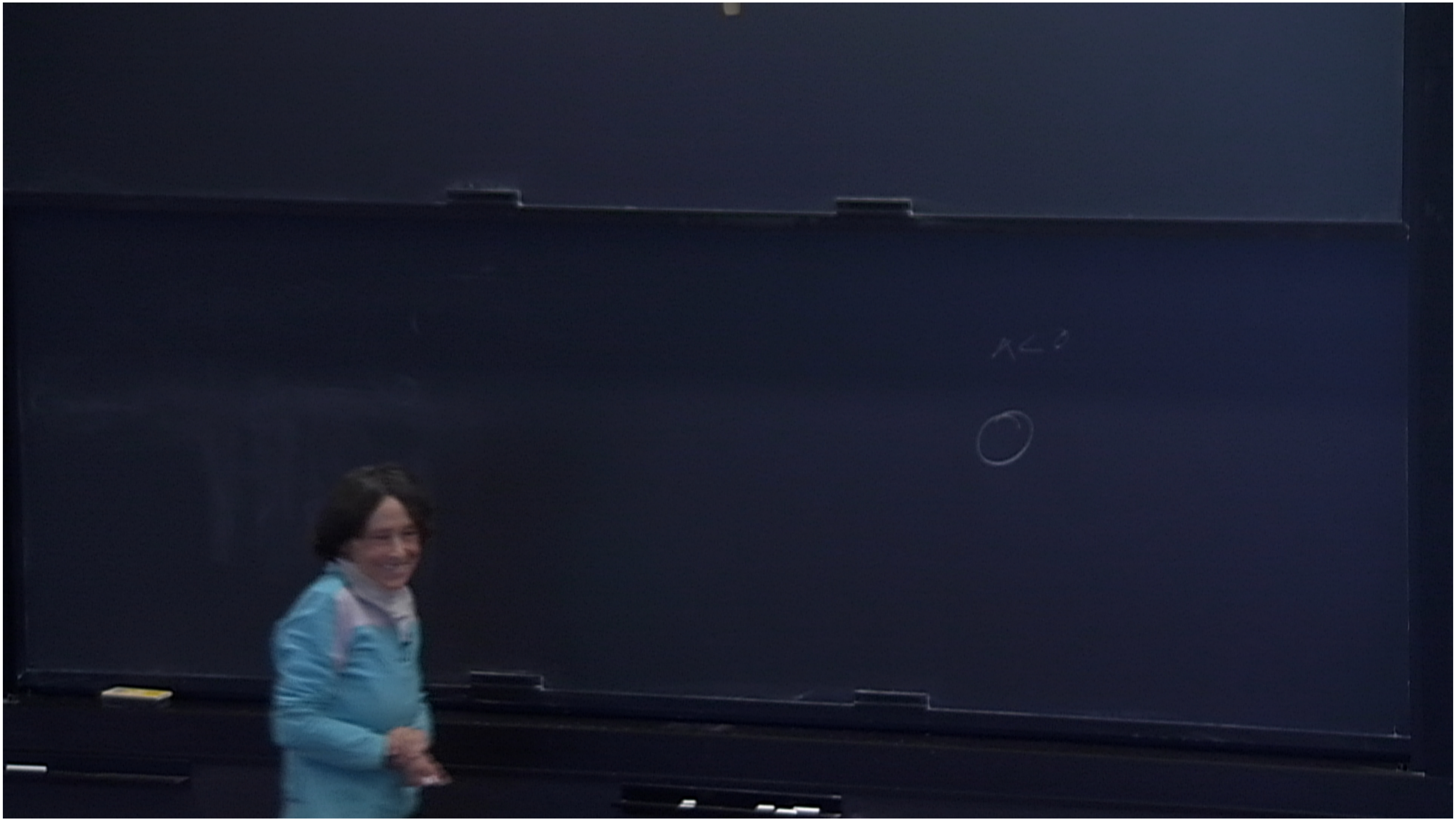

planar BH S.T.
AdS
Λ < 0

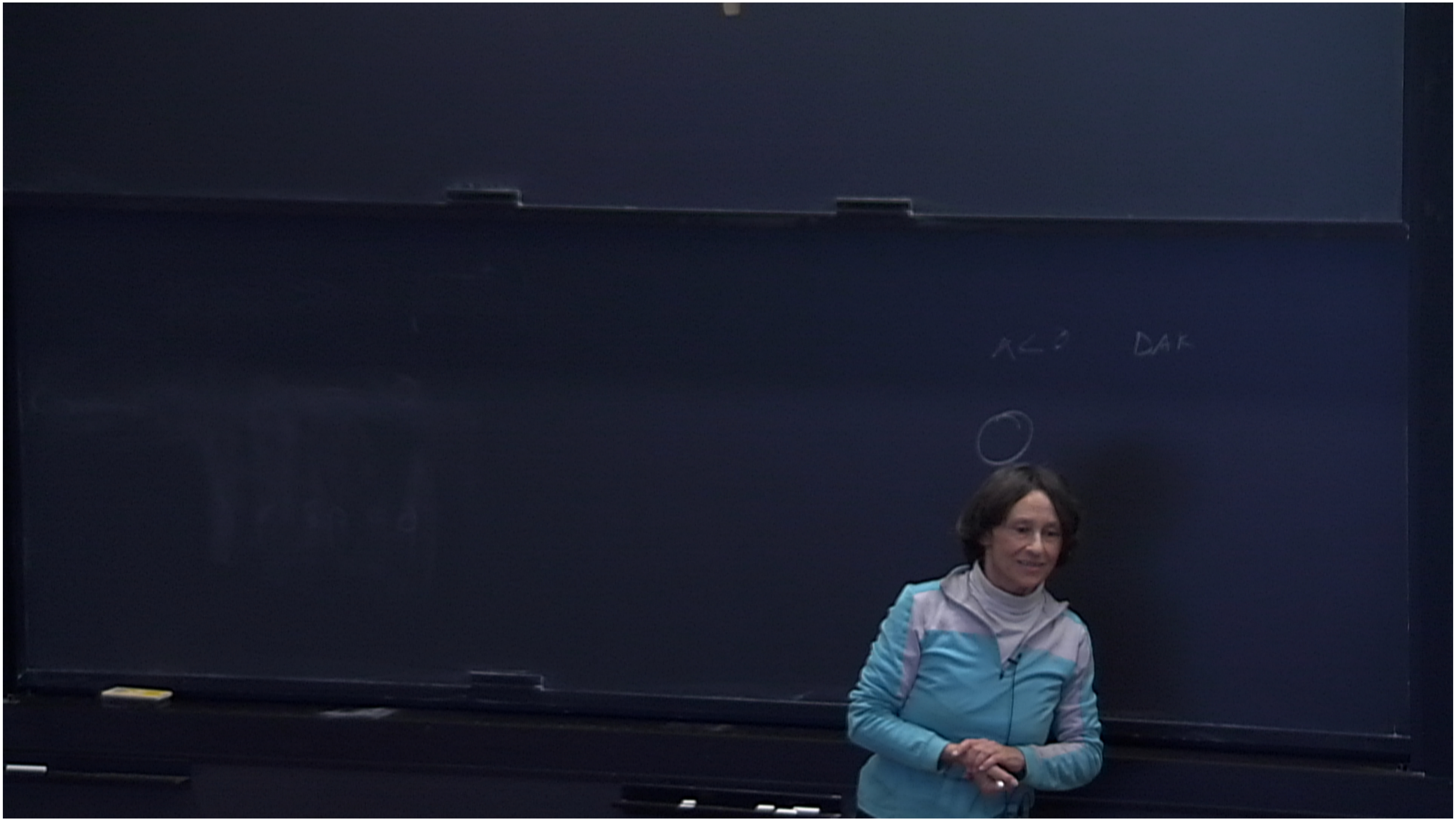

planar BH S.T.
r → ∞
AdS
Λ < 0

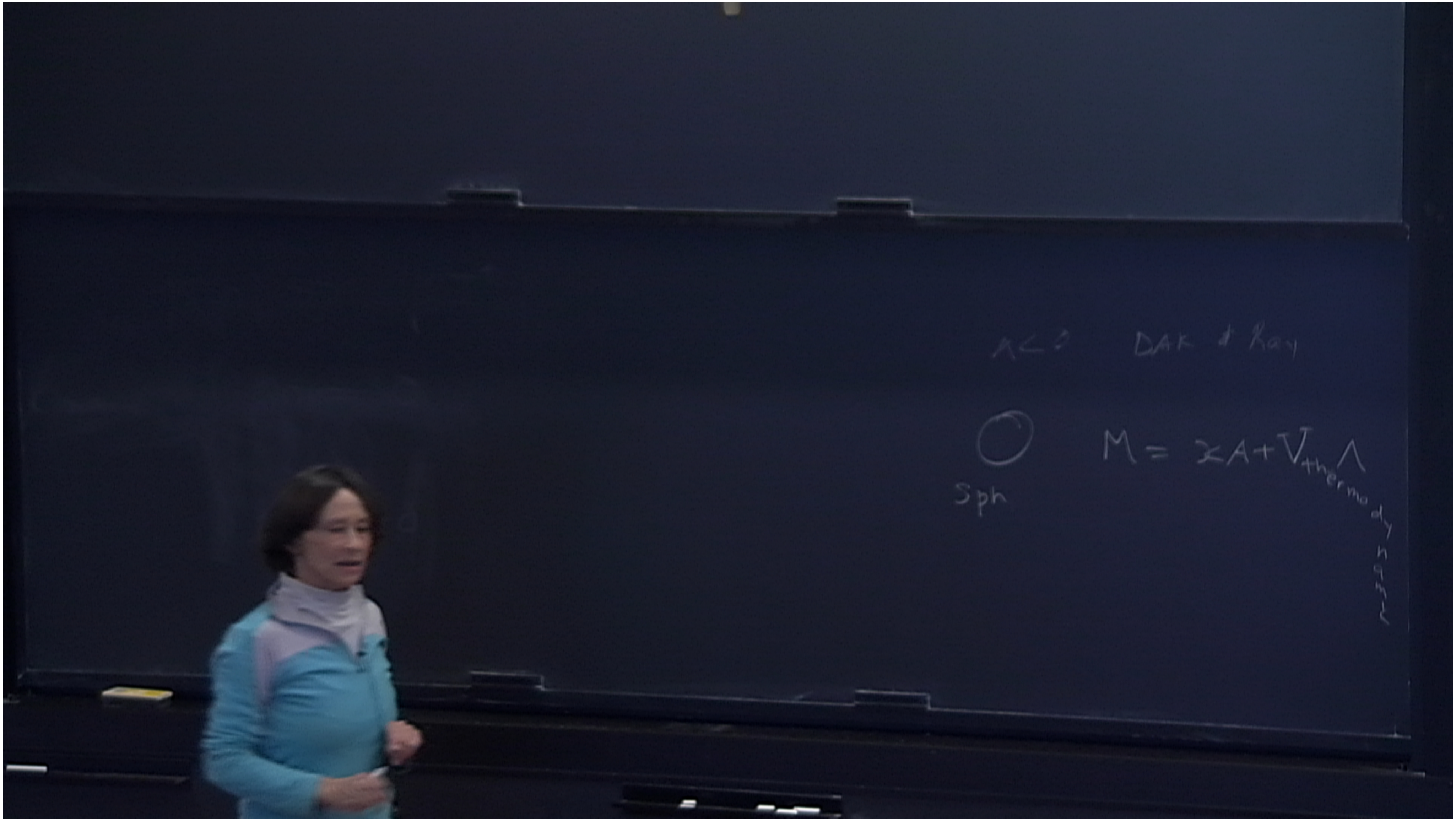

planar BH S.T.
BH
r → ∞
AdS
Λ < 0

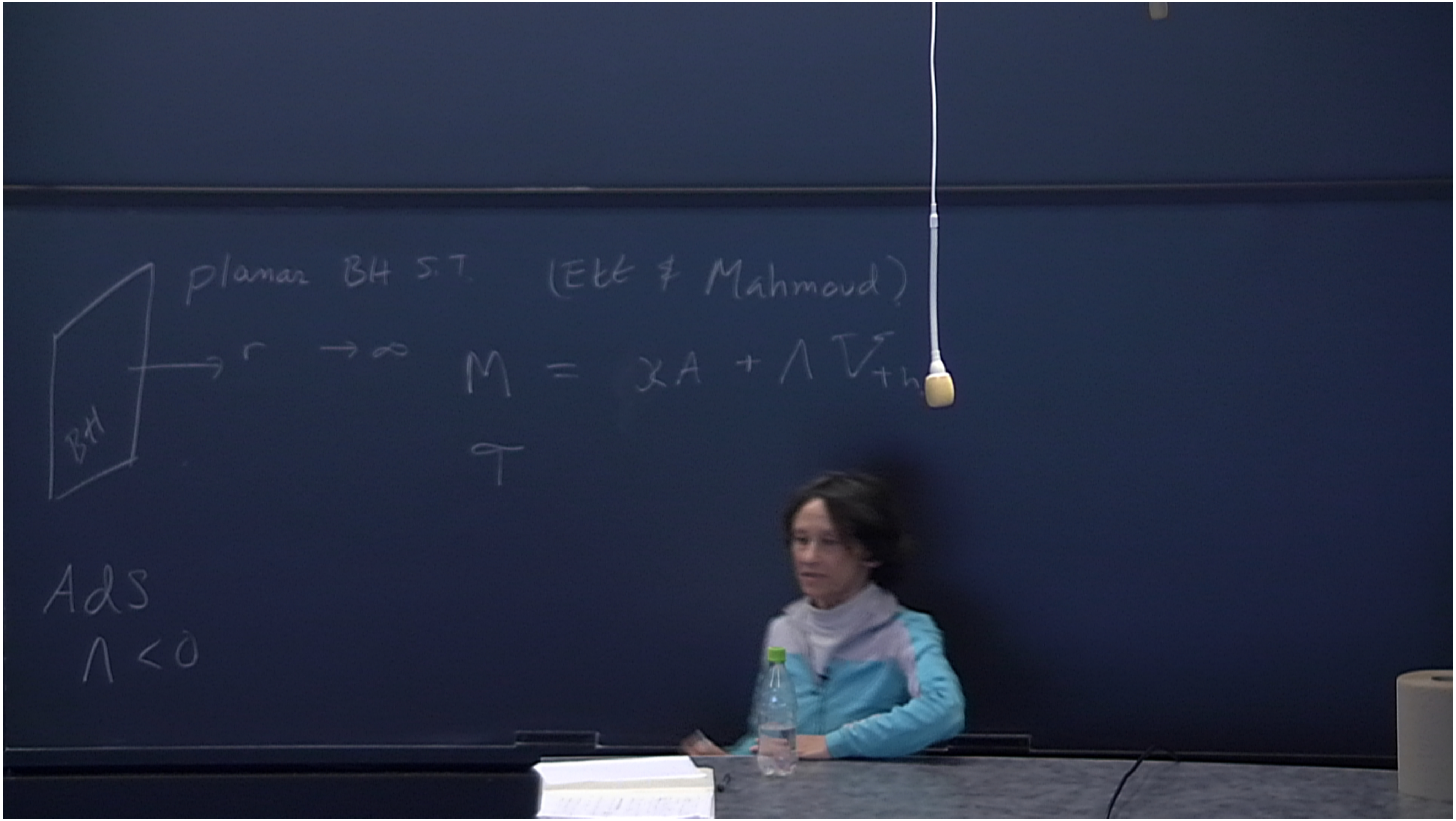

planar BH S.T.
(Ett & Mahmoud)
r → ∞
BH
AdS
Λ < 0

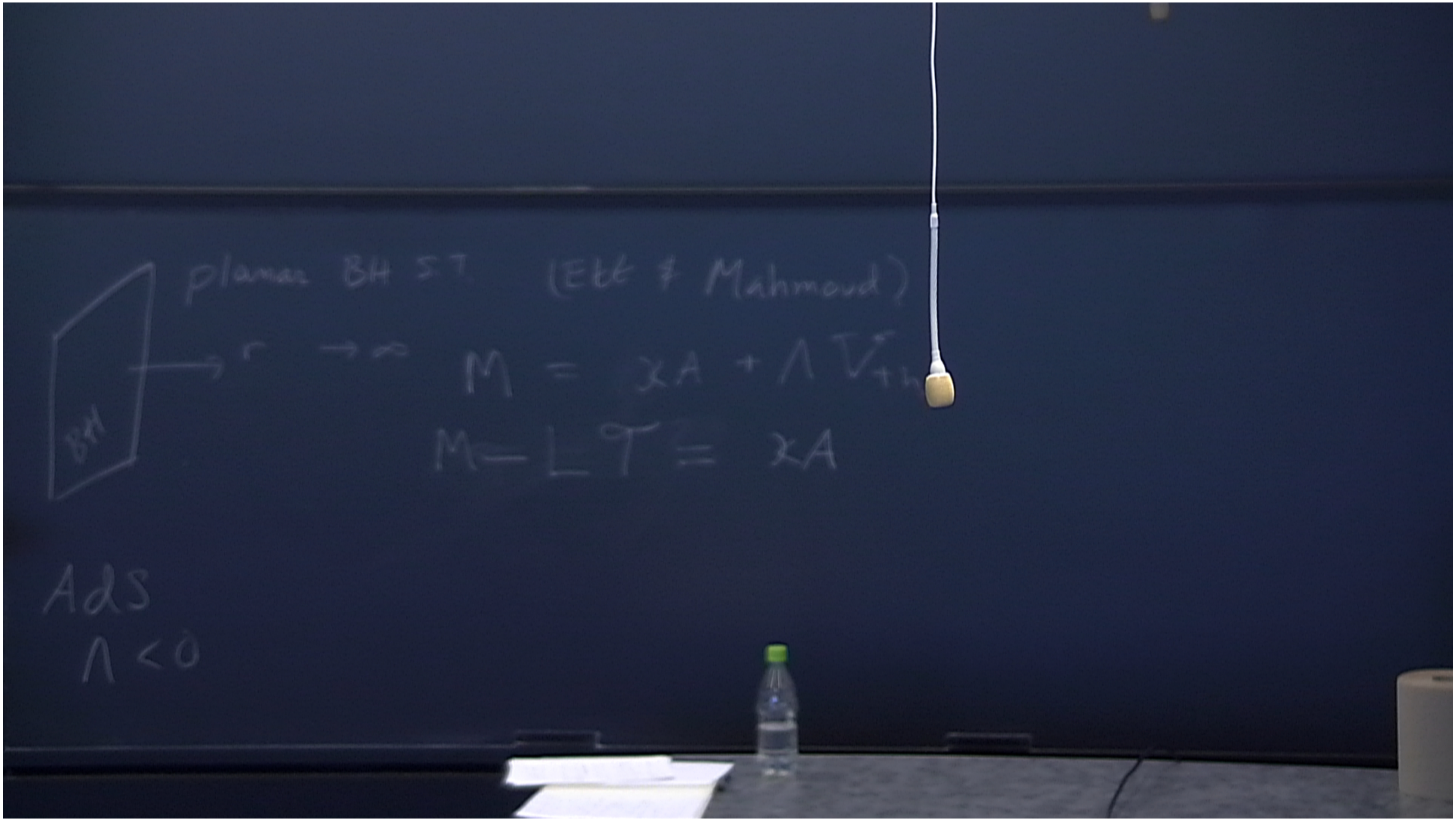

planar BH S.T. (Ett & Mahmoud)
BH
r → ∞
M = χA
AdS
Λ < 0

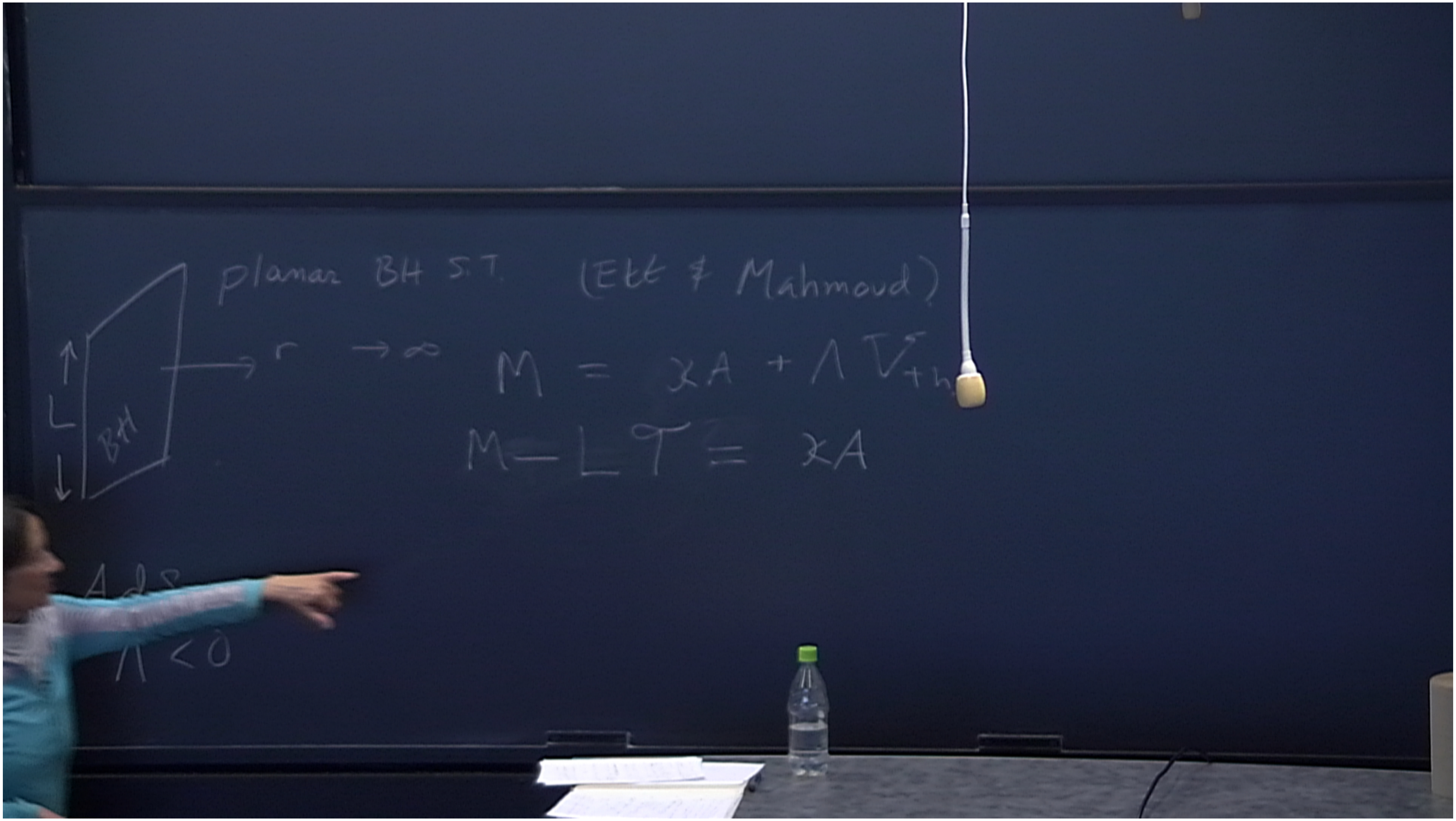


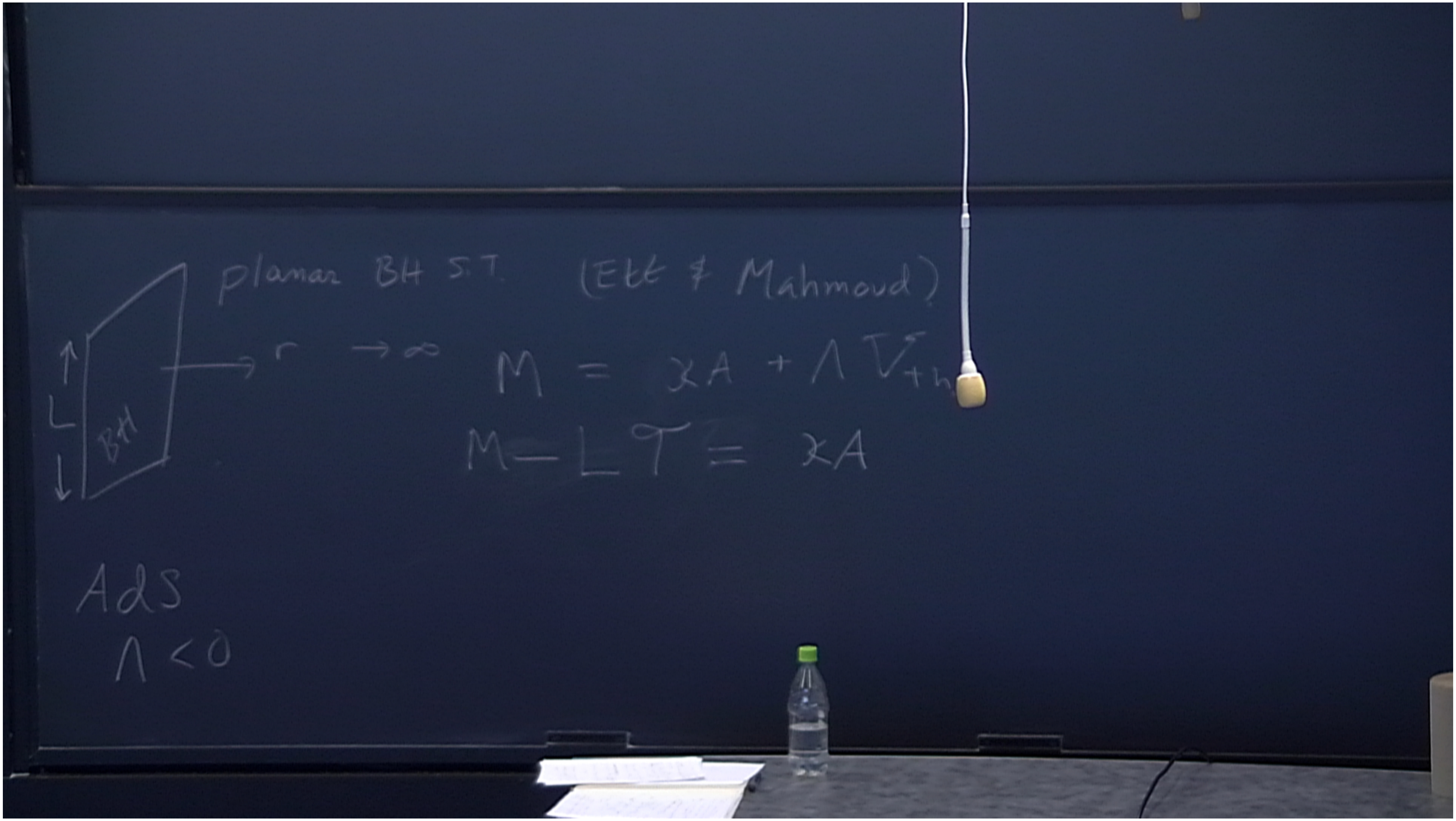


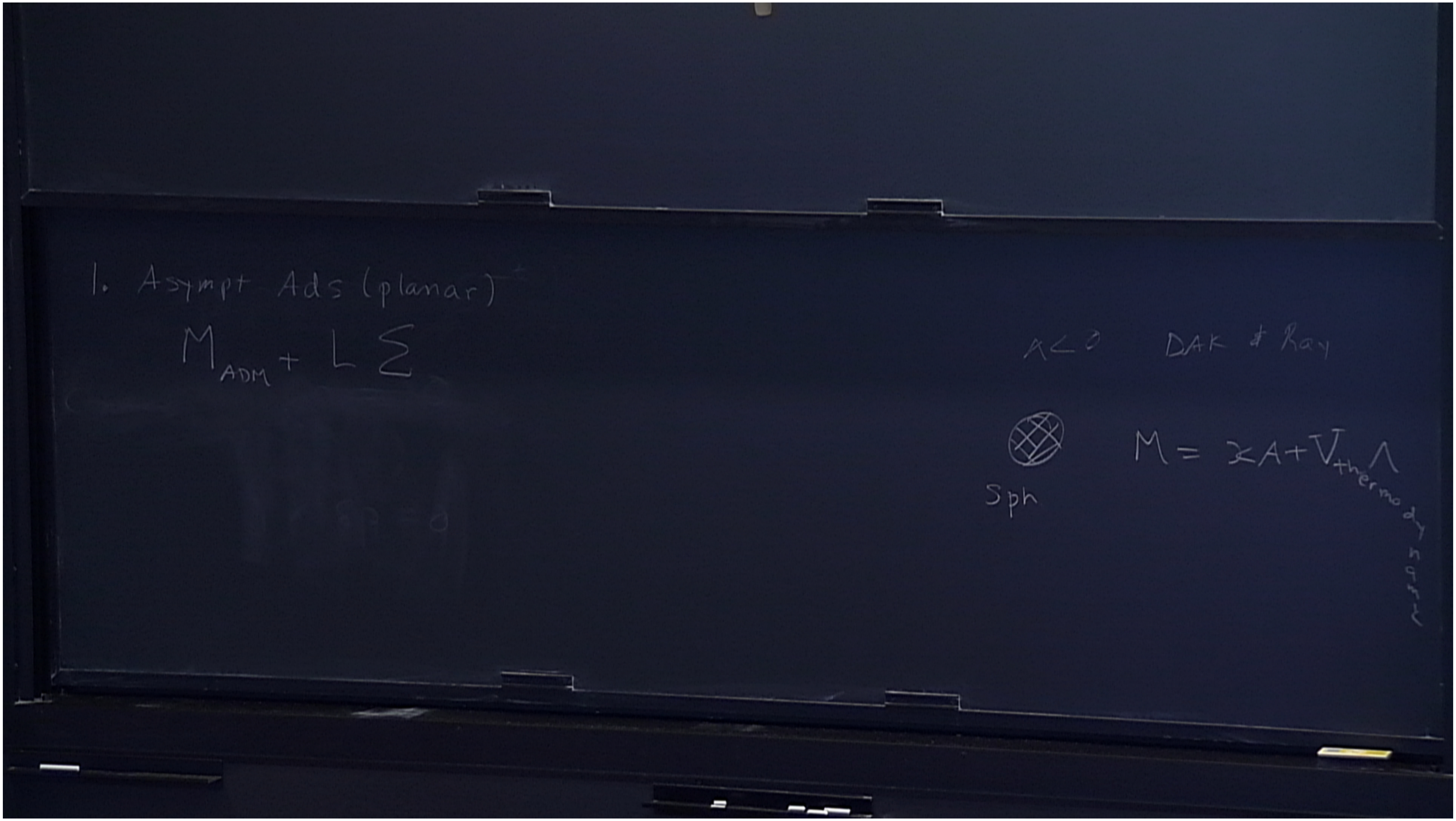

Λ<0
DAK & Ray
Sph
M = κA + V Λ
thermodynamical

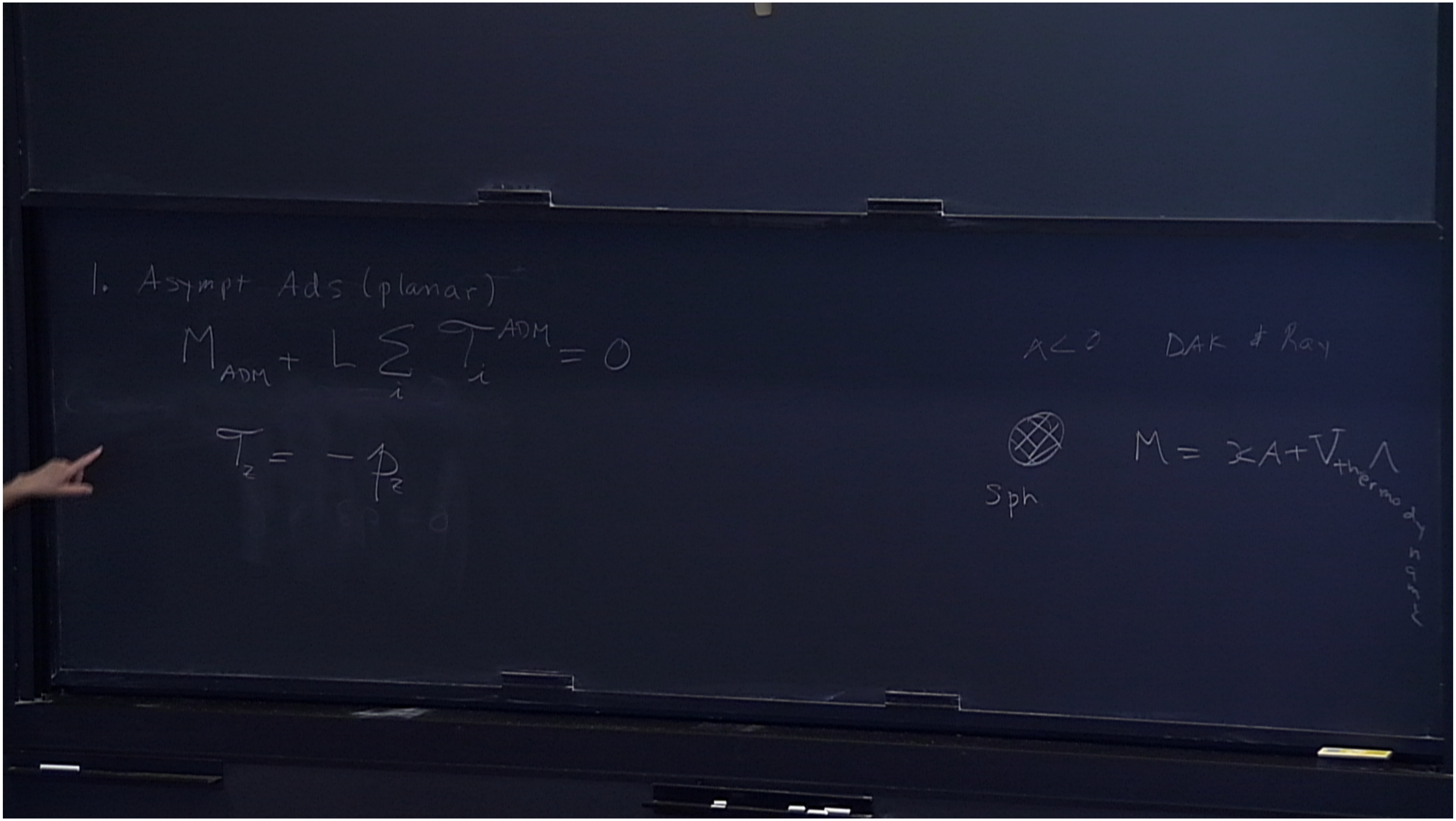

planar BH S.T.
(Ett & Mahmoud)
BH
r → ∞
M = χA + Λ V_th
T
AdS
Λ < 0

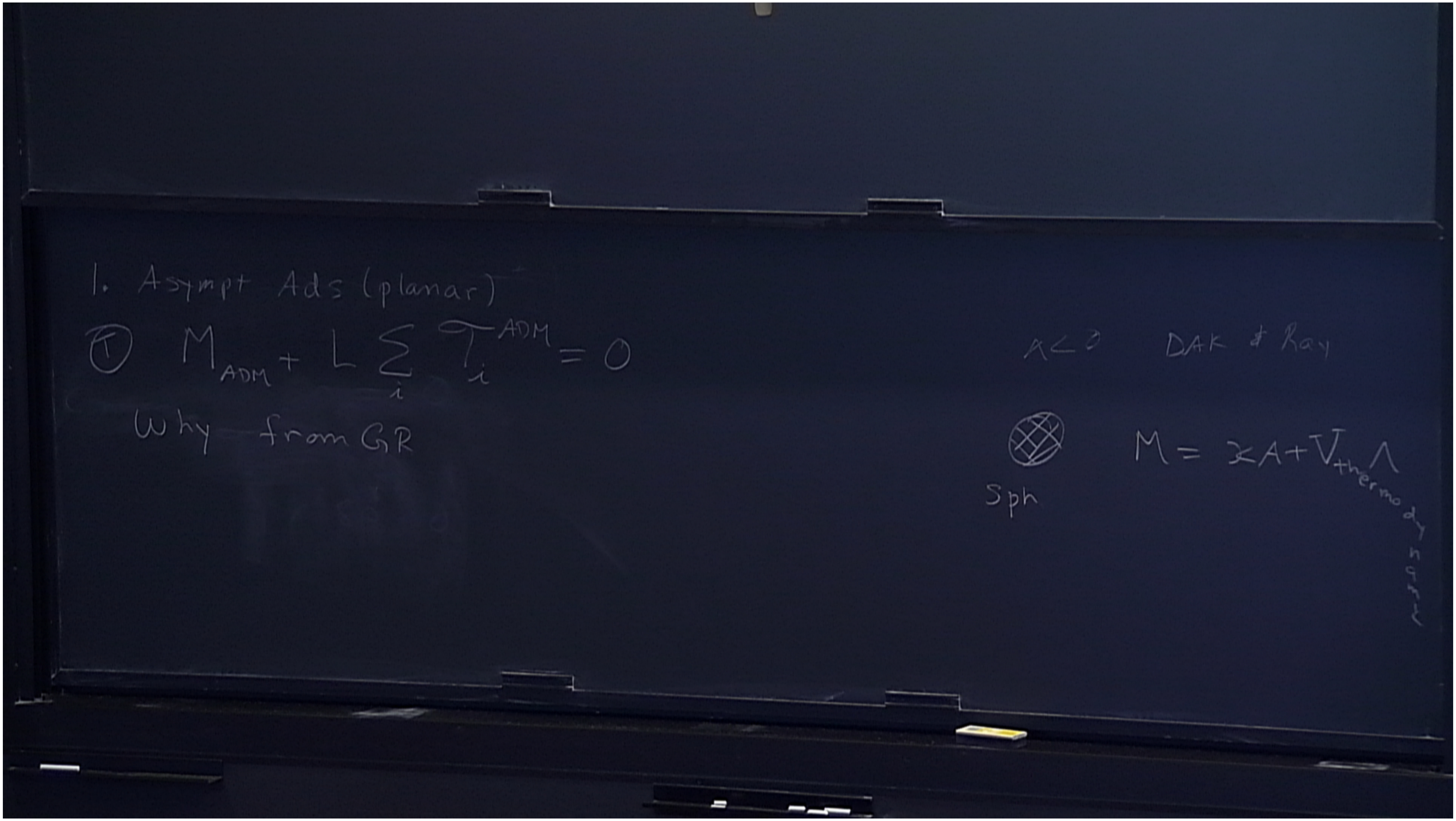

planar BH S.T. (Ett & Mahmoud)
BH
r → ∞
M = κA + Λ V_th
M − L T = κA
AdS
Λ < 0


planar BH S.T.
(Ett & Mahmoud)
r → ∞
L
BH
M = κA + Λ V
M = L T = κA
AdS
Λ < 0


planar BH S.T. (Ett & Mahmoud)
L
BH
r → ∞
M = κA + Λ V_th
M − LT = κA
AdS
Λ < 0


1. Asympt Ads (planar)
M_ADM + L Σ
Λ<0
DAK & Ray
Sph
M = κA + V_th Λ
thermodynamic


1. Asympt AdS (planar)
M_ADM + L Σ_i T_i^ADM = 0
T_z = − p_z
Λ<0
DAK & Ray
Sph
M = κA + V_thermodynamic Λ


1. Asympt AdS (planar)
① $M_{ADM} + L \sum_i T_i^{ADM} = 0$
Why from GR
$\Lambda < 0$
DAK & Ray
Sph
$M = \kappa A + V_{th} \Lambda$
thermodynamic

1. Asympt AdS (planar)

(T) $M_{ADM} + L \sum_i T_i^{ADM} = 0$

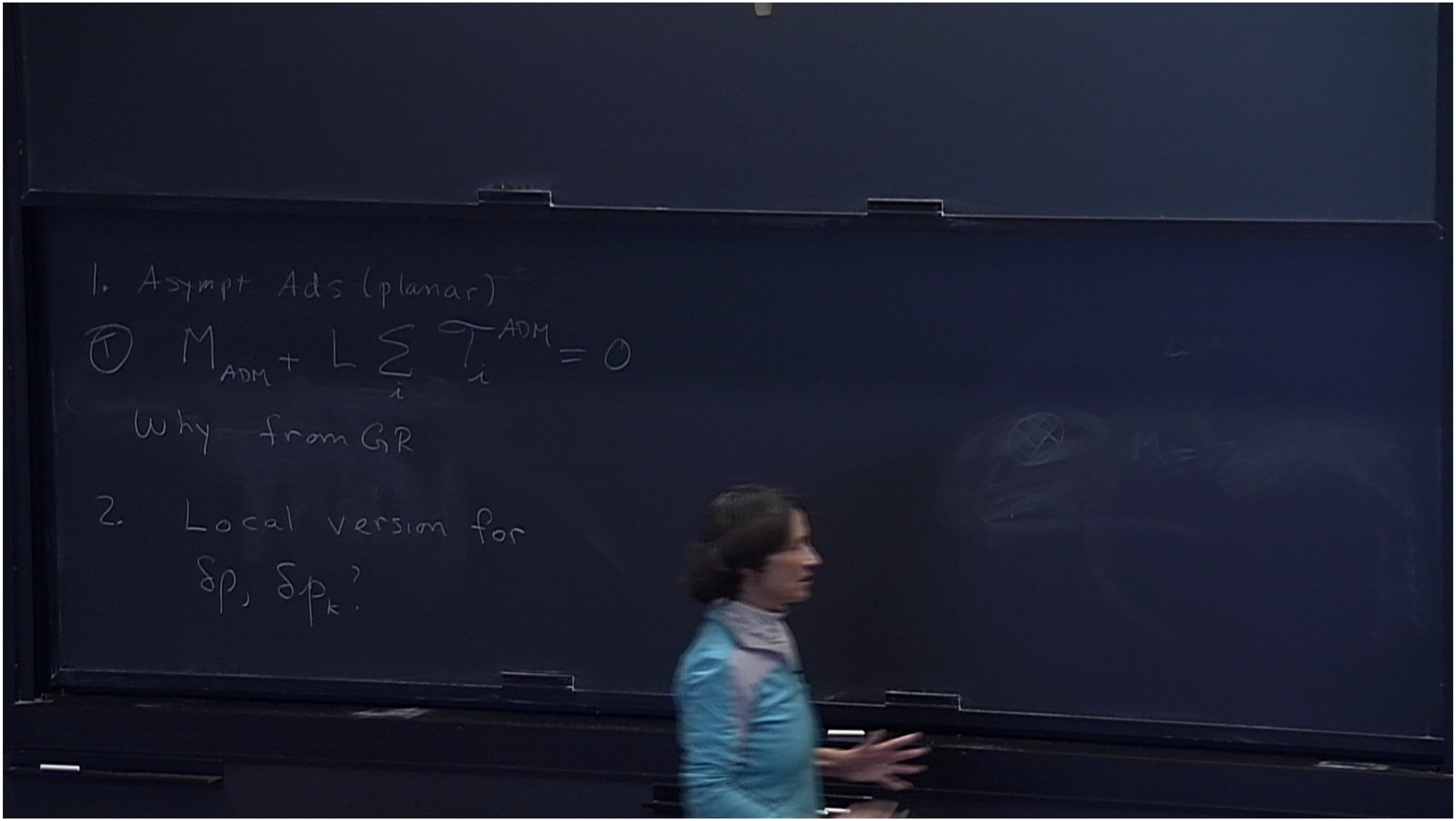
Why from GR

2. Local version for $\delta\rho, \delta p_k$?

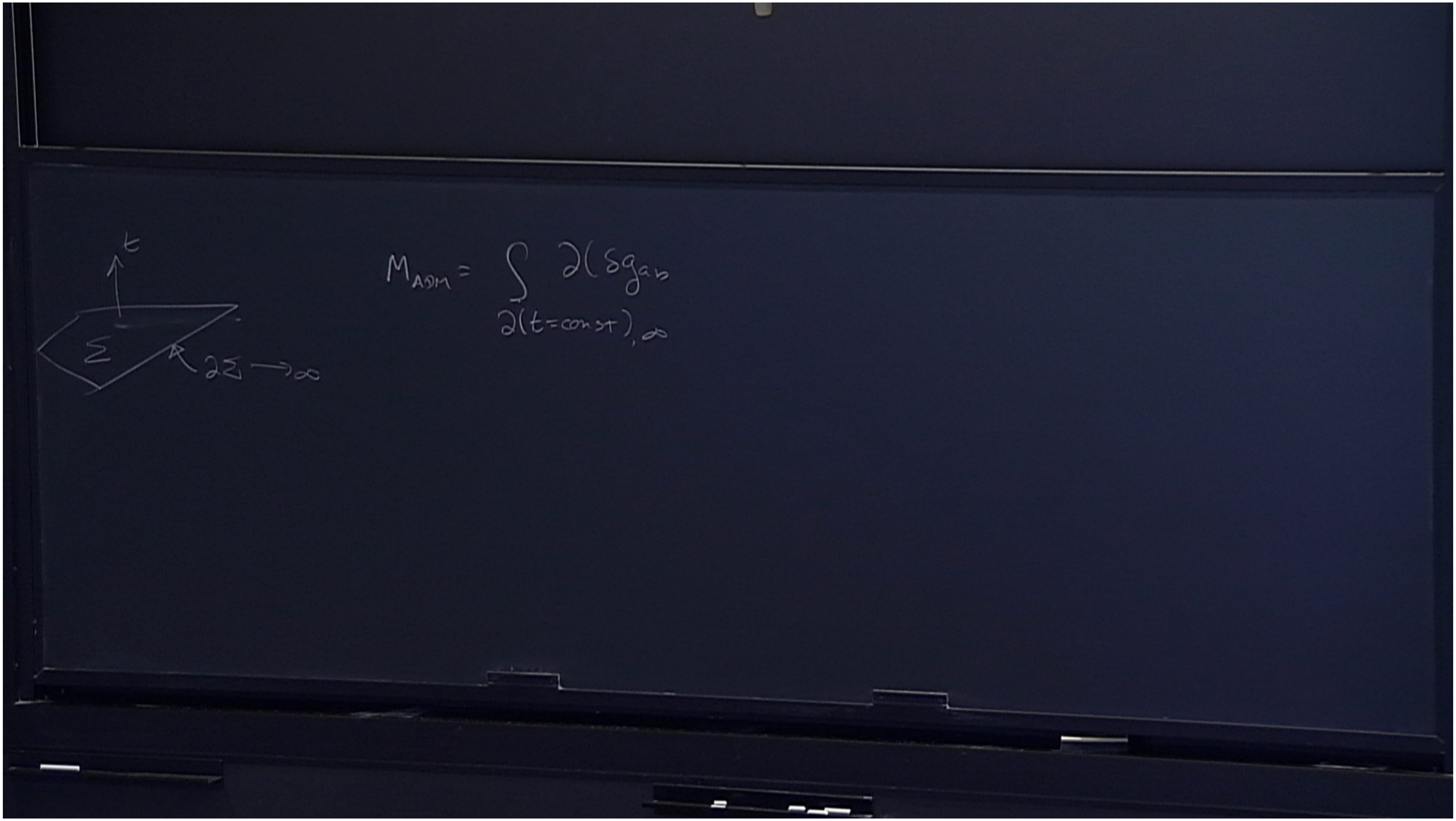
$\Lambda < 0$ DAK & Ray

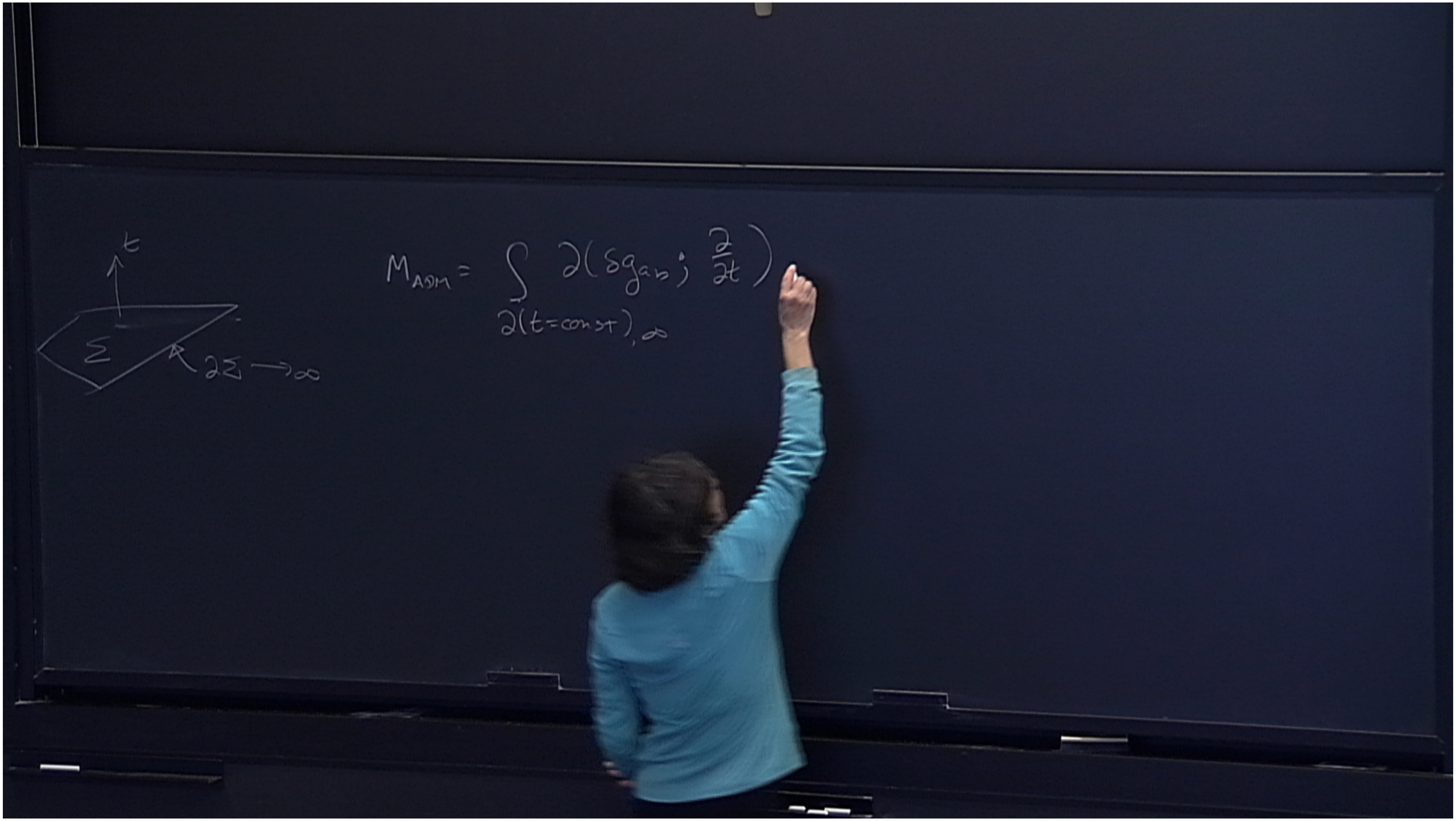
Sph

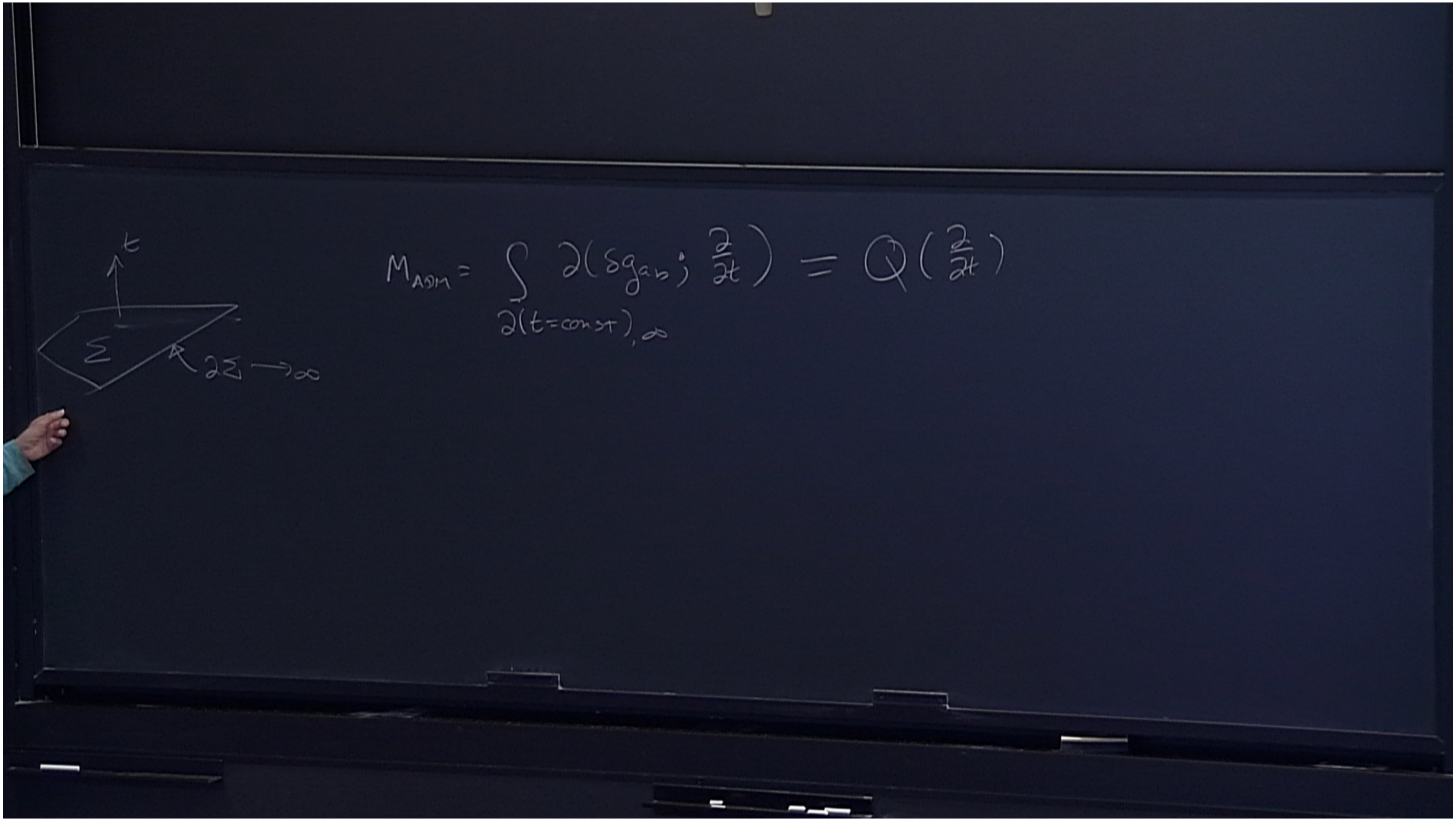
$M = \kappa A + V_{\text{thermodynamic}} \Lambda$

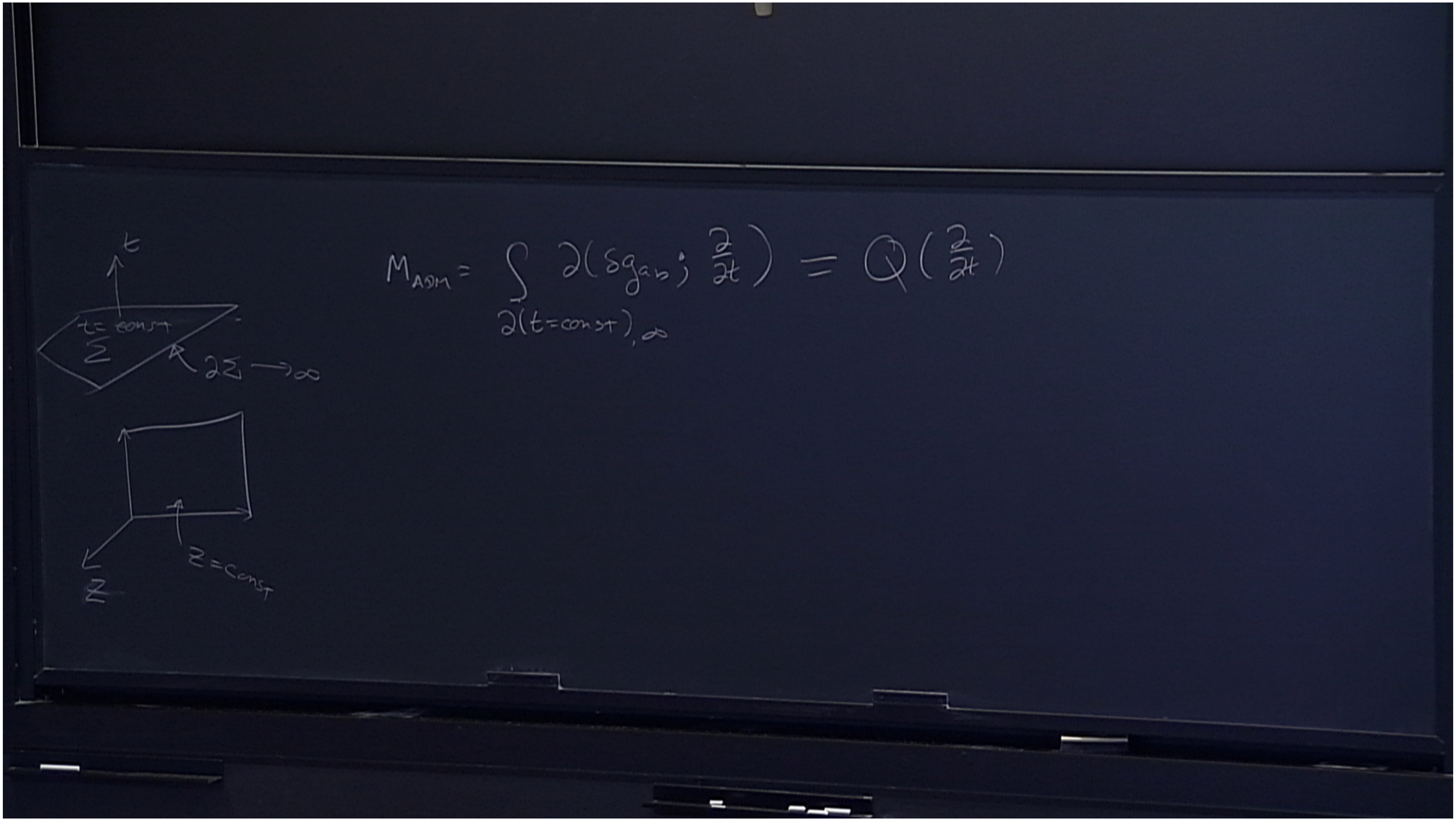

1. Asympt AdS (planar)
(T) M_ADM + L Σ_i T_i^ADM = 0
Why from GR
2. Local version for
δρ, δp_k ?

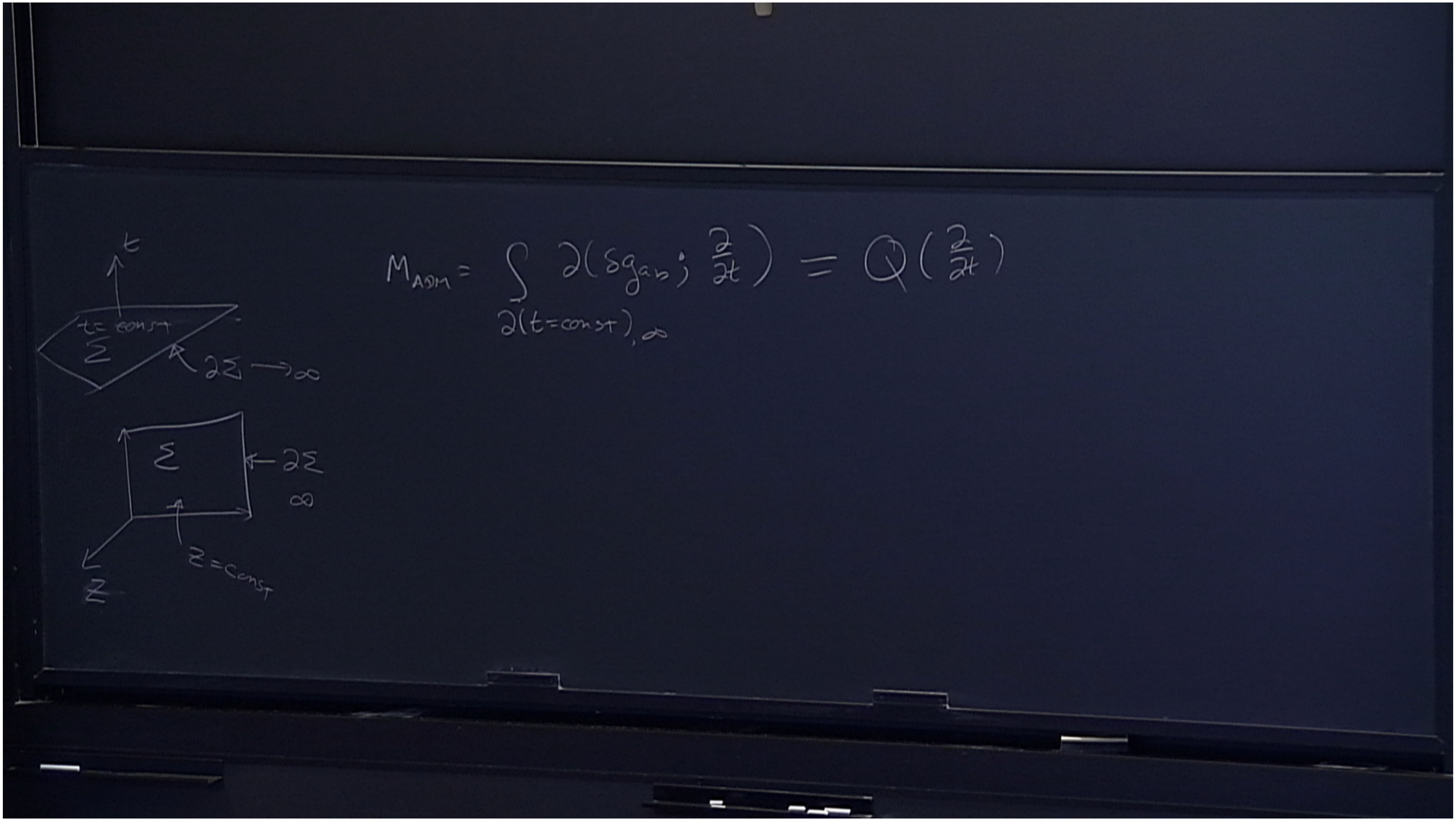

t
Σ

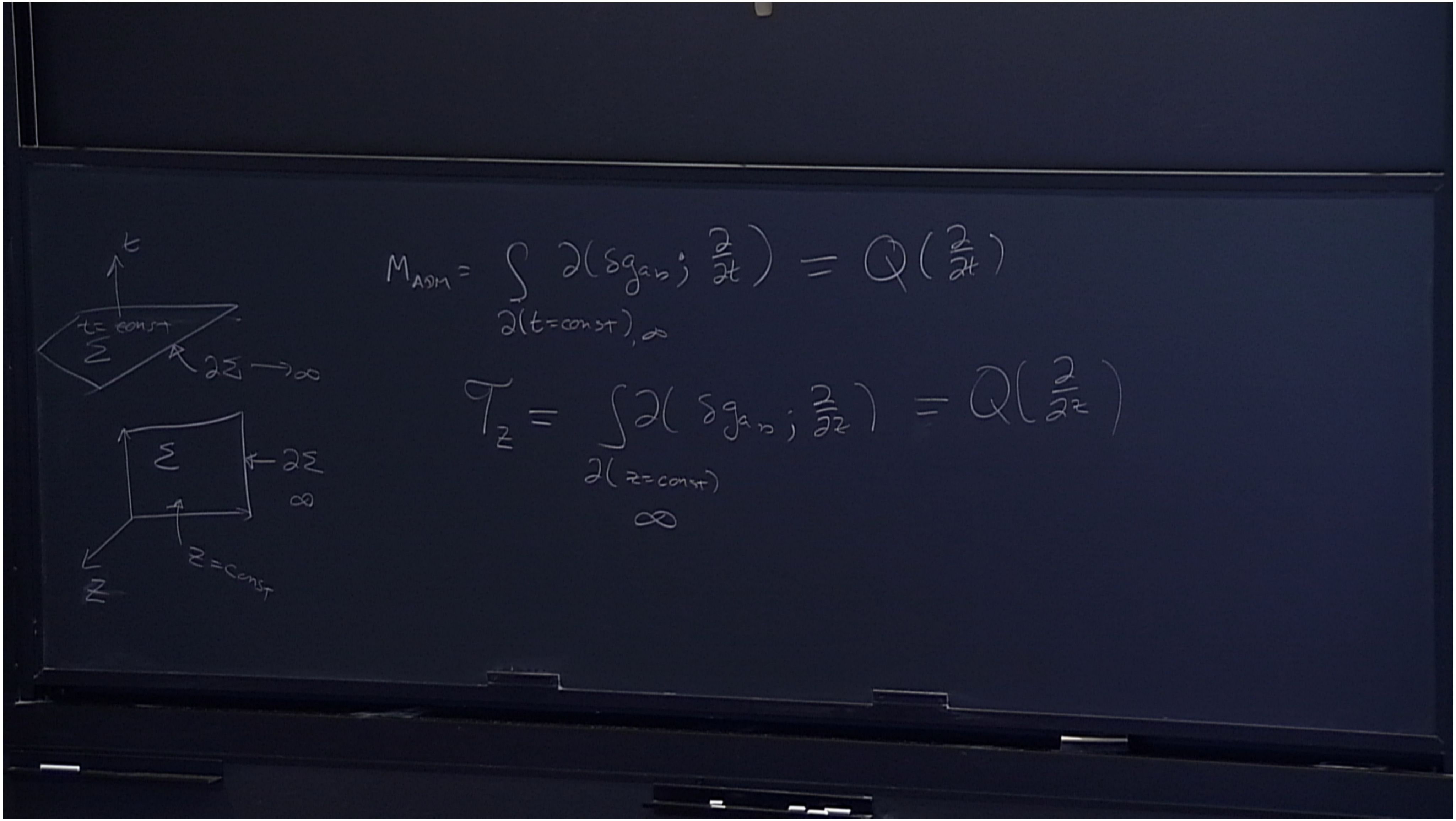

t
Σ
∂Σ ⟶ ∞
M_ADM = ∫ ∂(δg_ab
∂(t=const), ∞

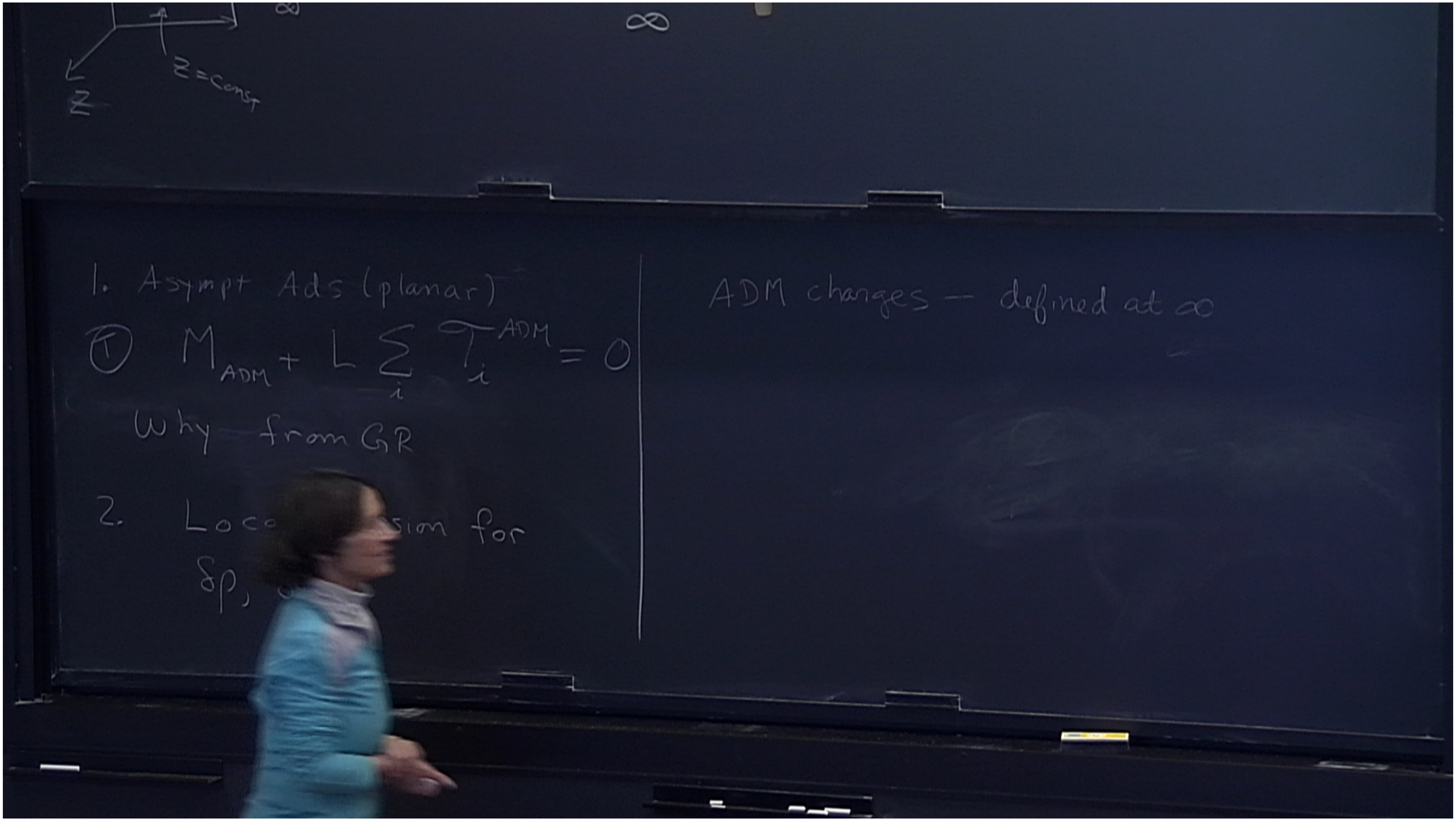

M_ADM = ∫ ∂(δg_ab ; ∂/∂t)
∂(t=const), ∞
t
Σ
∂Σ → ∞


$M_{ADM} = \int_{\partial(t=const),\infty} \partial(\delta g_{ab}; \frac{\partial}{\partial t}) = Q(\frac{\partial}{\partial t})$
t
Σ
$\partial\Sigma \to \infty$

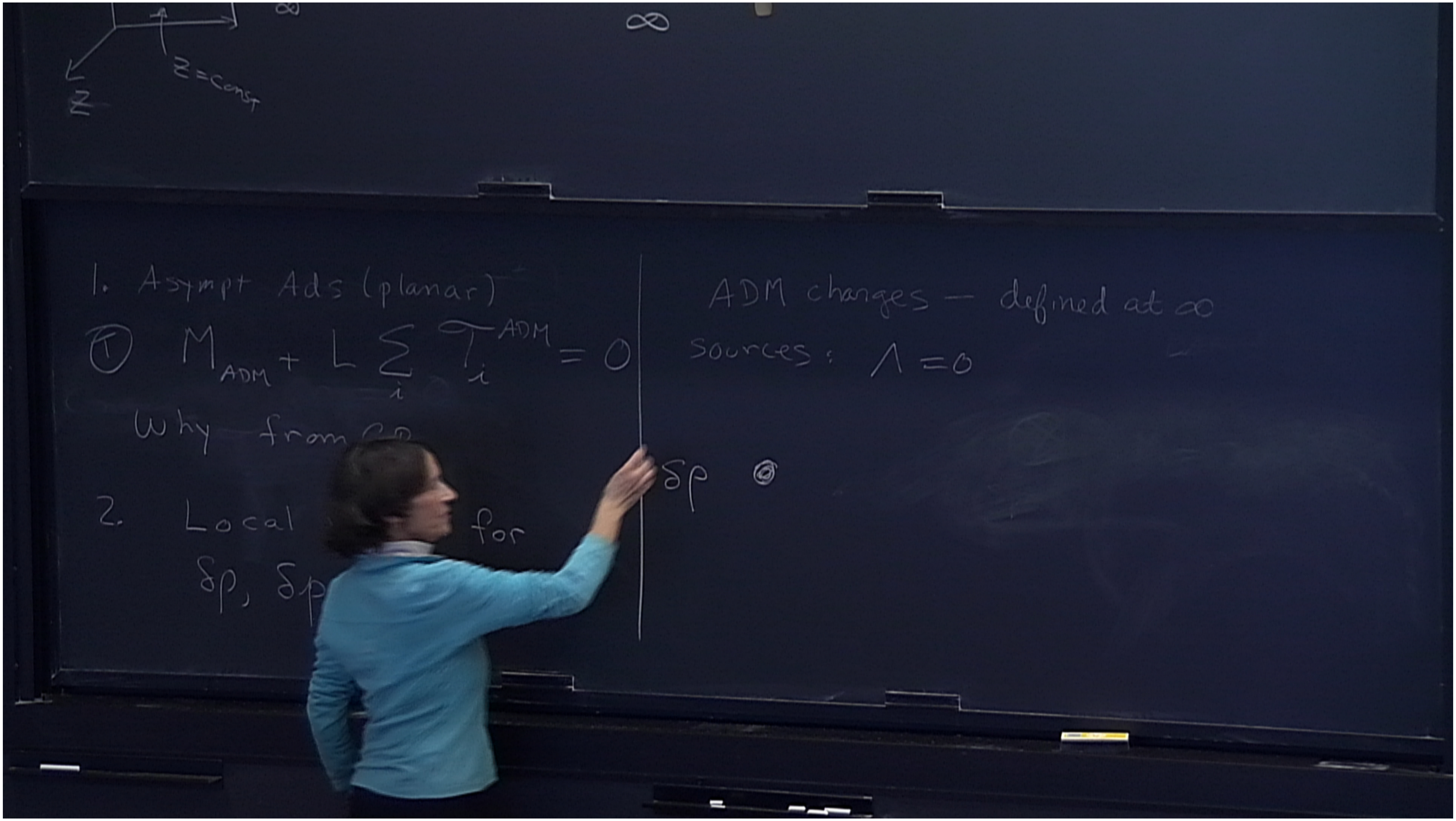

$M_{ADM} = \int_{\partial(t=const),\infty} \partial(\delta g_{ab}; \frac{\partial}{\partial t}) = Q(\frac{\partial}{\partial t})$
t
t= const
Σ
$\partial\Sigma \longrightarrow \infty$
Z
Z = const

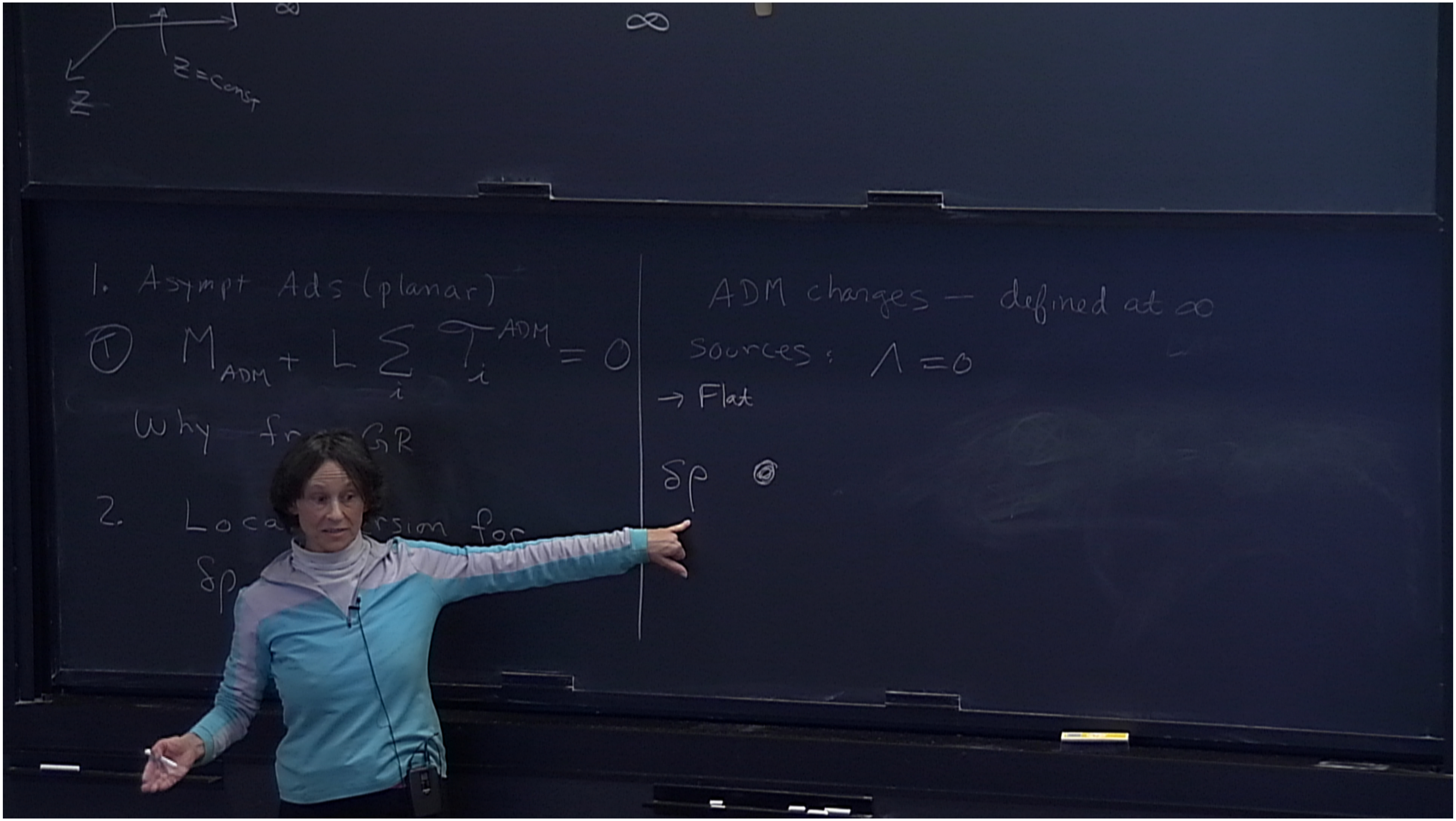

$M_{ADM} = \int_{\partial(t=const),\infty} \partial(\delta g_{ab}; \frac{\partial}{\partial t}) = Q(\frac{\partial}{\partial t})$
t
t= const
Σ
∂Σ → ∞
Σ
∂Σ
∞
z
z = const

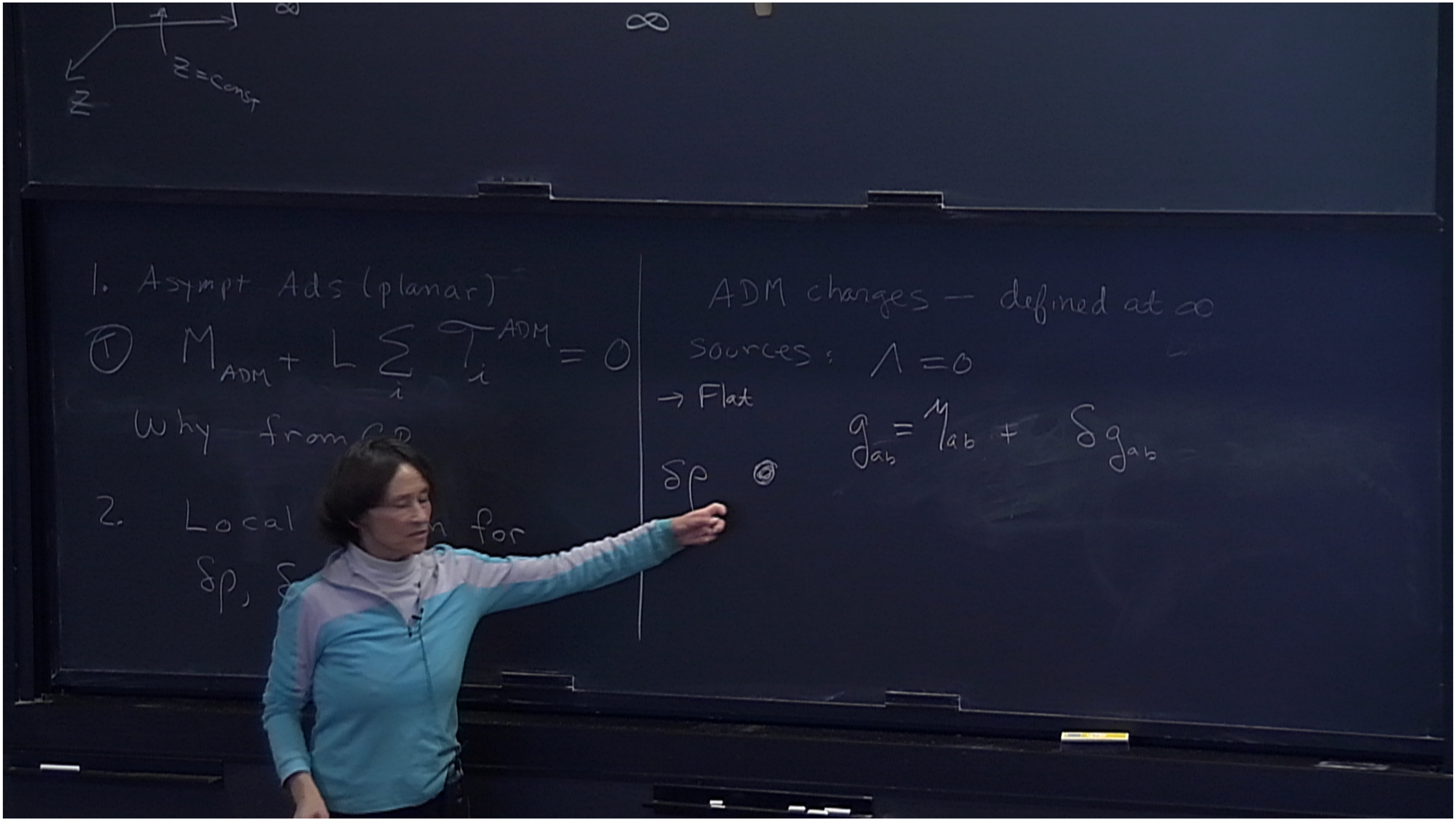

$M_{ADM} = \int_{\partial(t=const),\infty} \partial(\delta g_{ab}; \frac{\partial}{\partial t}) = Q(\frac{\partial}{\partial t})$
$T_z = \int_{\partial(z=const)\,\infty} \partial(\delta g_{ab}; \frac{\partial}{\partial z}) = Q(\frac{\partial}{\partial z})$
t
t = const
Σ
∂Σ → ∞
Σ
∂Σ
∞
z = const
z

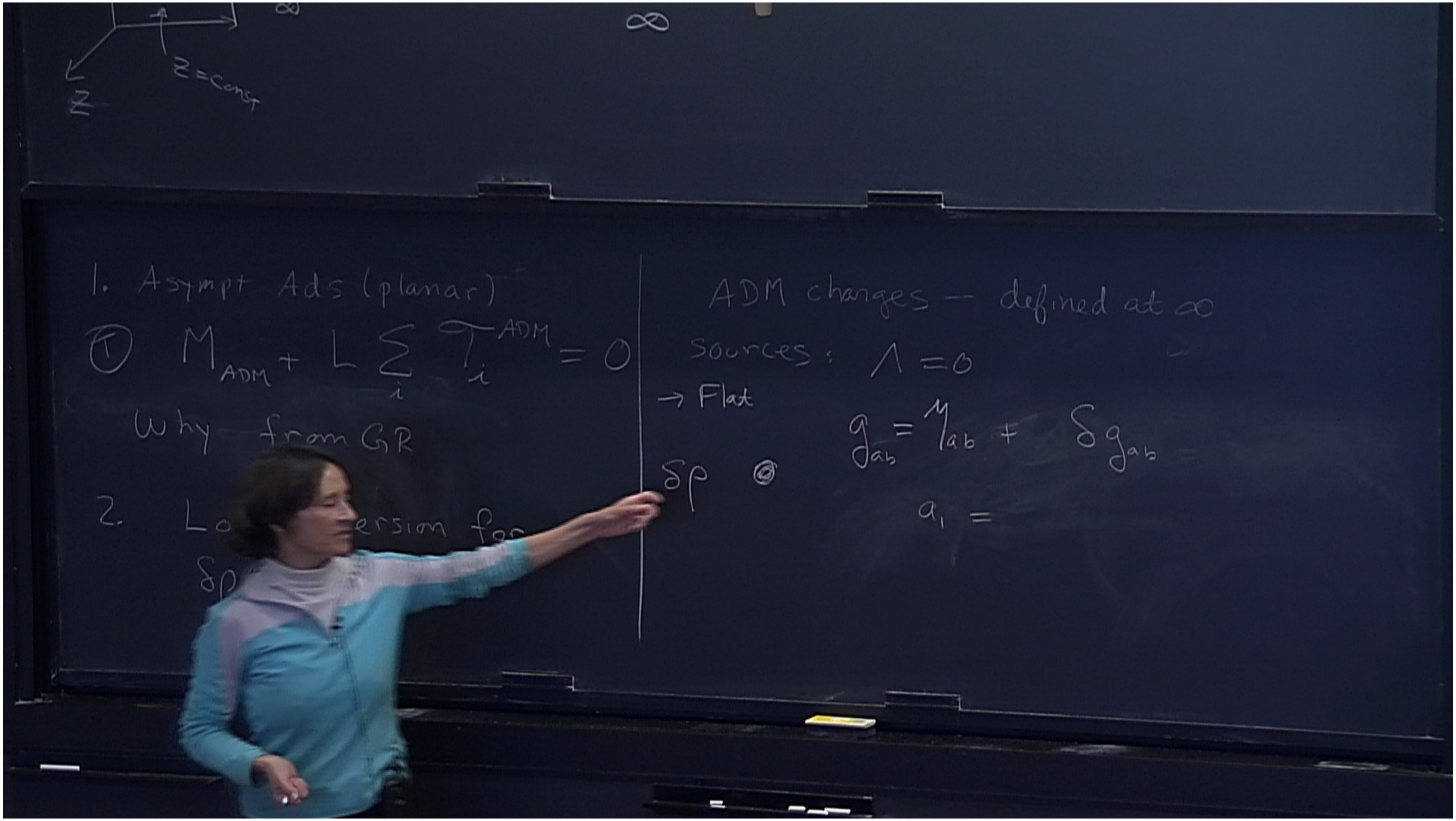


z = const
1. Asympt Ads (planar)
① M_ADM + L Σ_i T_i^ADM = 0
Why from GR
ADM charges -- defined at ∞


∞
∞
z = const
z
1. Asympt AdS (planar)
① M_ADM + L Σ_i T_i^ADM = 0
Why from
2. Local
for
δρ, δρ
ADM changes — defined at ∞
sources: Λ = 0
δρ


z = const
z
∞
1. Asympt Ads (planar)
M_ADM + L Σ_i T_i^ADM = 0
Why
GR
2.
δρ
ADM charges — defined at ∞
Sources: Λ = 0
→ Flat
δρ


z = const
z
1. Asympt Ads (planar)
① M_ADM + L Σ_i T_i^ADM = 0
Why
2. Local
ADM changes — defined at ∞
sources: Λ = 0
→ Flat
g_ab = η_ab + δg_ab
δρ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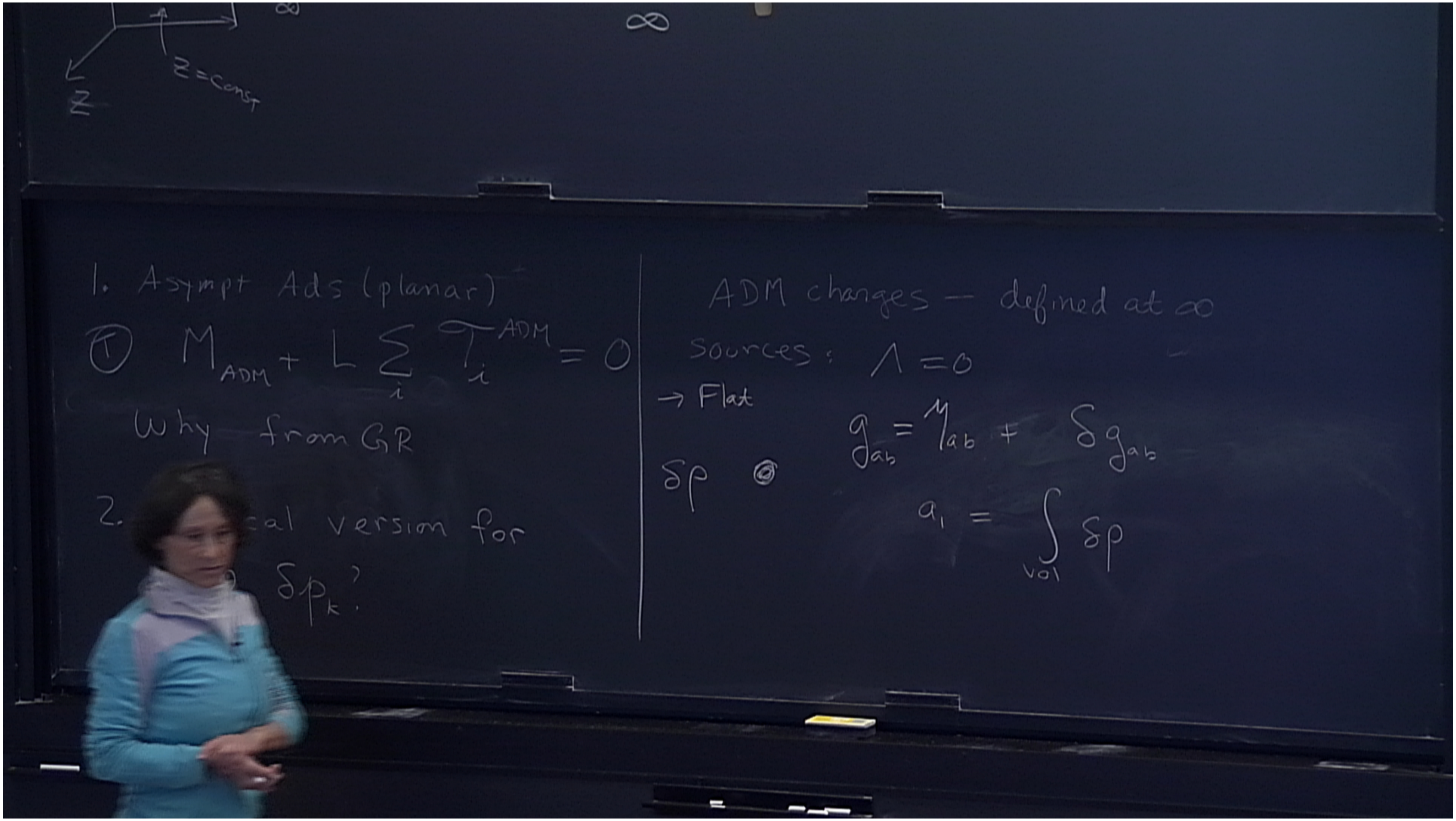
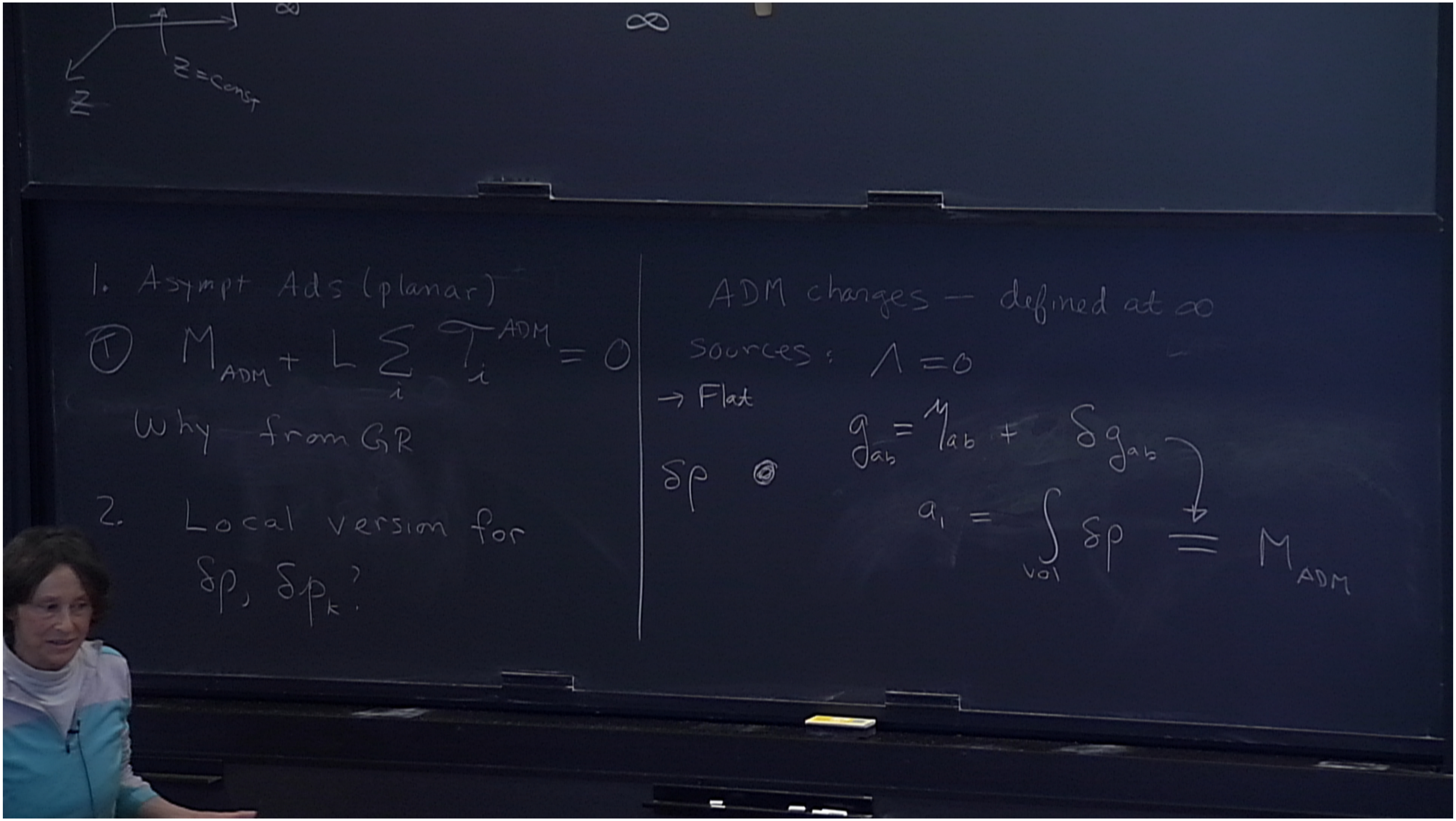
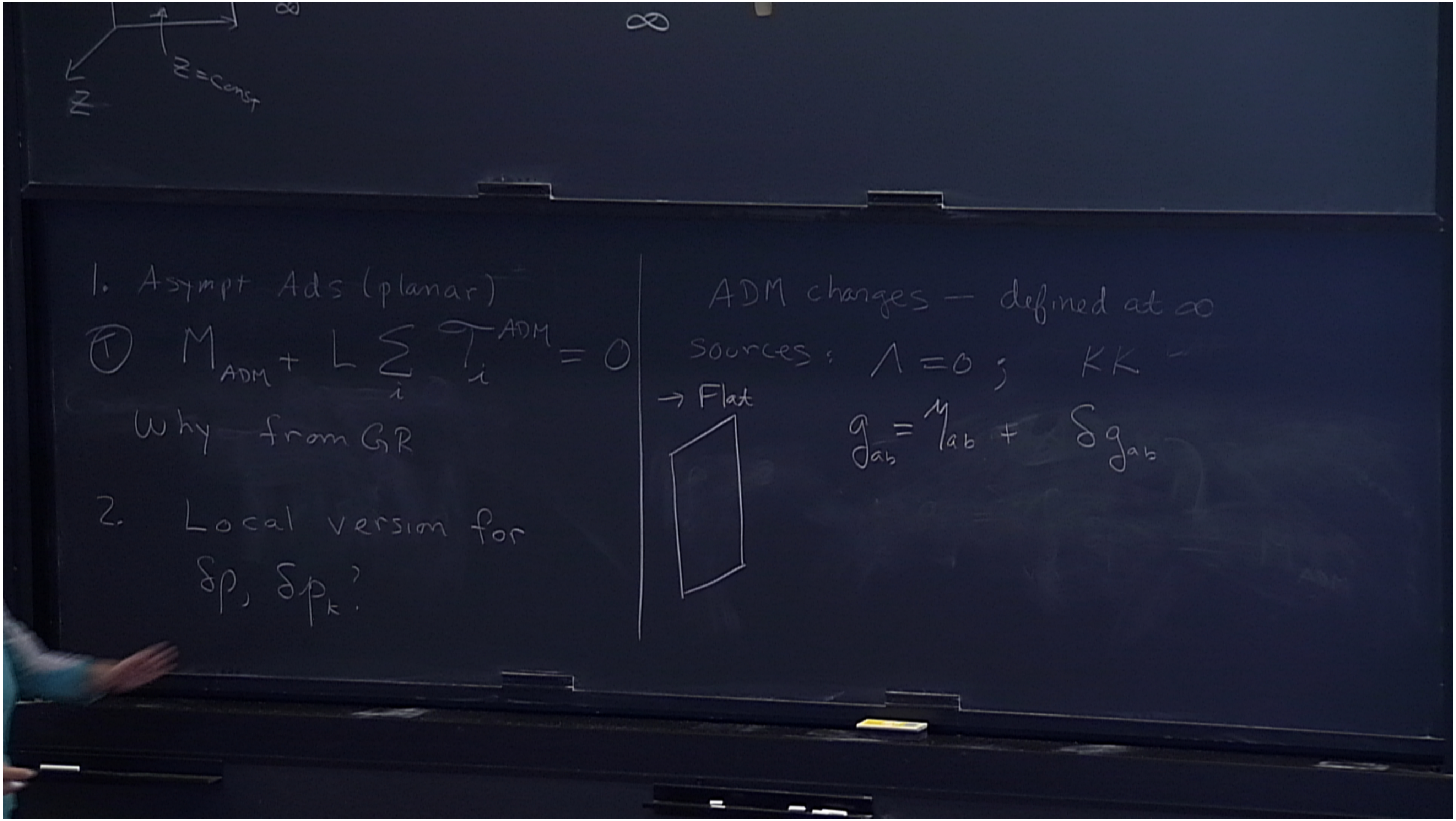
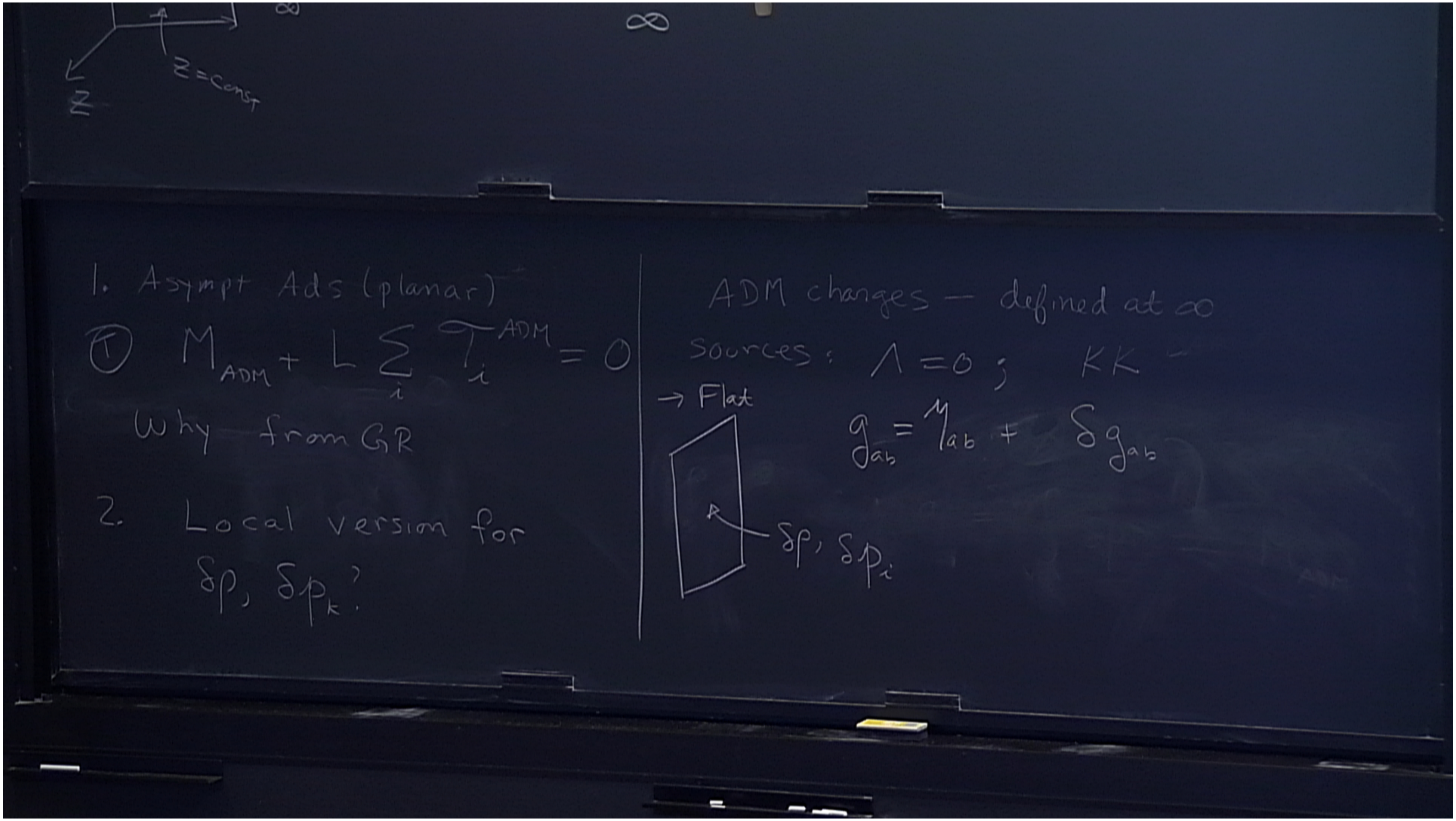
1. Asympt AdS (planar)
① M_ADM + L Σ_i T_i^ADM = 0
Why from GR
ADM changes — defined at ∞
sources: Λ = 0
→ Flat
g_ab = η_ab + δg_ab
δρ
a_1 =


z = const
z
∞
1. Asympt AdS (planar)
M_ADM + L Σ_i T_i^ADM = 0
Why from GR
2. cal version for
δp_k ?
ADM charges — defined at ∞
sources: Λ = 0
→ Flat
g_ab = η_ab + δg_ab
δρ
a_1 = ∫_vol δρ


z = const
1. Asympt Ads (planar)
M_ADM + L Σ_i T_i^ADM = 0
Why from GR
2. Local version for
δρ, δp_k ?
ADM changes — defined at ∞
sources : Λ = 0
→ Flat
g_ab = η_ab + δg_ab
a_1 = ∫_vol δρ = M_ADM


∞
z = const
z
1. Asympt AdS (planar)
① $M_{ADM} + L \sum_i T_i^{ADM} = 0$
Why from GR
2. Local version for
$\delta\rho, \delta p_k$?
ADM charges — defined at ∞
Sources: $\Lambda = 0$; KK
→ Flat
$g_{ab} = \eta_{ab} + \delta g_{ab}$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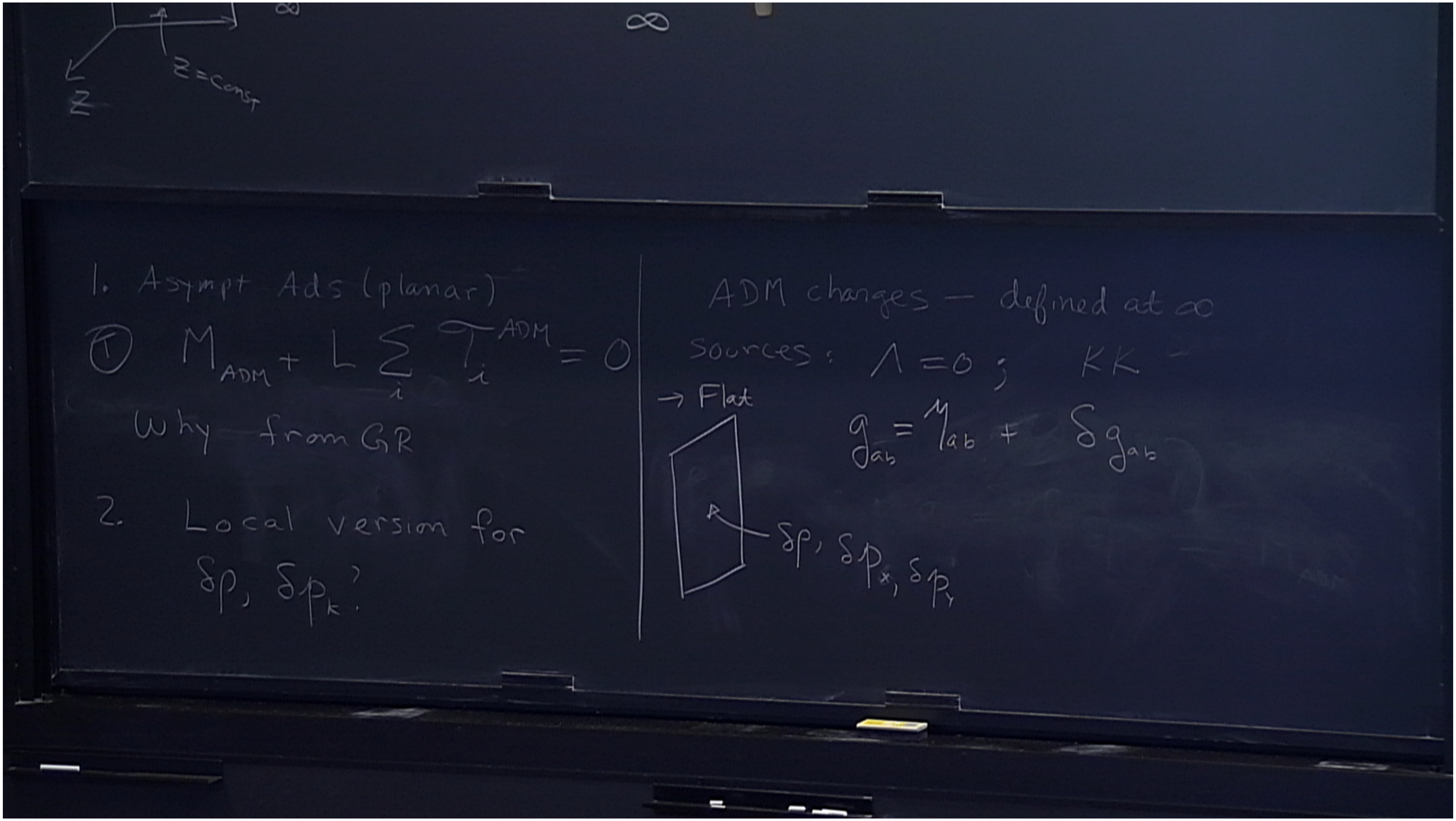
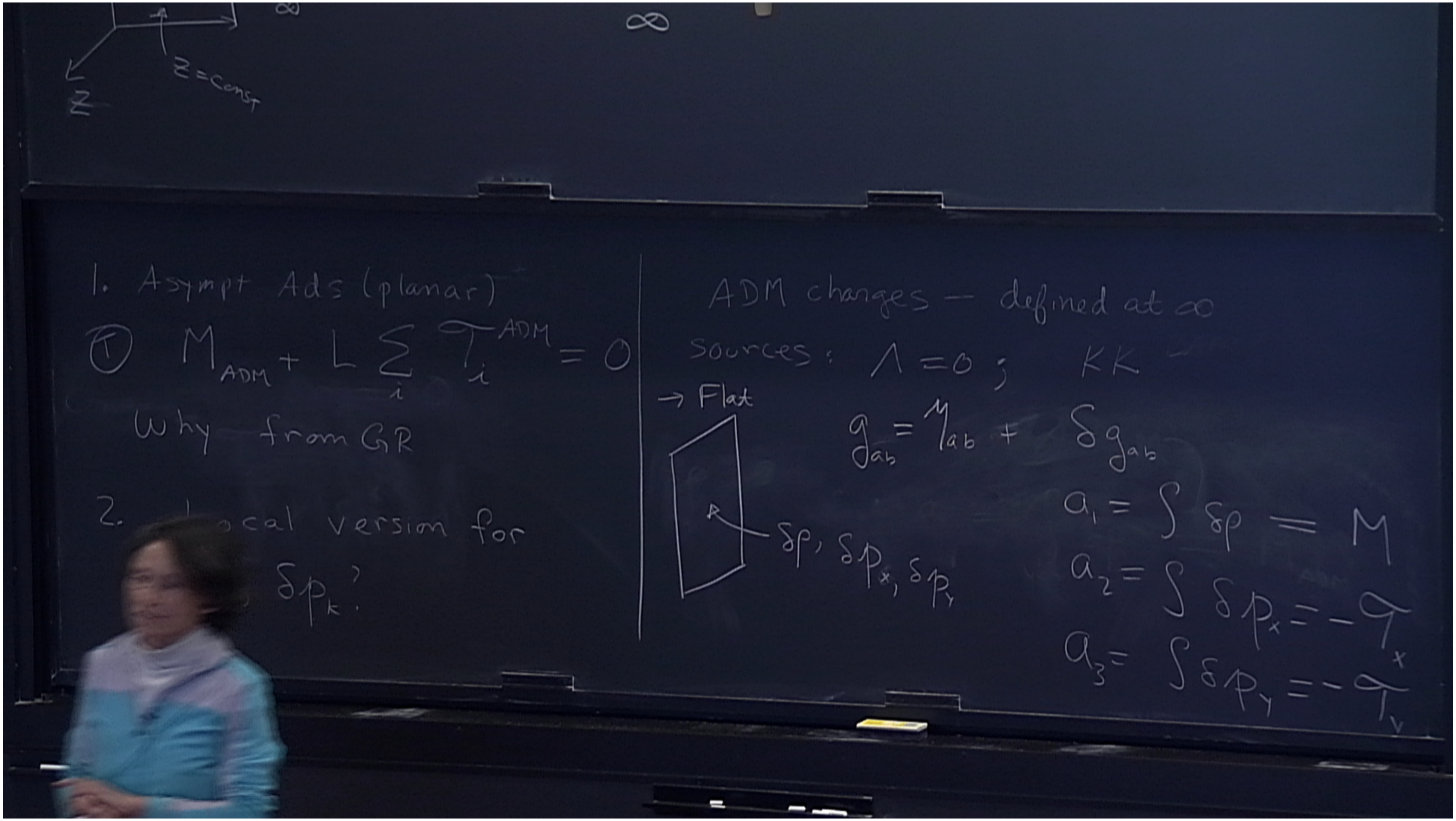
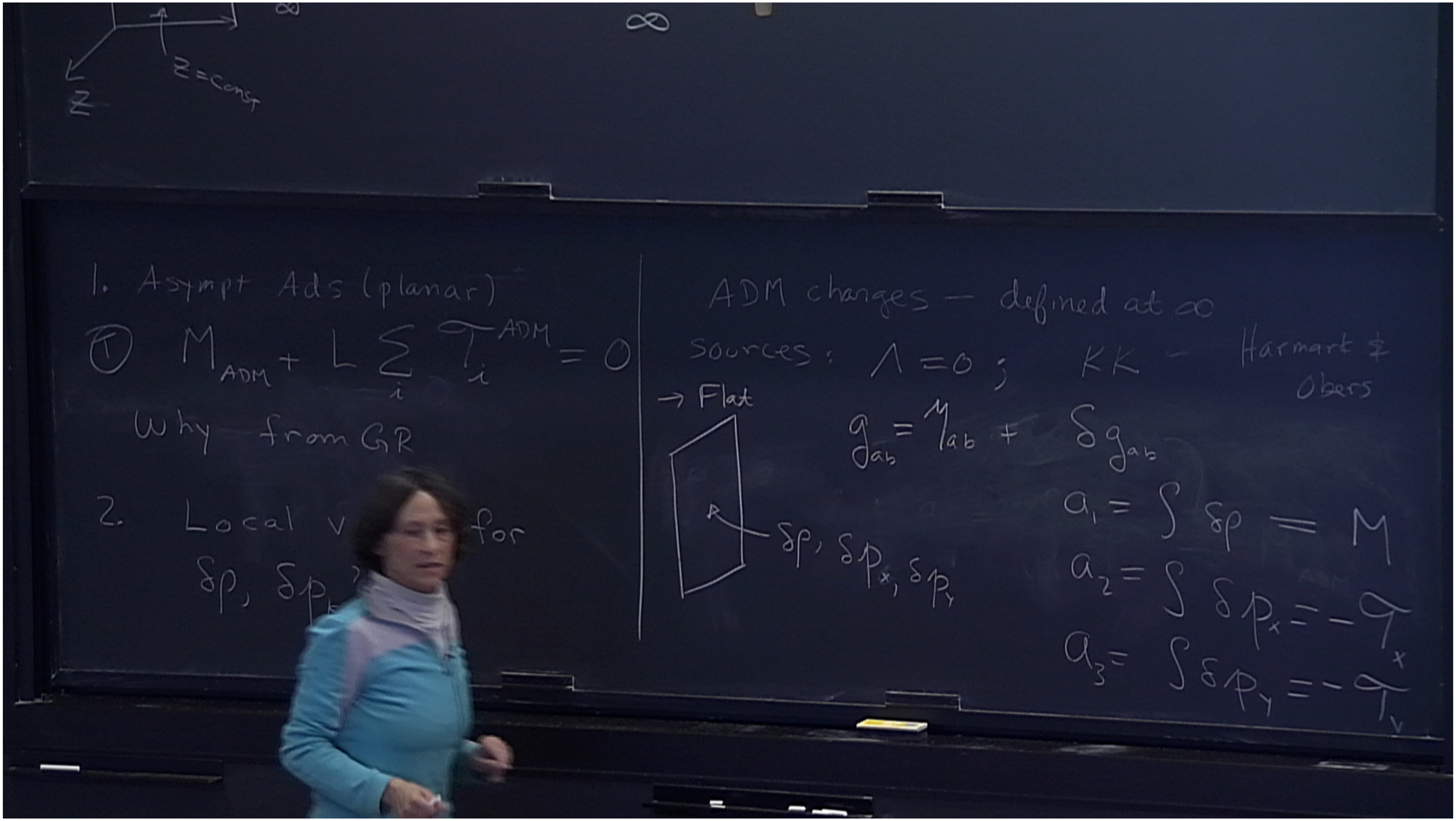
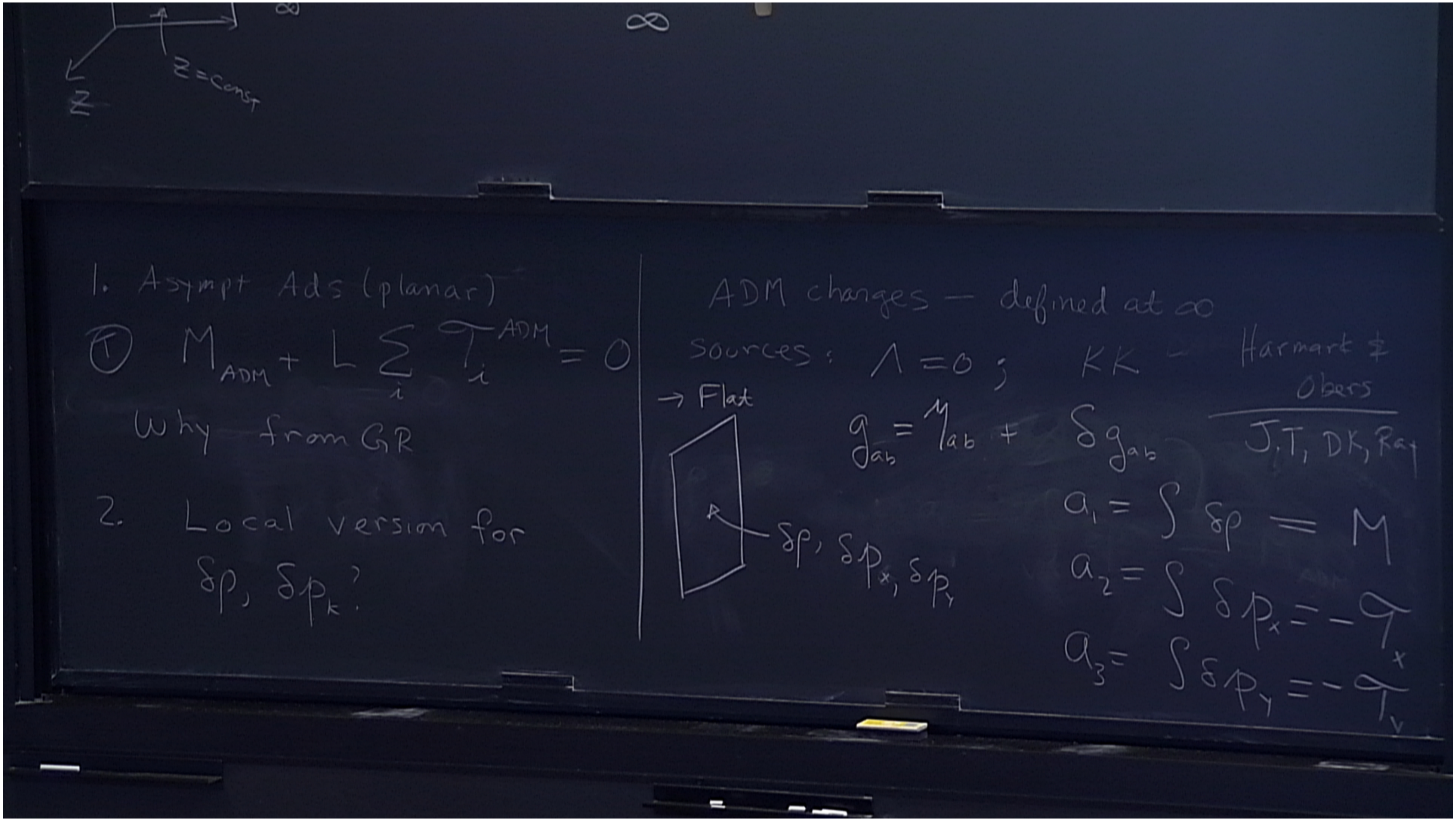
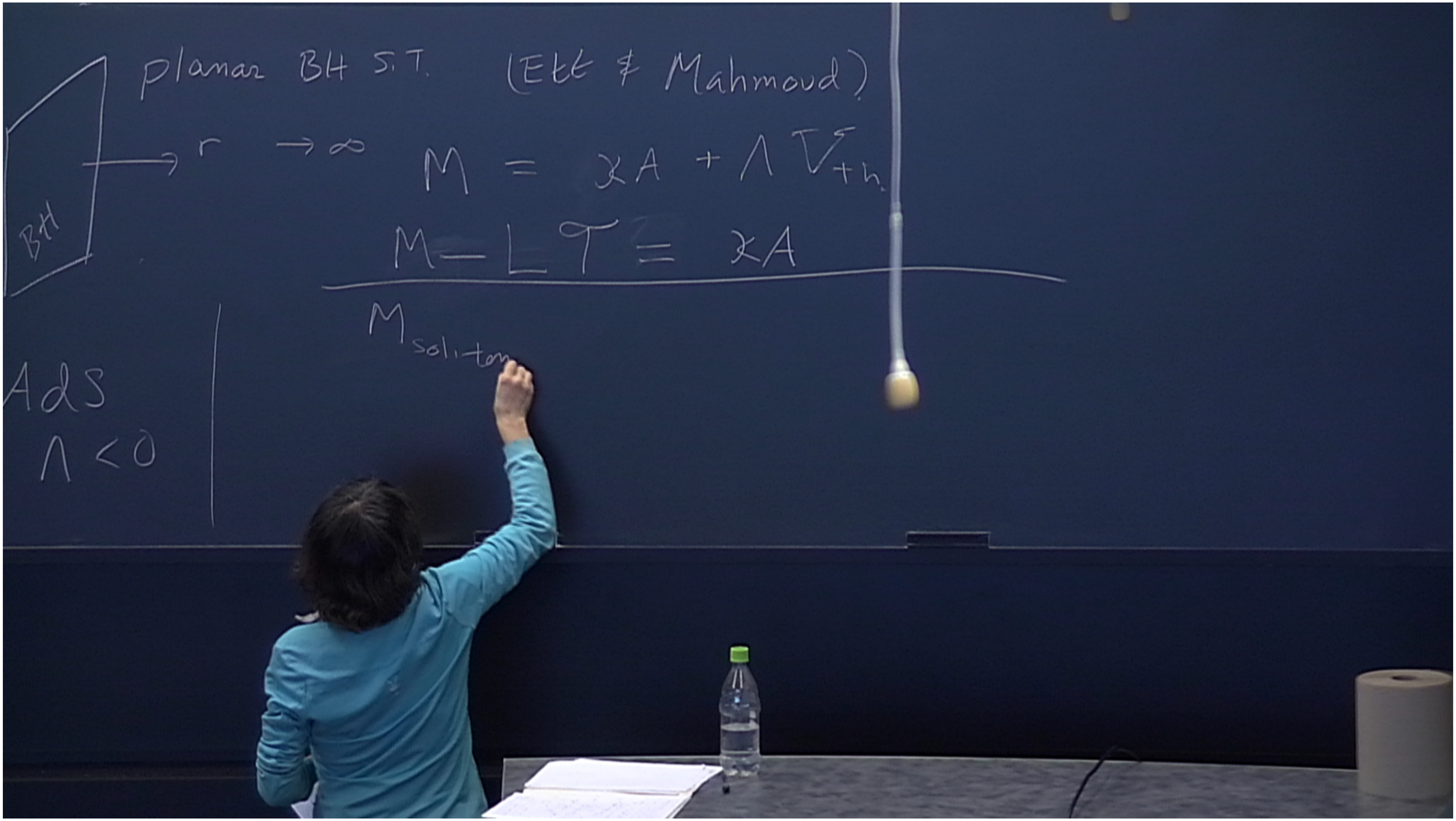
∞
1. Asympt Ads (planar)
① M_ADM + L Σ_i T_i^ADM = 0
Why from GR
2. Local version for
δρ, δp_k ?
ADM charges — defined at ∞
sources: Λ = 0 ; KK
→ Flat
g_ab = η_ab + δg_ab
δρ, δp_i

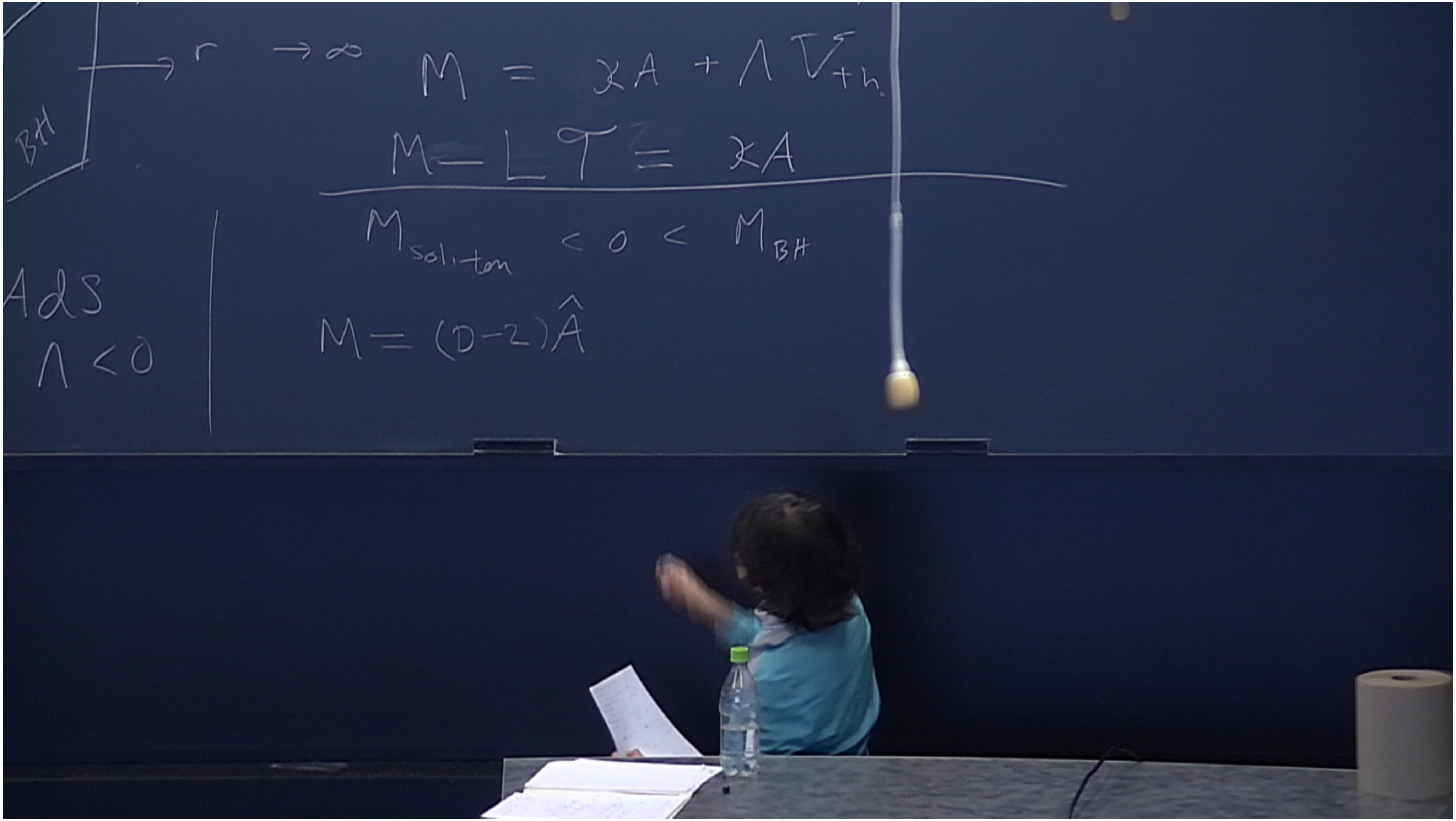

z = const
z
∞
∞
1. Asympt AdS (planar)
① M_ADM + L Σ_i T_i^ADM = 0
Why from GR
2. Local version for
δρ, δp_k ?
ADM charges — defined at ∞
Sources: Λ = 0 ; KK
→ Flat
g_ab = η_ab + δg_ab
δρ, δp_x, δp_y

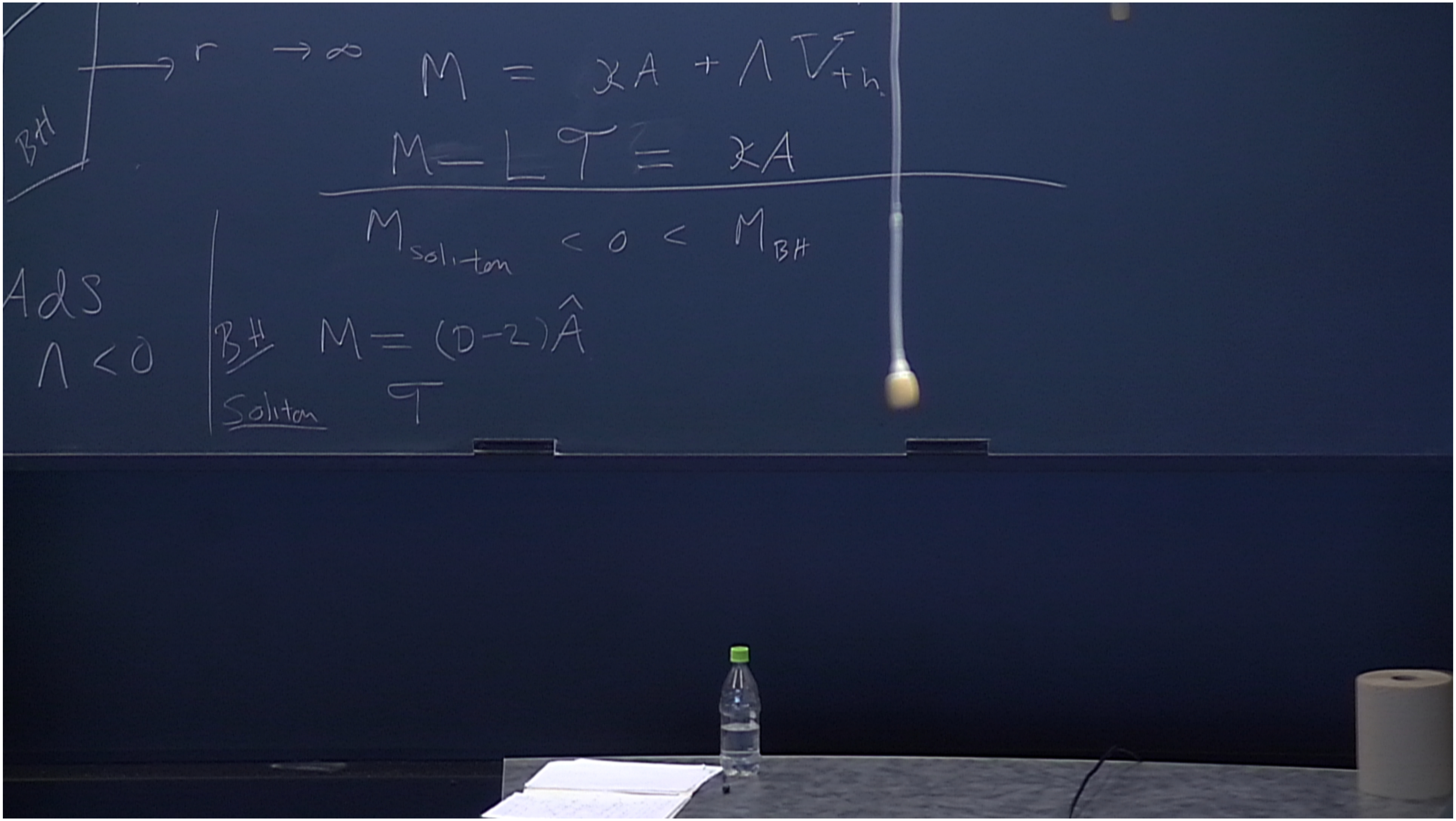

∞
z = const
z
∞
1. Asympt AdS (planar)
① M_ADM + L Σ_i T_i^ADM = 0
Why from GR
2. Local version for
δp_k ?
ADM charges — defined at ∞
Sources: Λ = 0 ; KK
→ Flat
g_ab = η_ab + δg_ab
δρ, δp_x, δp_y
a_1 = ∫ δρ = M
a_2 = ∫ δp_x = − T_x
a_3 = ∫ δp_y = − T_y

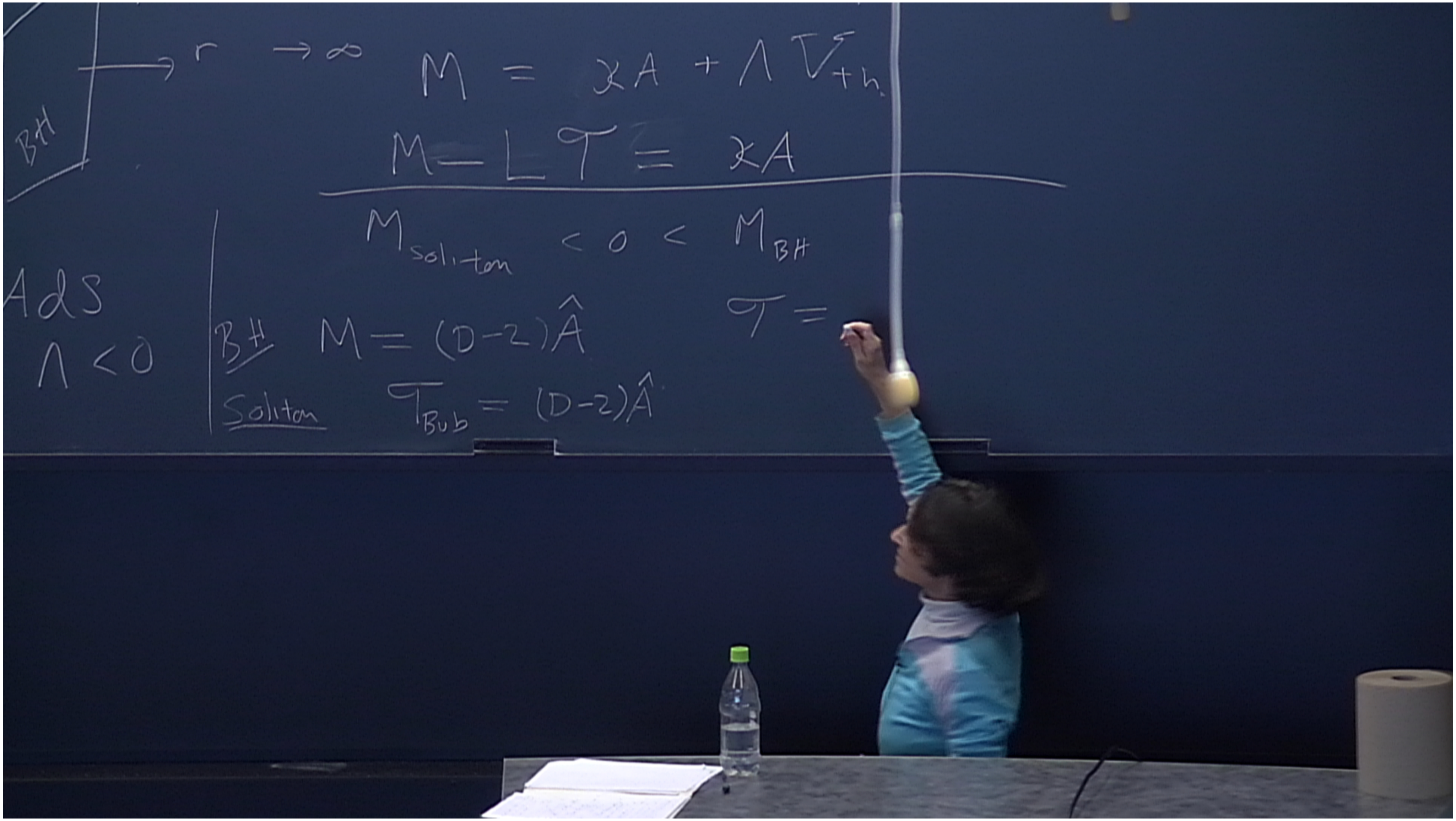

z = const
1. Asympt Ads (planar)
Why from GR
2. Local
for
ADM charges — defined at ∞
sources: Λ = 0 ; KK — Harmark & Obers
→ Flat

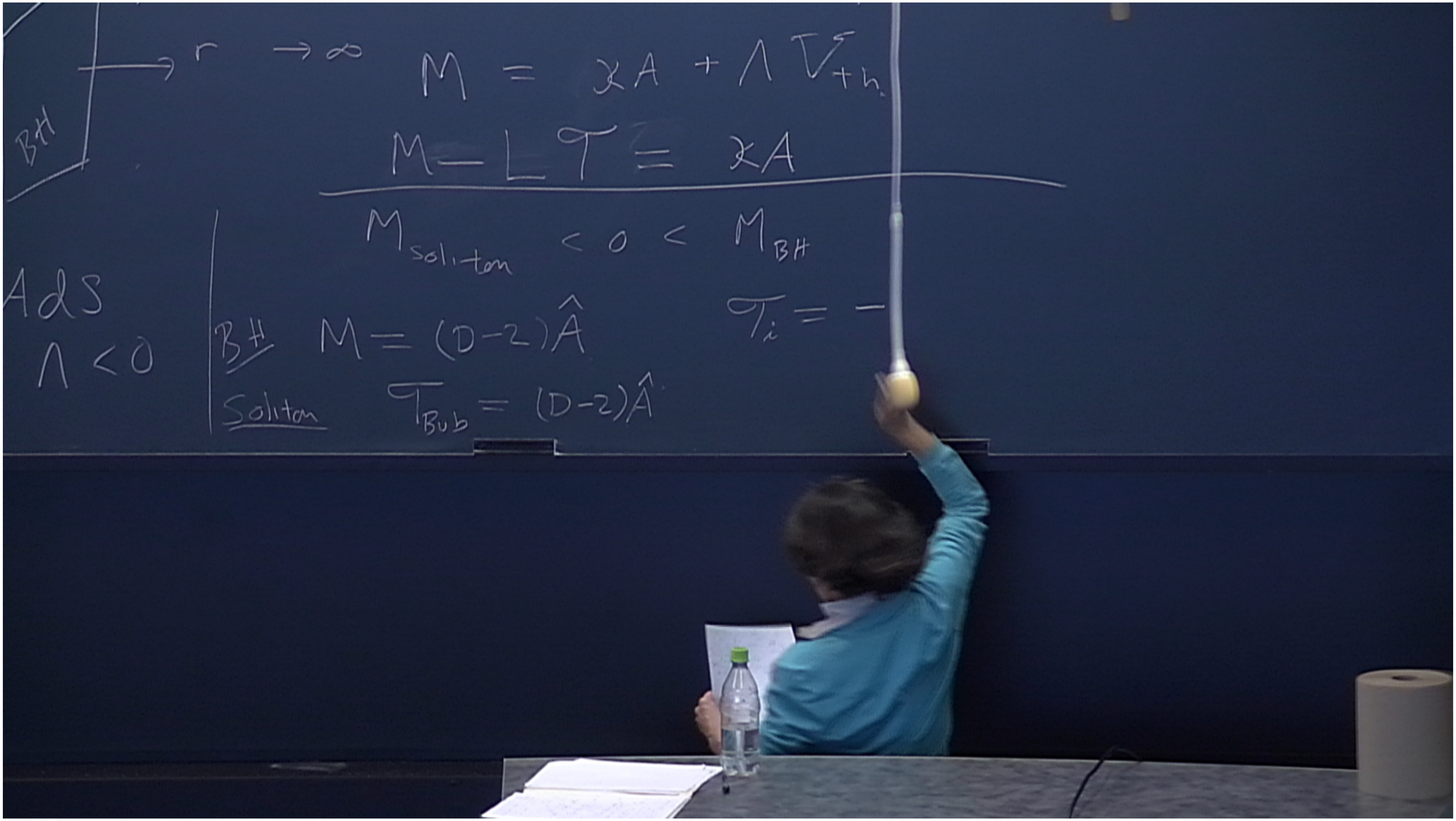

z = const
z
1. Asympt AdS (planar)
(T) M_ADM + L Σ_i T_i^ADM = 0
Why from GR
2. Local version for δρ, δp_k ?
ADM charges — defined at ∞
Sources: Λ = 0 ; KK — Harmark & Obers
J, T, DK, Ray
→ Flat
g_ab = η_ab + δg_ab
δρ, δp_x, δp_y
a_1 = ∫ δρ = M
a_2 = ∫ δp_x = −T_x
a_3 = ∫ δp_y = −T_y

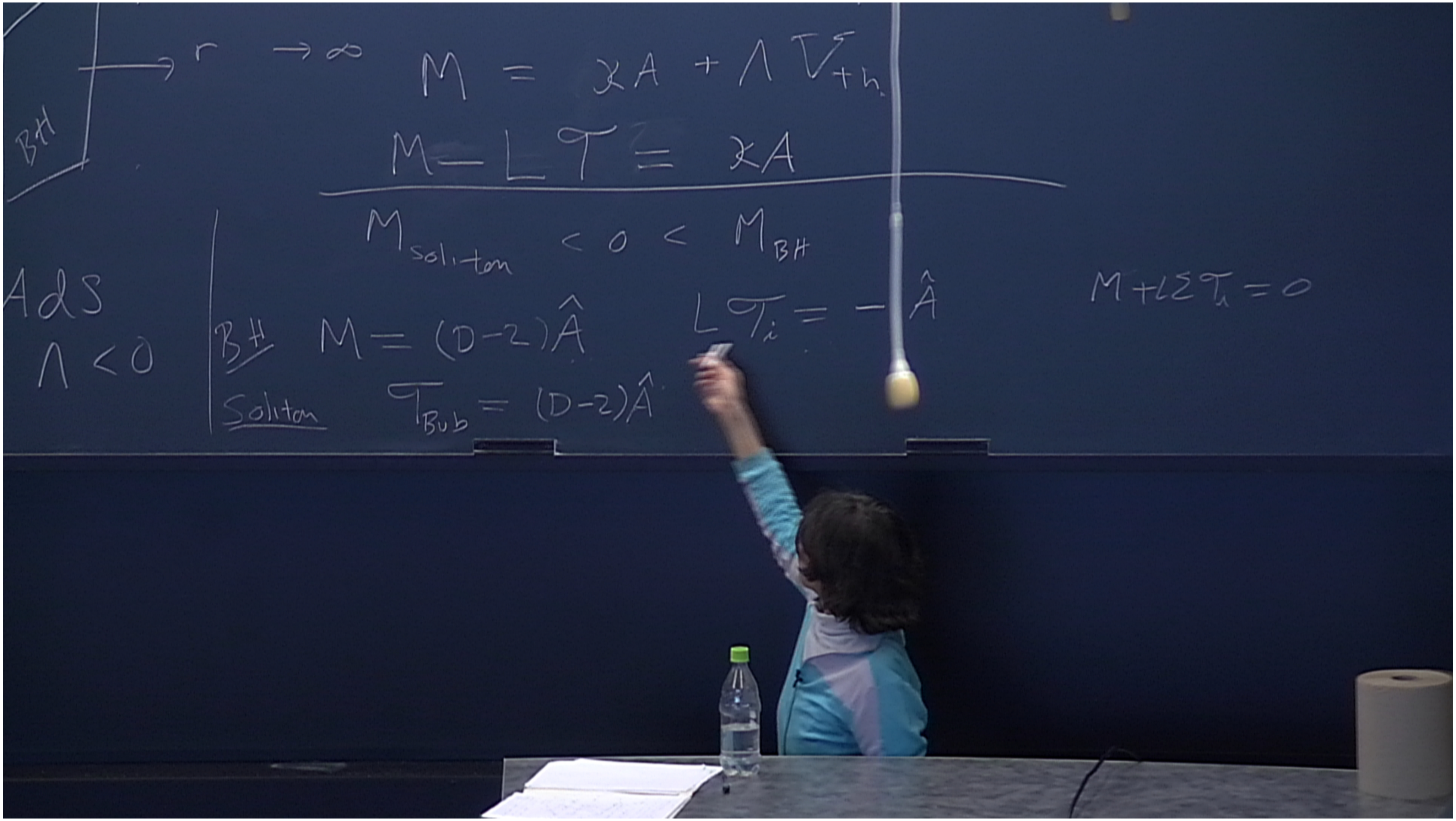

planar BH S.T. (Ekk & Mahmoud)
BH
r → ∞
M = κA + Λ V_th
M − LT = κA
M_soliton
AdS
Λ < 0

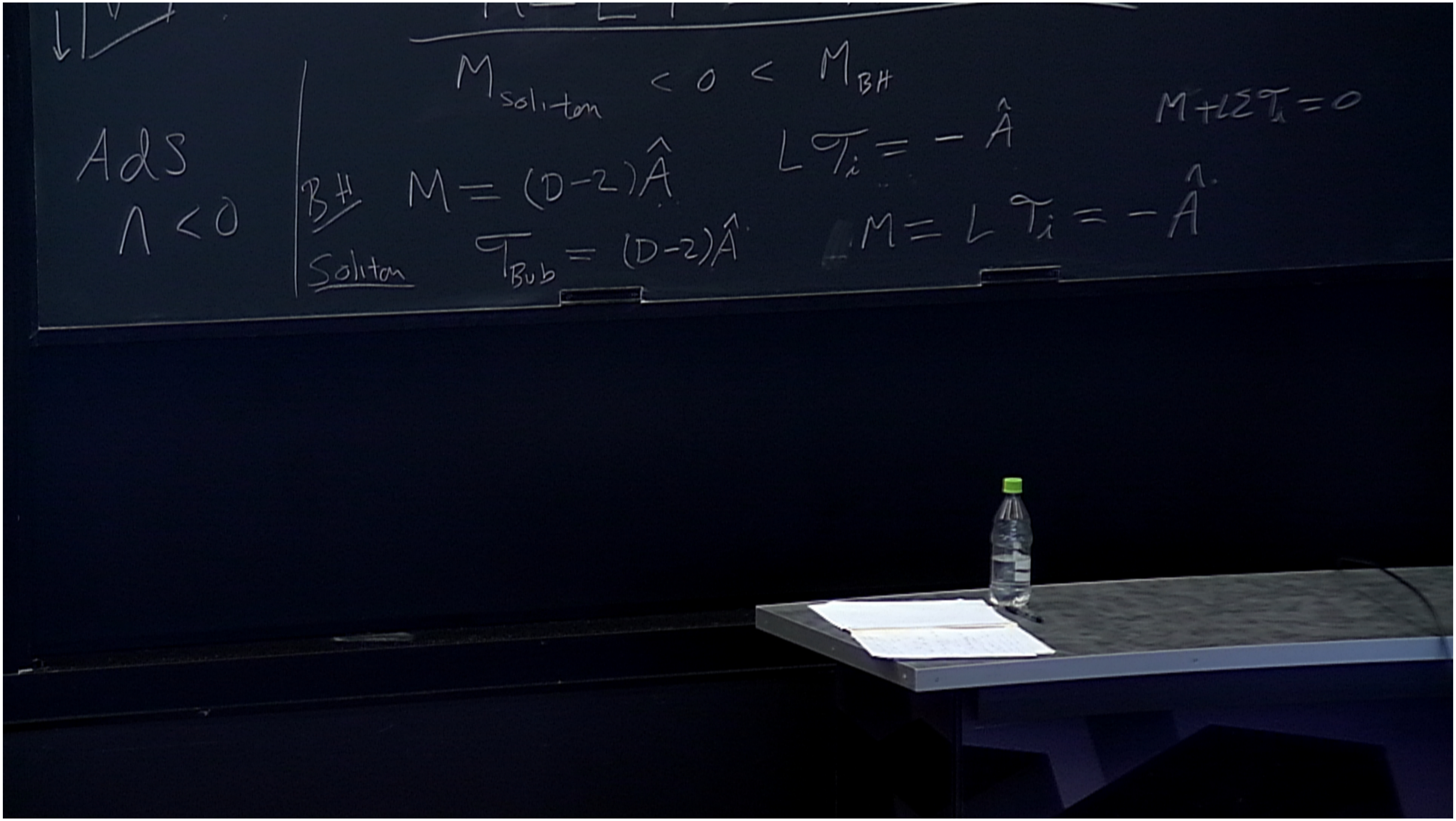

BH
r → ∞
M = κA + Λ V_th
M − LT = κA
M_soliton < 0 < M_BH
AdS
Λ < 0
M = (D−2)Â

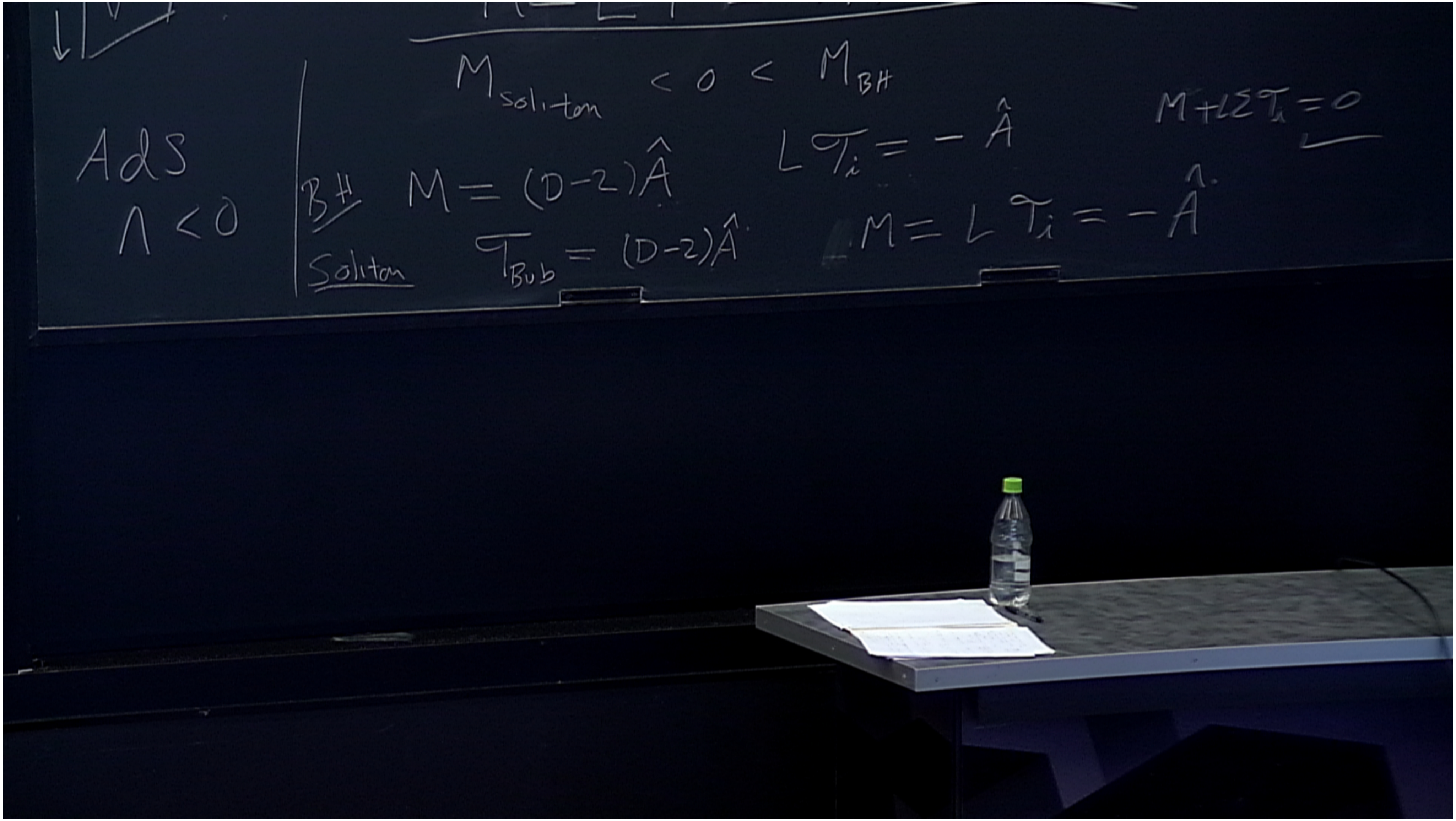

BH
r → ∞
M = κA + Λ V_th
M − LT = κA
M_soliton < 0 < M_BH
AdS
Λ < 0
BH M = (D−2)Â
Soliton T

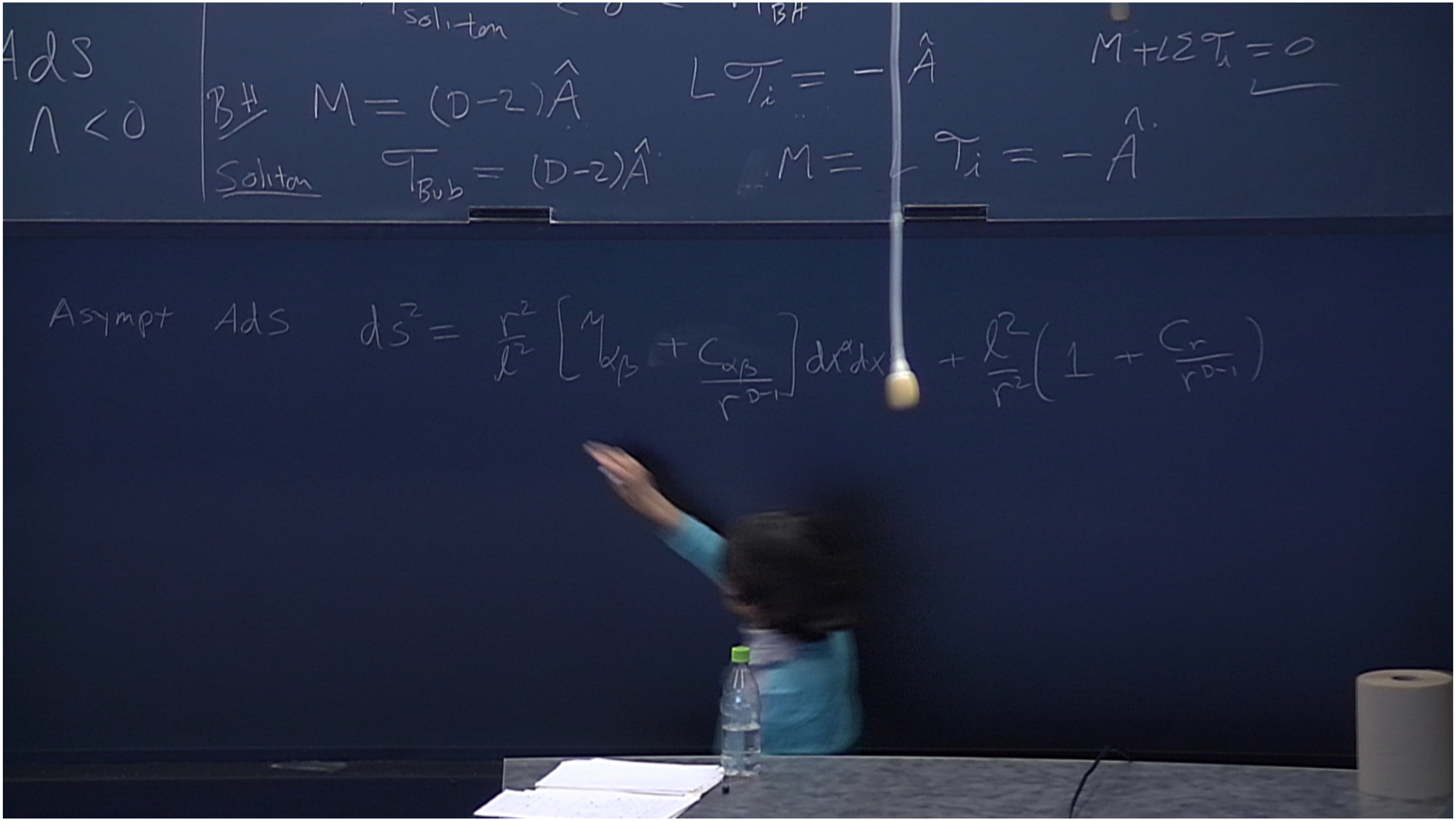

BH
r → ∞
M = κA + Λ V_th
M − LT = κA
M_soliton < 0 < M_BH
AdS
Λ < 0
BH M = (D−2)Â
T =
Soliton T_Bub = (D−2)Â

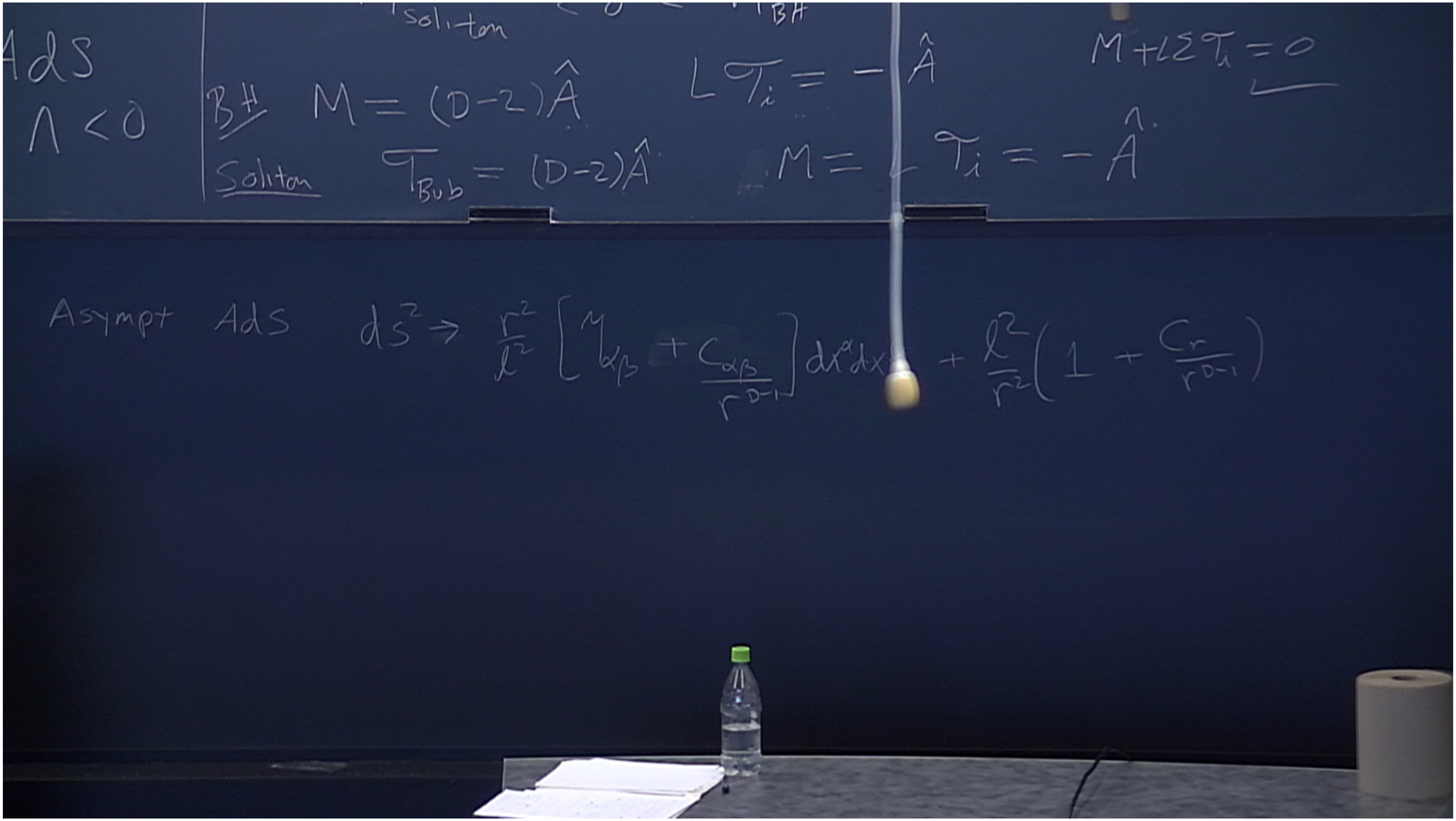

r → ∞
M = κA + Λ V_th
M − LT = κA
M_soliton < 0 < M_BH
AdS
Λ < 0
BH M = (D−2)Â
Soliton T_Bub = (D−2)Â
T_i = −

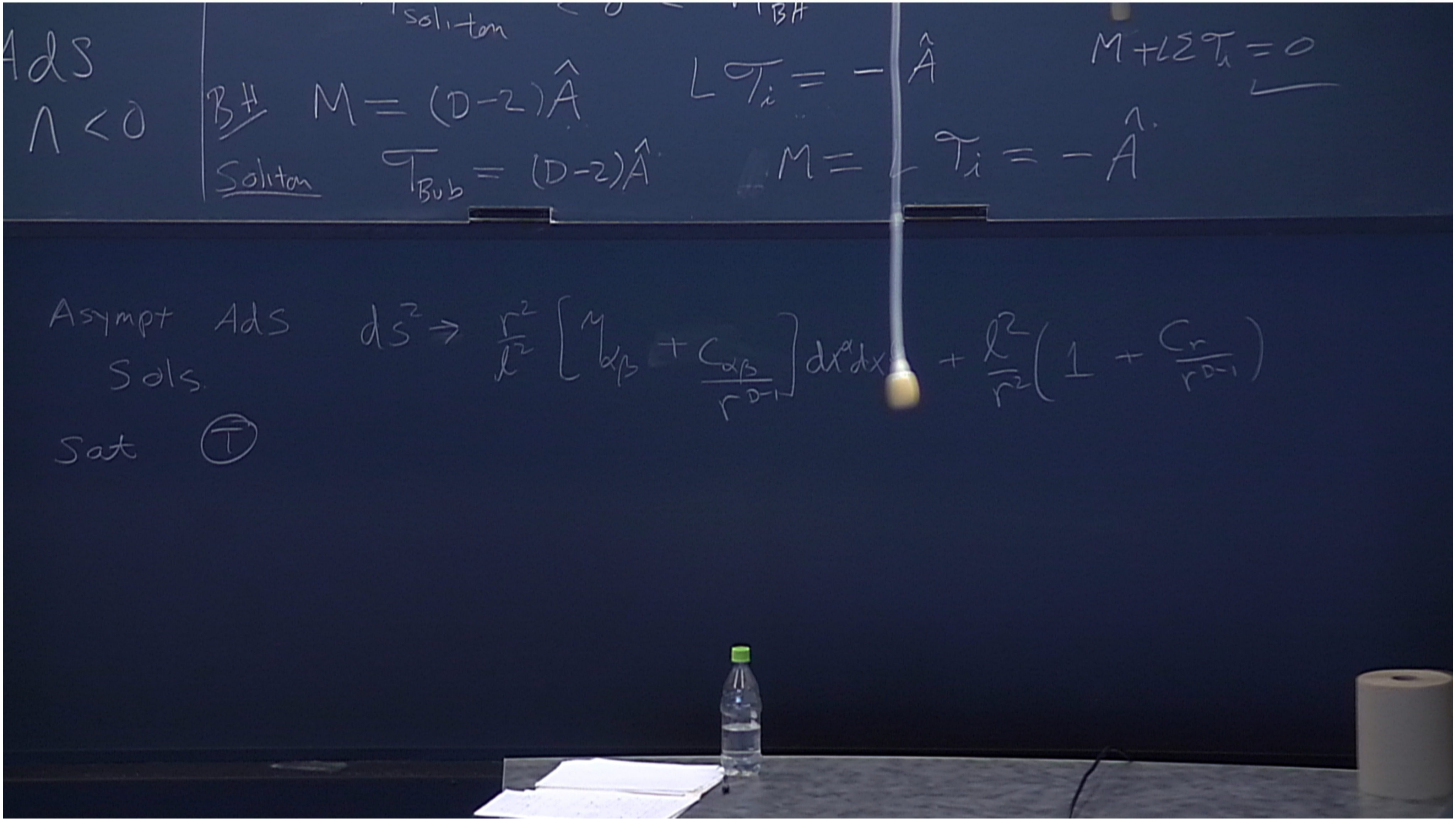

r → ∞
M = κA + Λ V_th
M − LT = κA
M_soliton < 0 < M_BH
AdS
Λ < 0
BH M = (D−2)Â
Soliton T_Bub = (D−2)Â
LT_i = −Â
M + LΣT_i = 0

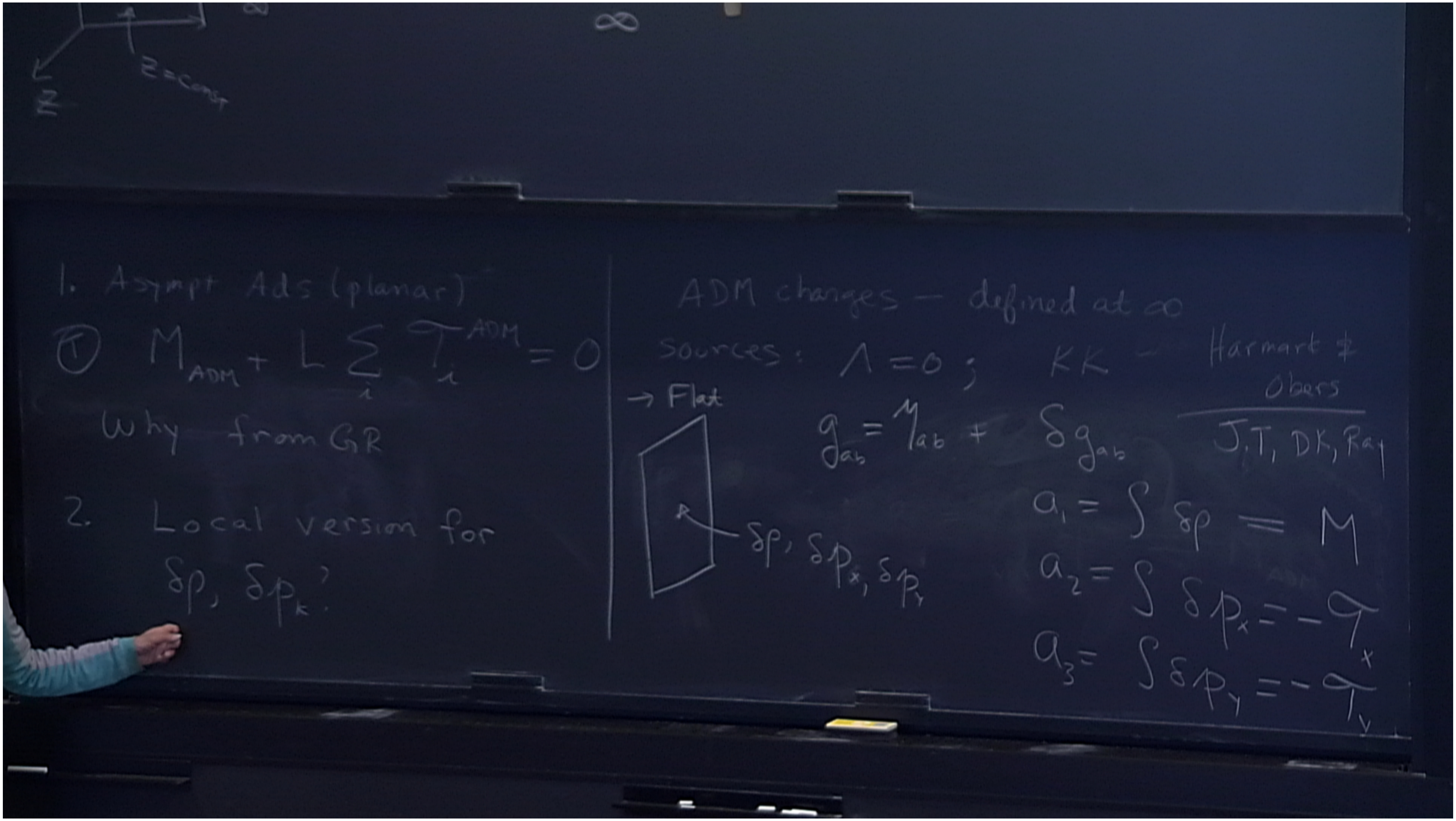

M_soliton < 0 < M_BH
AdS
Λ < 0
BH M = (D-2)Â
Soliton τ_Bub = (D-2)Â
Lτ_i = - Â
M = Lτ_i = - Â
M + LΣτ_i = 0


M_soliton < 0 < M_BH
AdS
Λ < 0
BH M = (D−2)Â
Soliton T_Bub = (D−2)Â
L T_i = − Â
M = L T_i = − Â
M + L Σ T_i = 0


AdS
Λ < 0
BH M = (D−2)Â
Soliton T_Bub = (D−2)Â
L T_i = −Â
M = L T_i = −Â
M + L Σ T_i = 0
Asympt AdS ds² = r²/l² [η_αβ + C_αβ/r^(D−1)] dx^α dx^β + l²/r² (1 + C_r/r^(D−1))


AdS
Λ < 0
BH M = (D−2)Â
Soliton τ_Bub = (D−2)Â
L τ_i = − Â
M = L τ_i = − Â
M + L Σ τ_i = 0
Asympt AdS ds² → r²/l² [η_αβ + C_αβ/r^(D−1)] dx^α dx^β + l²/r² (1 + C_r/r^(D−1))


AdS
Λ < 0
BH M = (D−2)Â
Soliton T_Bub = (D−2)Â
L T_i = − Â
M = L T_i = − Â
M + L Σ T_i = 0
Asympt AdS
Sols.
Sat (T)
ds² → r²/l² [η_αβ + C_αβ / r^(D−1)] dx^α dx^β + l²/r² (1 + C_r / r^(D−1))


1. Asympt AdS (planar)
(T) M_ADM + L Σ_i T_i^ADM = 0
Why from GR
2. Local version for δρ, δp_k ?
ADM charges — defined at ∞
sources: Λ = 0 ; KK — Harmark & Obers
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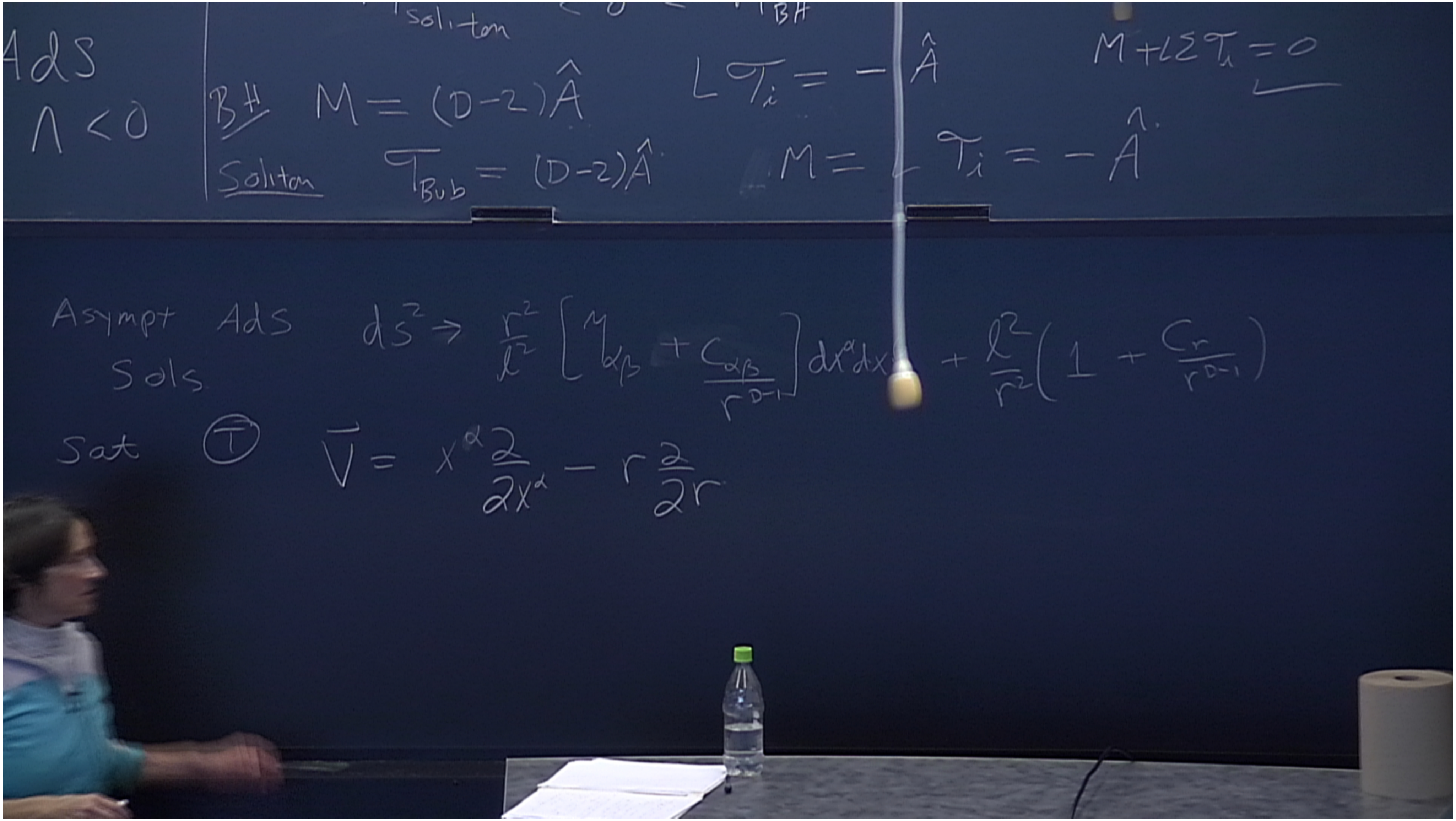
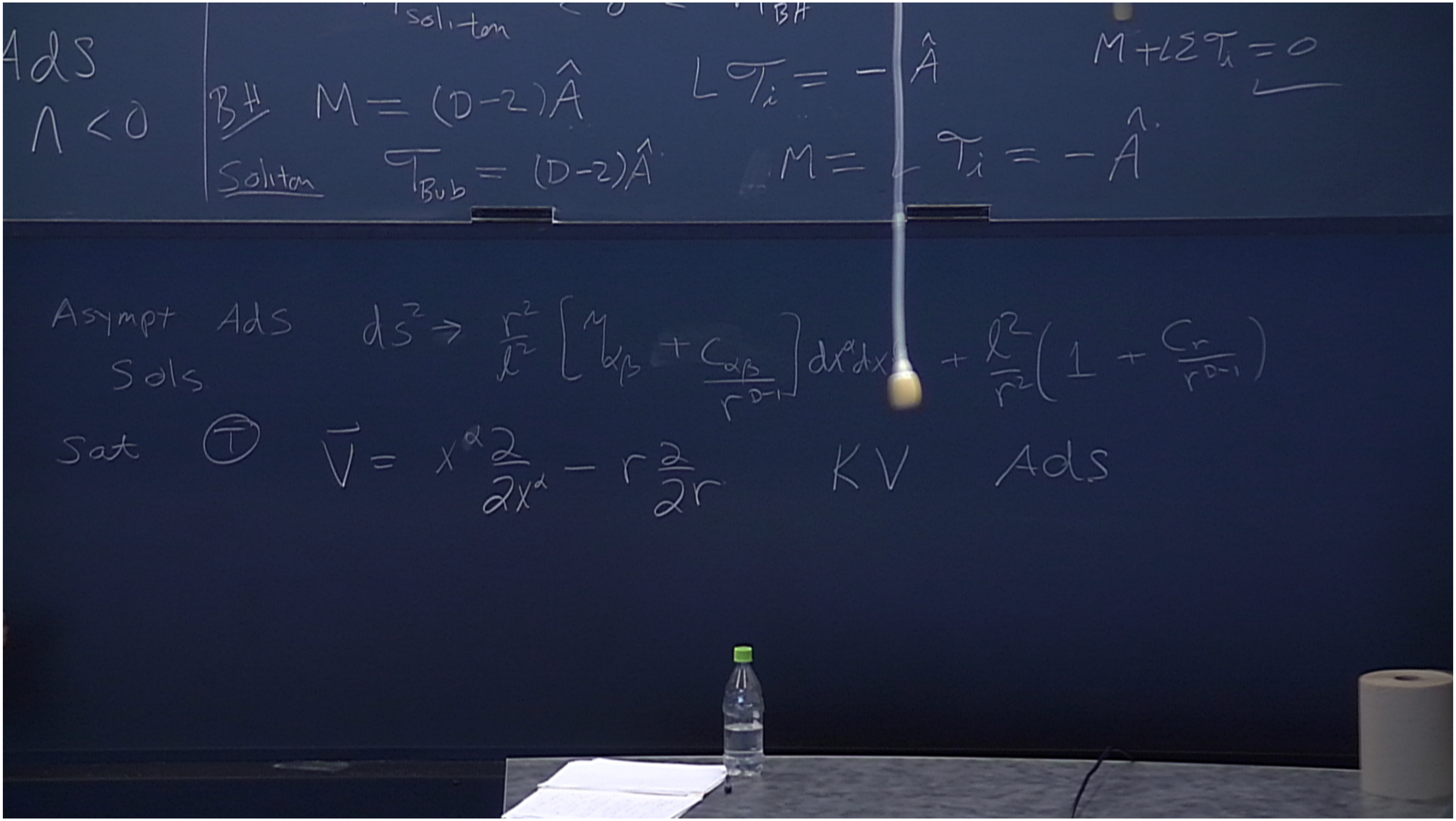
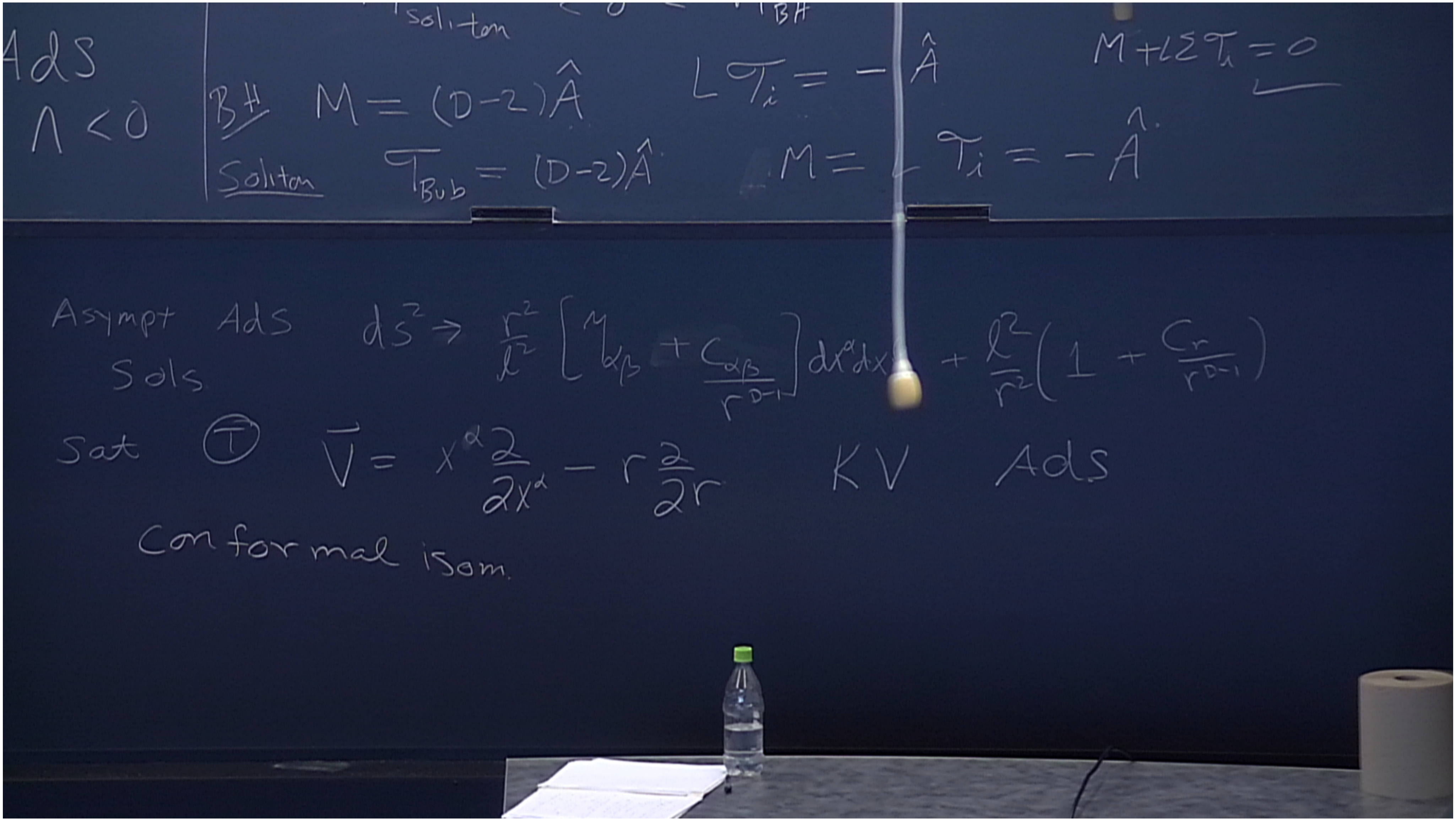
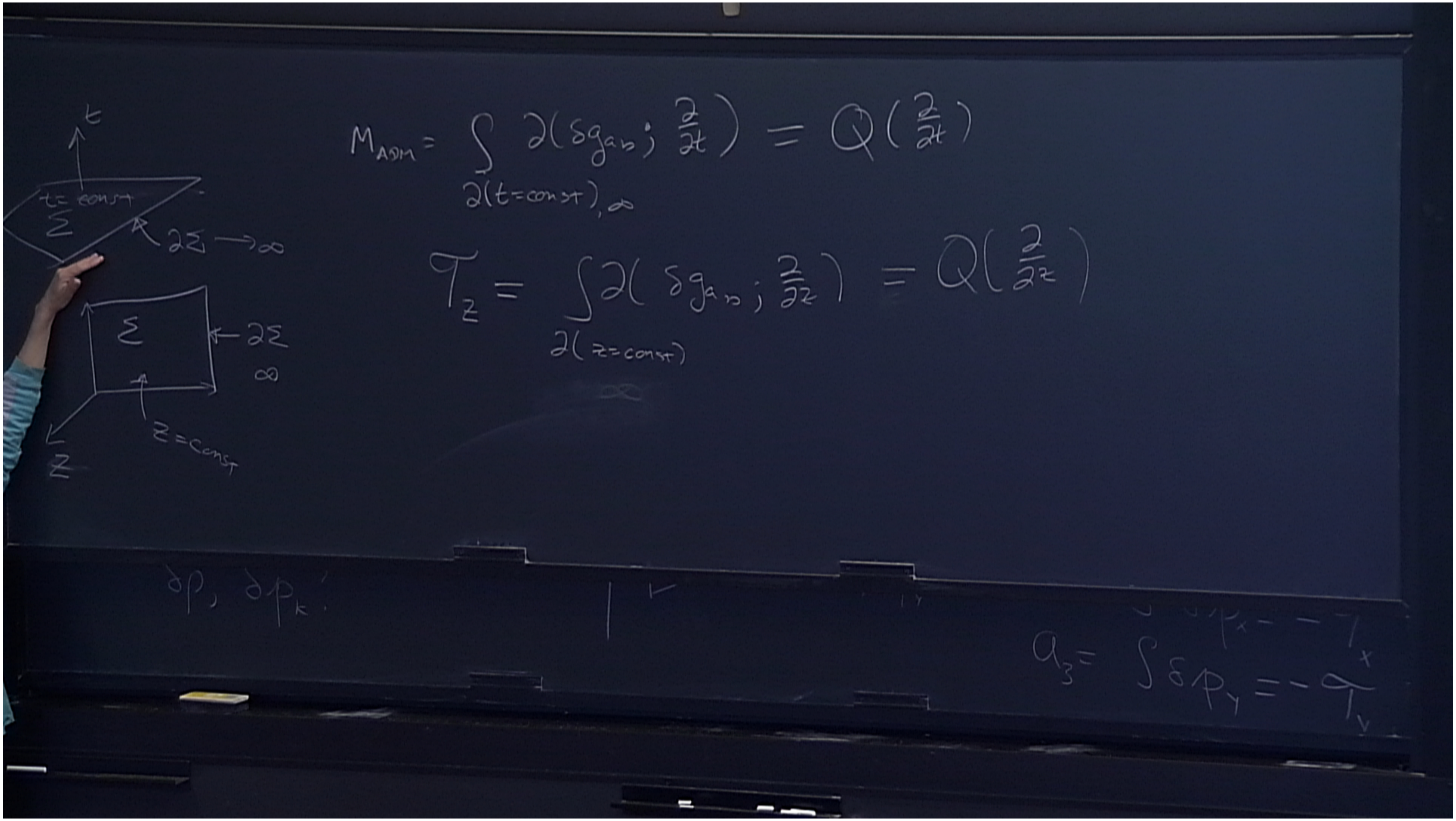
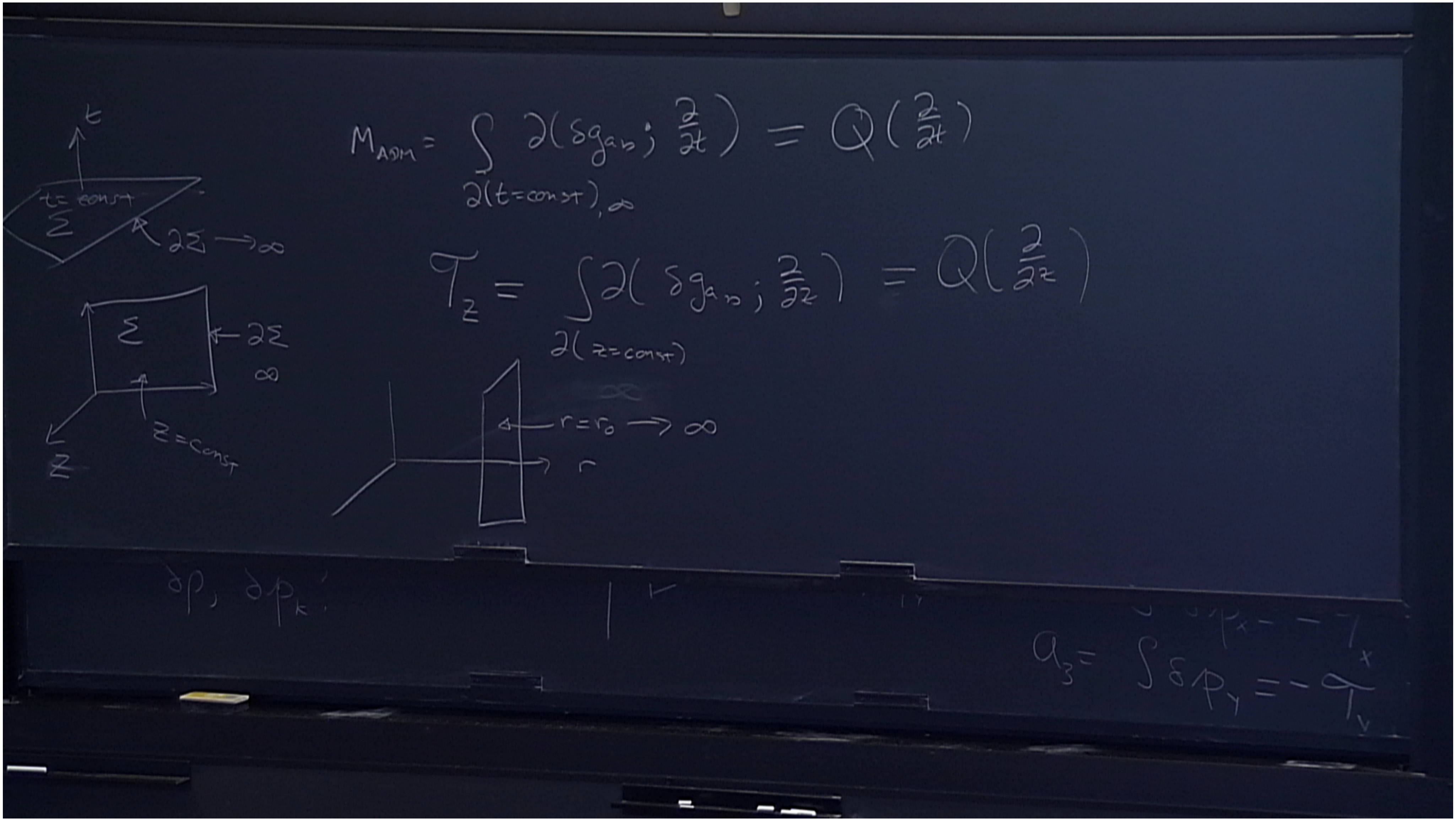
→ Flat
g_ab = η_ab + δg_ab
δρ, δp_x, δp_y
a_1 = ∫ δρ = M
a_2 = ∫ δp_x = −T_x
a_3 = ∫ δp_y = −T_y

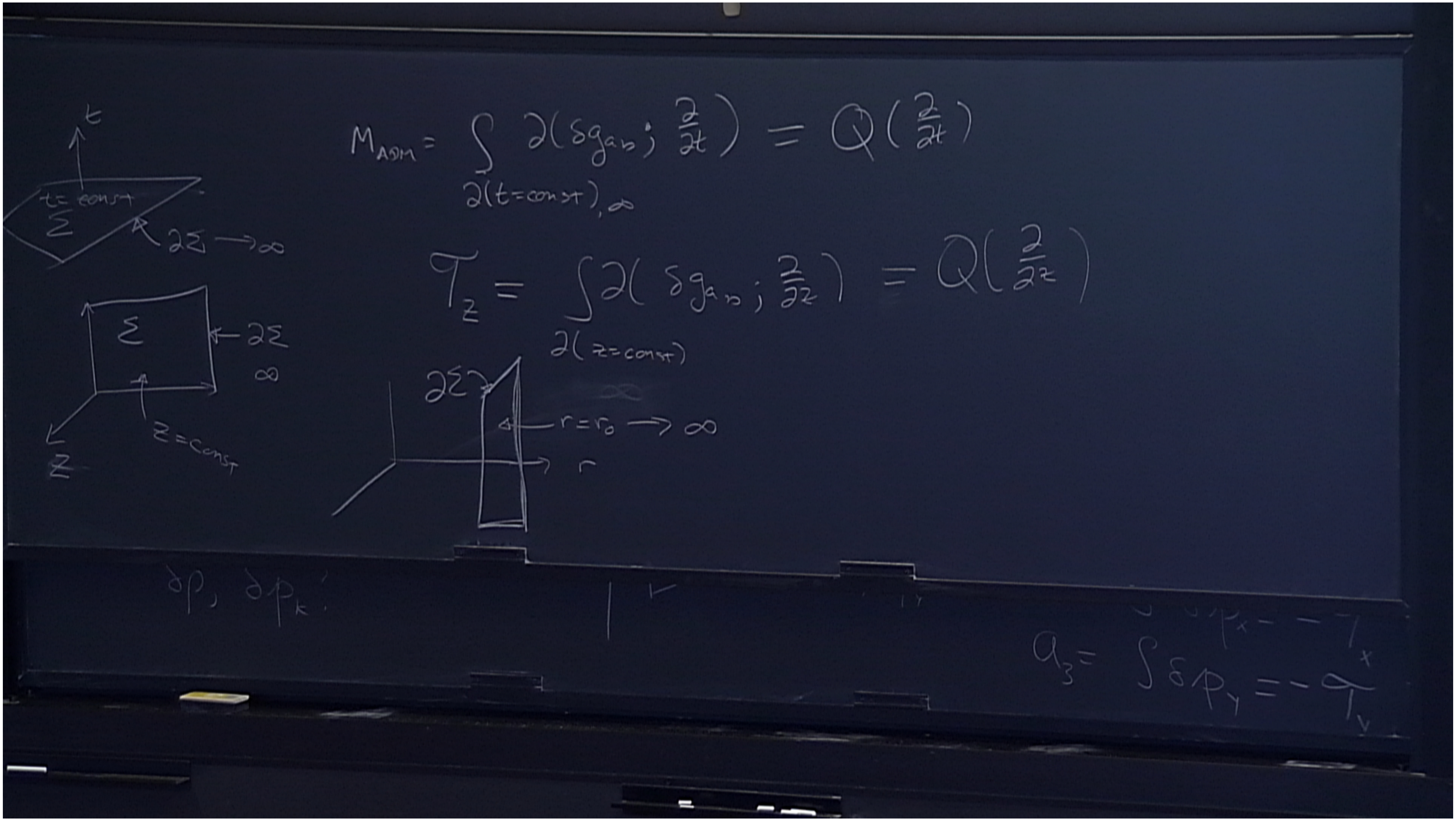

soliton
BH
AdS
$\Lambda < 0$
BH $M = (D-2)\hat{A}$
Soliton $\tau_{Bub} = (D-2)\hat{A}$
$L\tau_i = -\hat{A}$
$M = L\tau_i = -\hat{A}$
$M + L\Sigma\tau_i = 0$
Asympt AdS Sols
$ds^2 \to \frac{r^2}{\ell^2}\left[\eta_{\alpha\beta} + \frac{C_{\alpha\beta}}{r^{D-1}}\right]dx^\alpha dx^\beta + \frac{\ell^2}{r^2}\left(1 + \frac{C_r}{r^{D-1}}\right)$
Sat (T)
$\vec{V} = x^\alpha \frac{\partial}{\partial x^\alpha} - r\frac{\partial}{\partial r}$


AdS
Λ < 0
BH M = (D−2)Â
Soliton τ_Bub = (D−2)Â
L τ_i = − Â
M + L Σ τ_i = 0
M = L τ_i = − Â
Asympt AdS Sols
ds² → r²/l² [η_αβ + C_αβ / r^(D−1)] dx^α dx^β + l²/r² (1 + C_r / r^(D−1))
Sat (T)
V = x^α ∂/∂x^α − r ∂/∂r
KV AdS

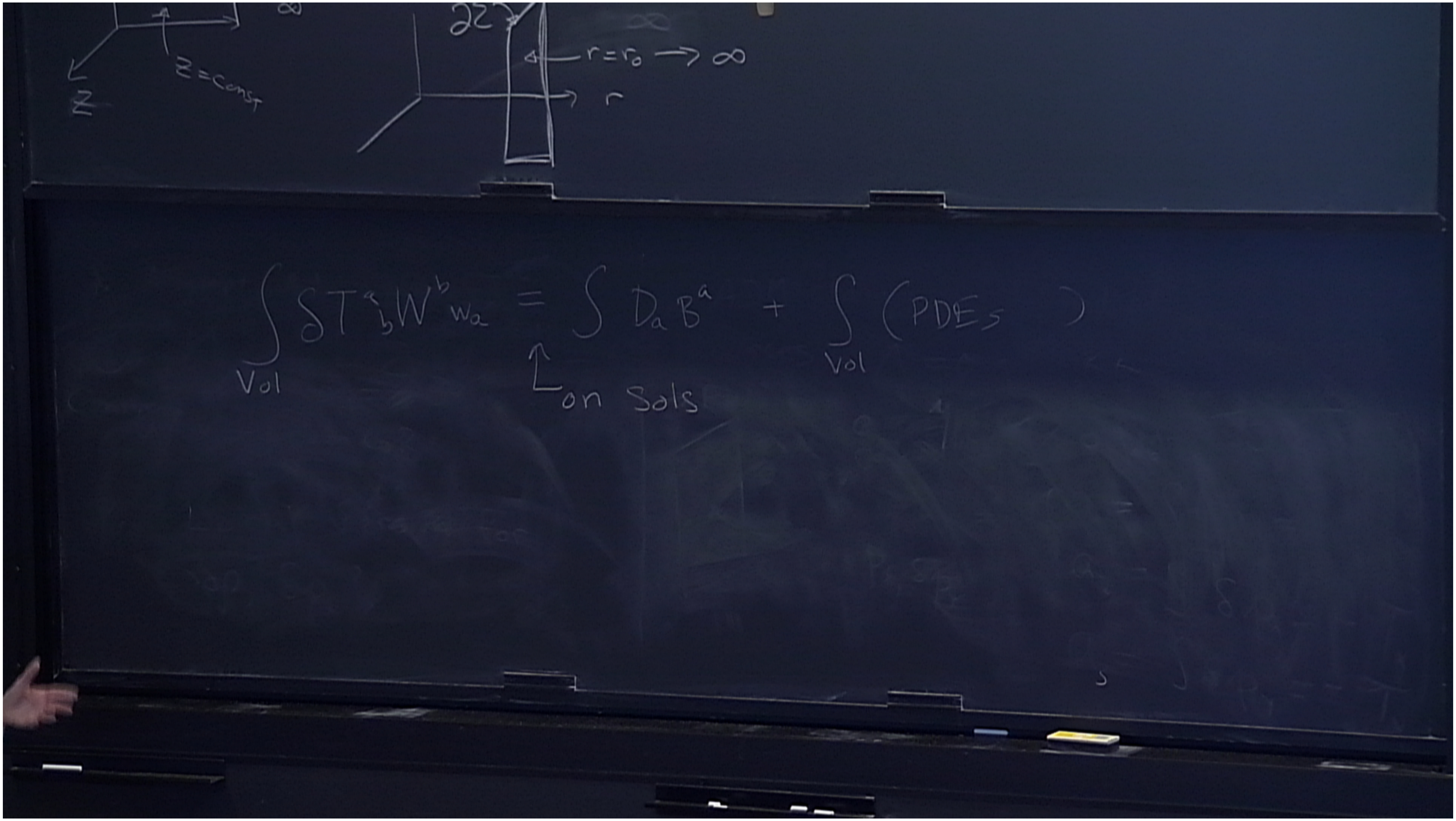

AdS
Λ < 0
BH M = (D−2)Â
Soliton τ_Bub = (D−2)Â
L τ_i = − Â
M = L τ_i = − Â
M + L Σ τ_i = 0
Asympt AdS Sols
ds² → r²/ℓ² [η_αβ + C_αβ / r^(D−1)] dx^α dx^β + ℓ²/r² (1 + C_r / r^(D−1))
Sat Ⓣ V = x^α ∂/∂x^α − r ∂/∂r KV AdS
Conformal isom.

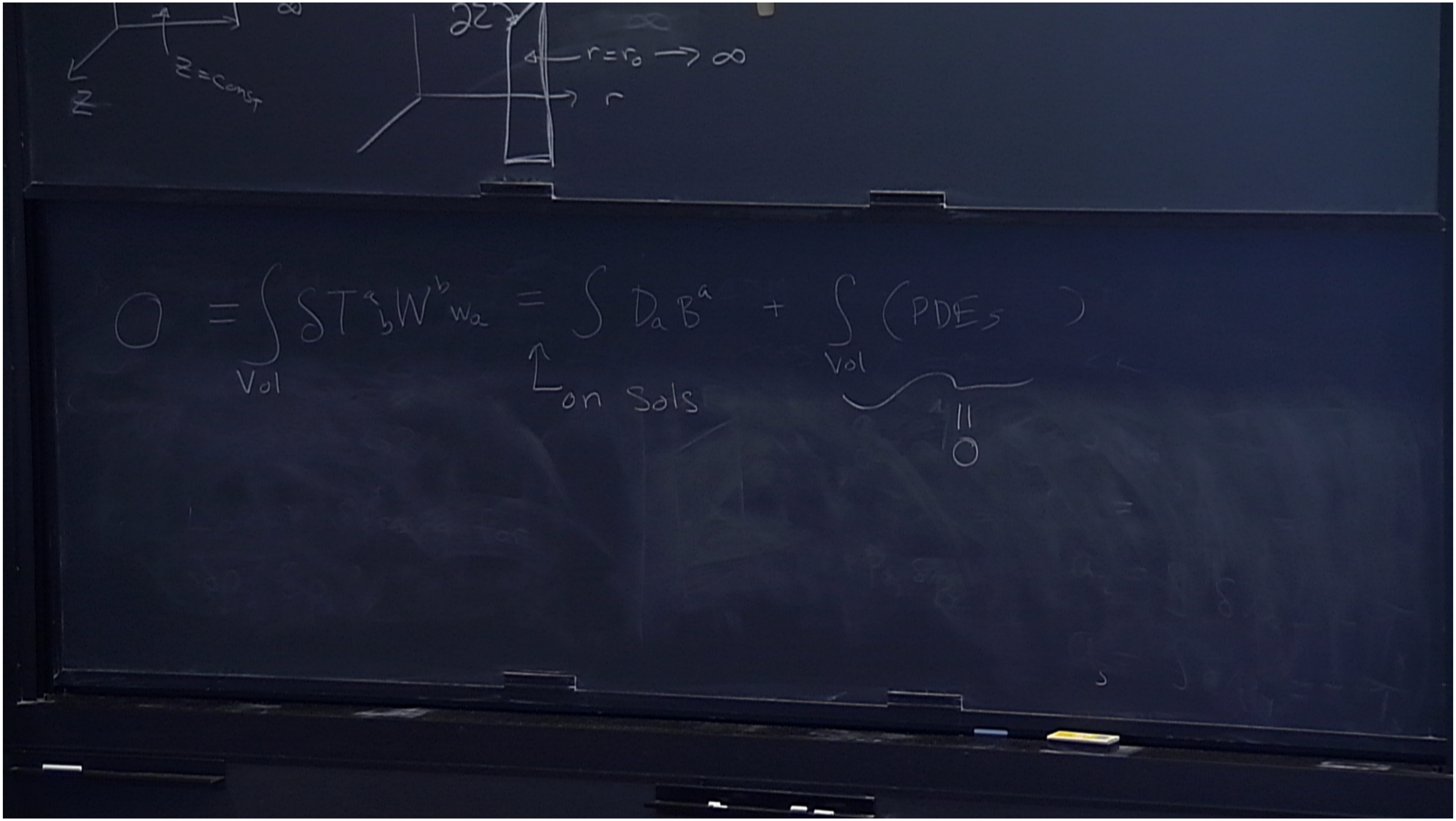

M_ADM = ∫ ∂(δg_ab ; ∂/∂t) = Q(∂/∂t)
∂(t=const), ∞
T_z = ∫ ∂(δg_ab ; ∂/∂z) = Q(∂/∂z)
∂(z=const)
t=const
Σ
∂Σ → ∞
∂Σ
∞
z=const
t
z

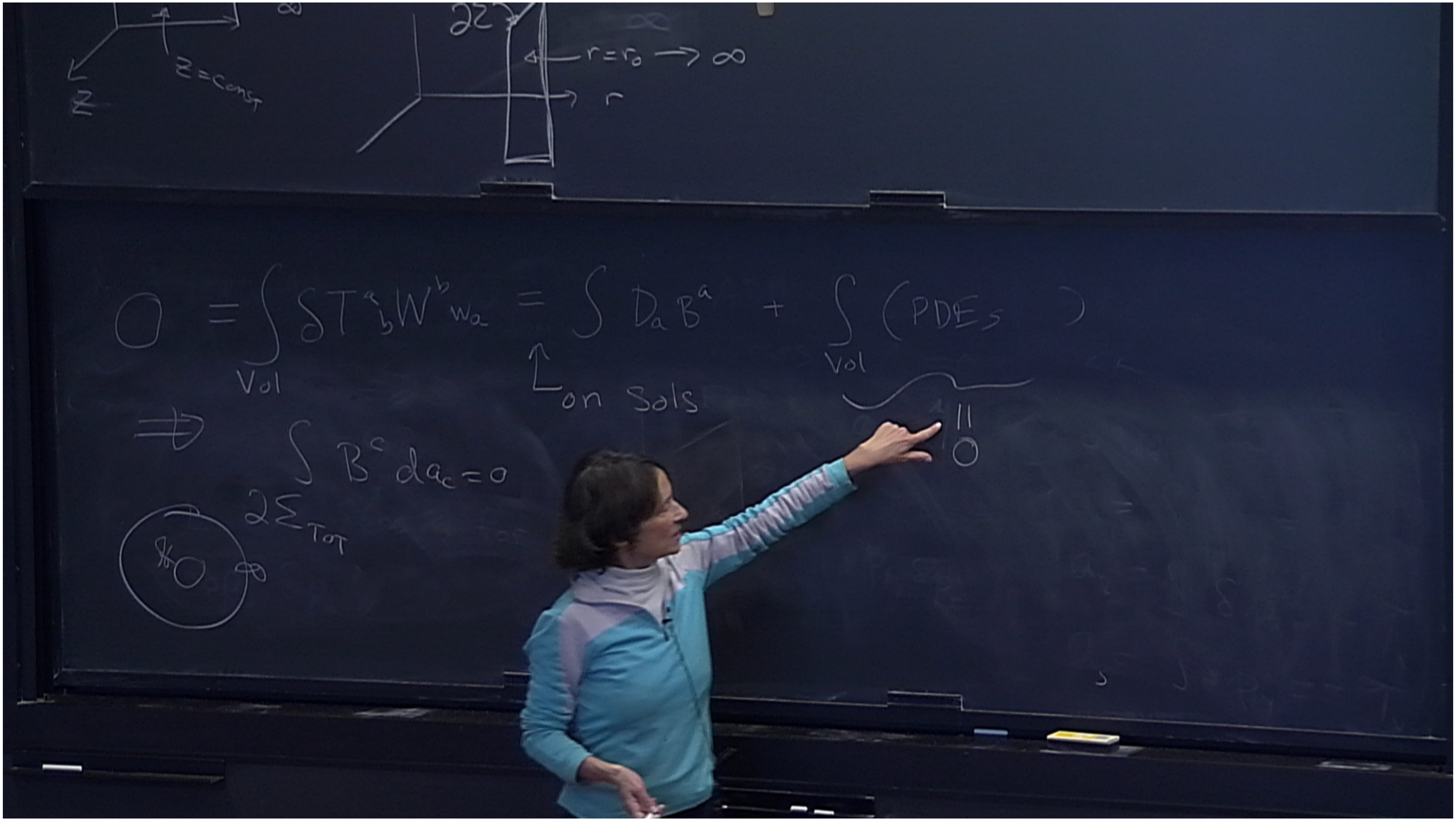

M_ADM = ∫ ∂(δg_ab ; ∂/∂t) = Q(∂/∂t)
∂(t=const), ∞
T_z = ∫ ∂(δg_ab ; ∂/∂z) = Q(∂/∂z)
∂(z=const)
t
t=const
Σ
∂Σ → ∞
Σ
∂Σ
∞
z=const
z
r=r_0 → ∞
r
q_3 = ∫ δp_y = - T_y

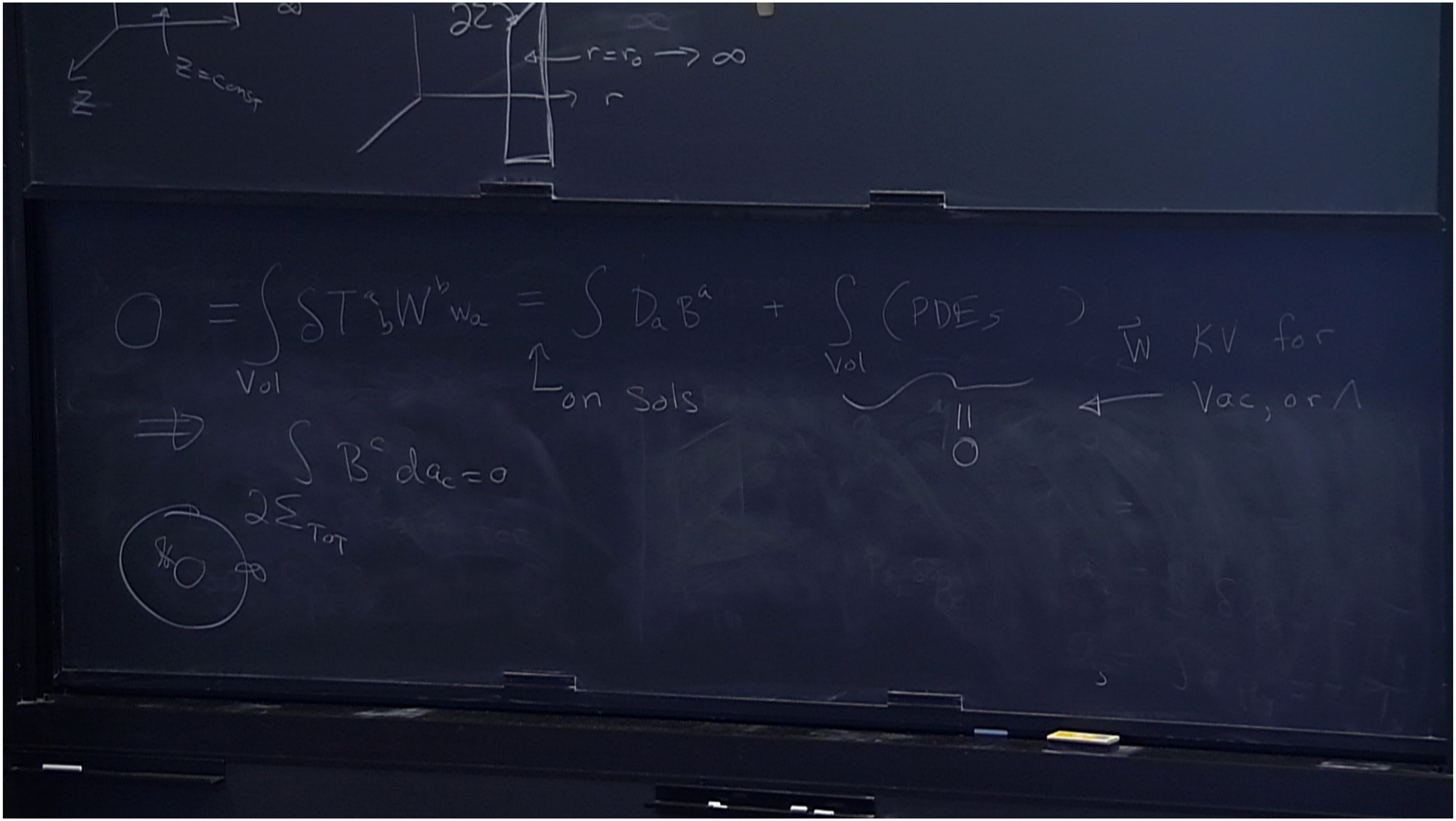


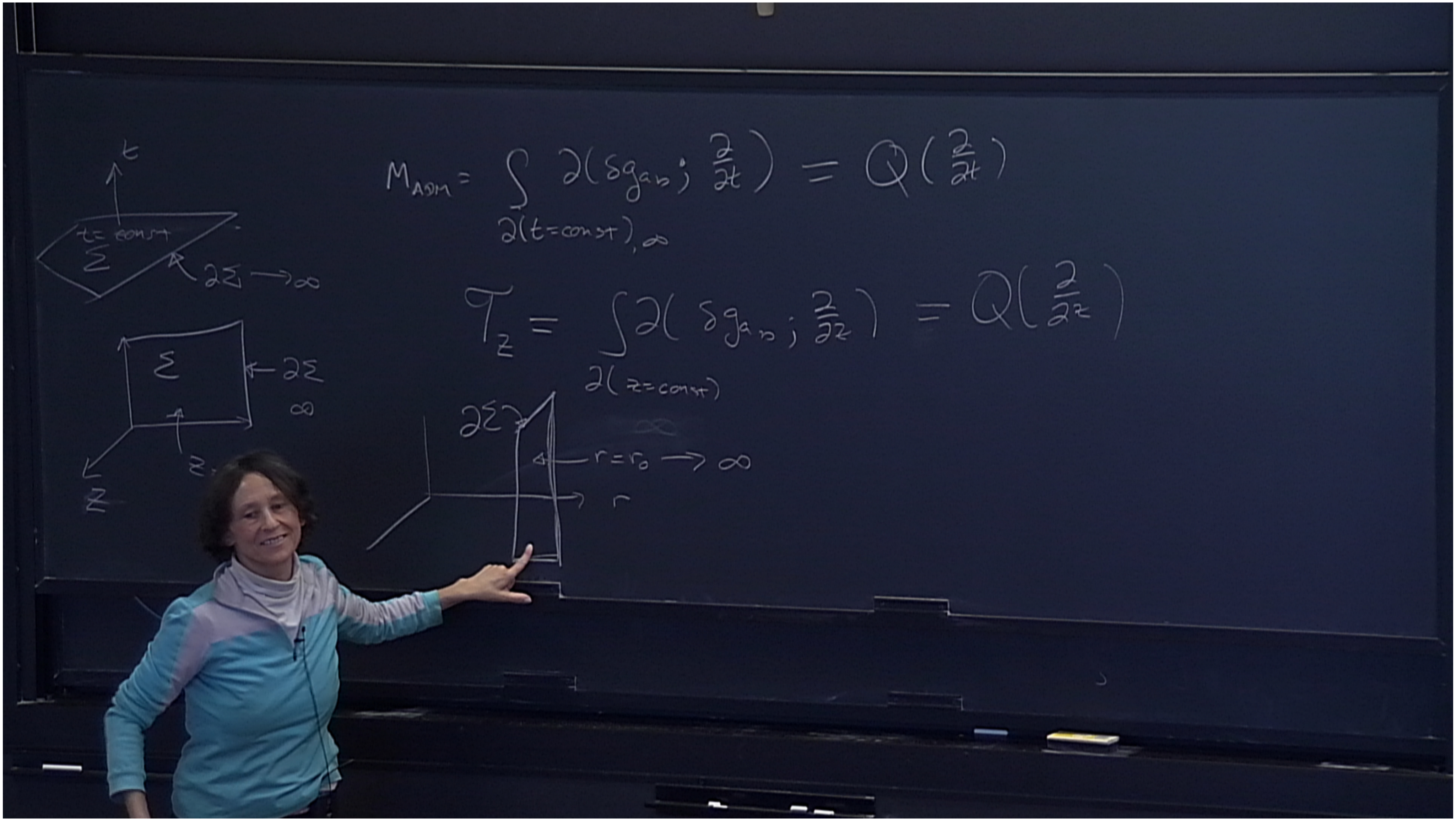
$M_{ADM} = \int_{\partial(t=\text{const}),\infty} \partial(\delta g_{ab}; \frac{\partial}{\partial t}) = Q(\frac{\partial}{\partial t})$
$\mathcal{T}_z = \int_{\partial(z=\text{const})} \partial(\delta g_{ab}; \frac{\partial}{\partial z}) = Q(\frac{\partial}{\partial z})$
t = const
$\partial\Sigma \to \infty$
z = const
$r = r_0 \to \infty$
$a_3 = \int \delta p_y = -\mathcal{T}_y$

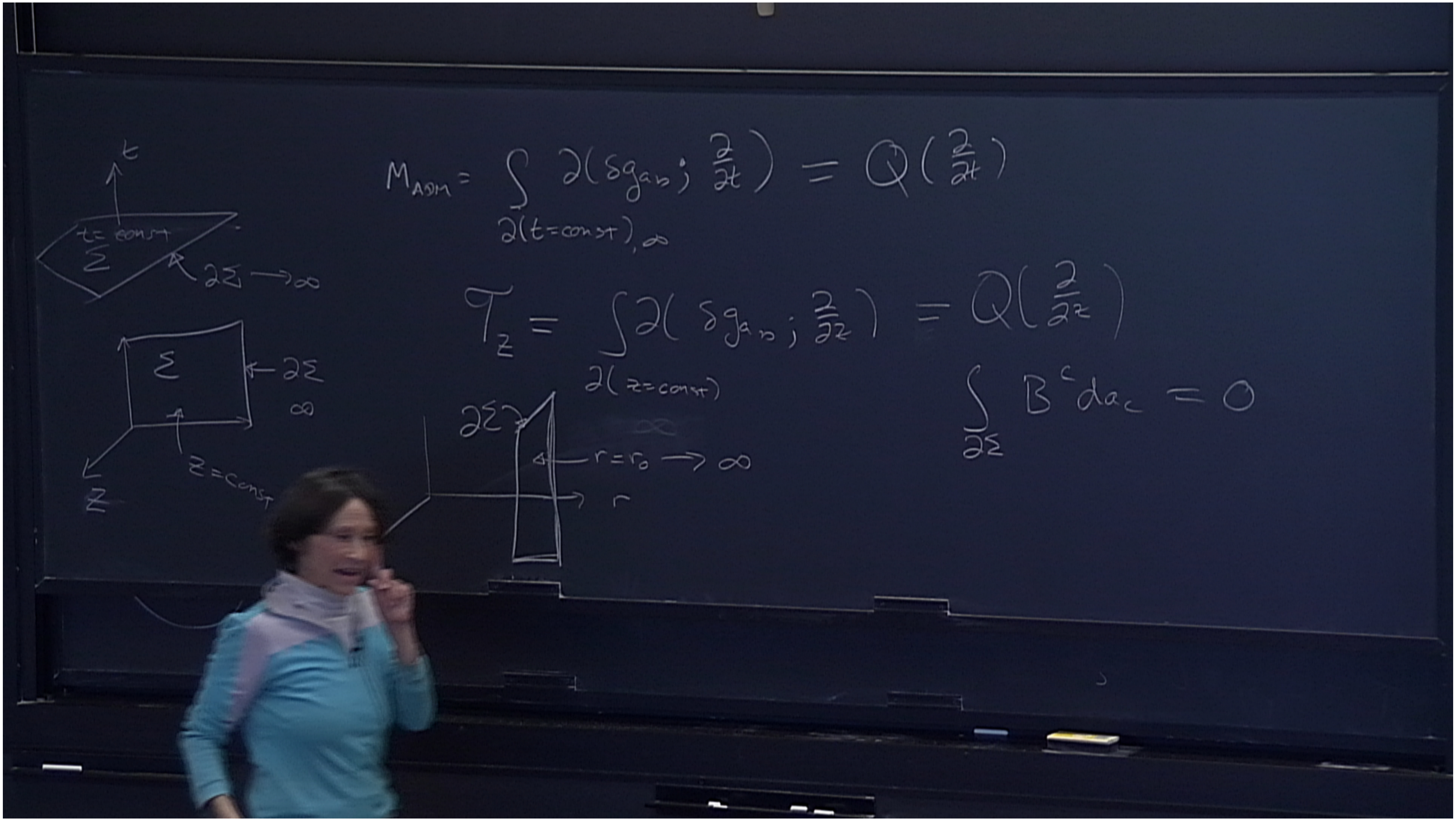

∂Σ
r = r₀ → ∞
r
z = const
z
∫ δT^a_b W^b w_a = ∫ D_a B^a + ∫ (PDEs)
Vol
Vol
on sols

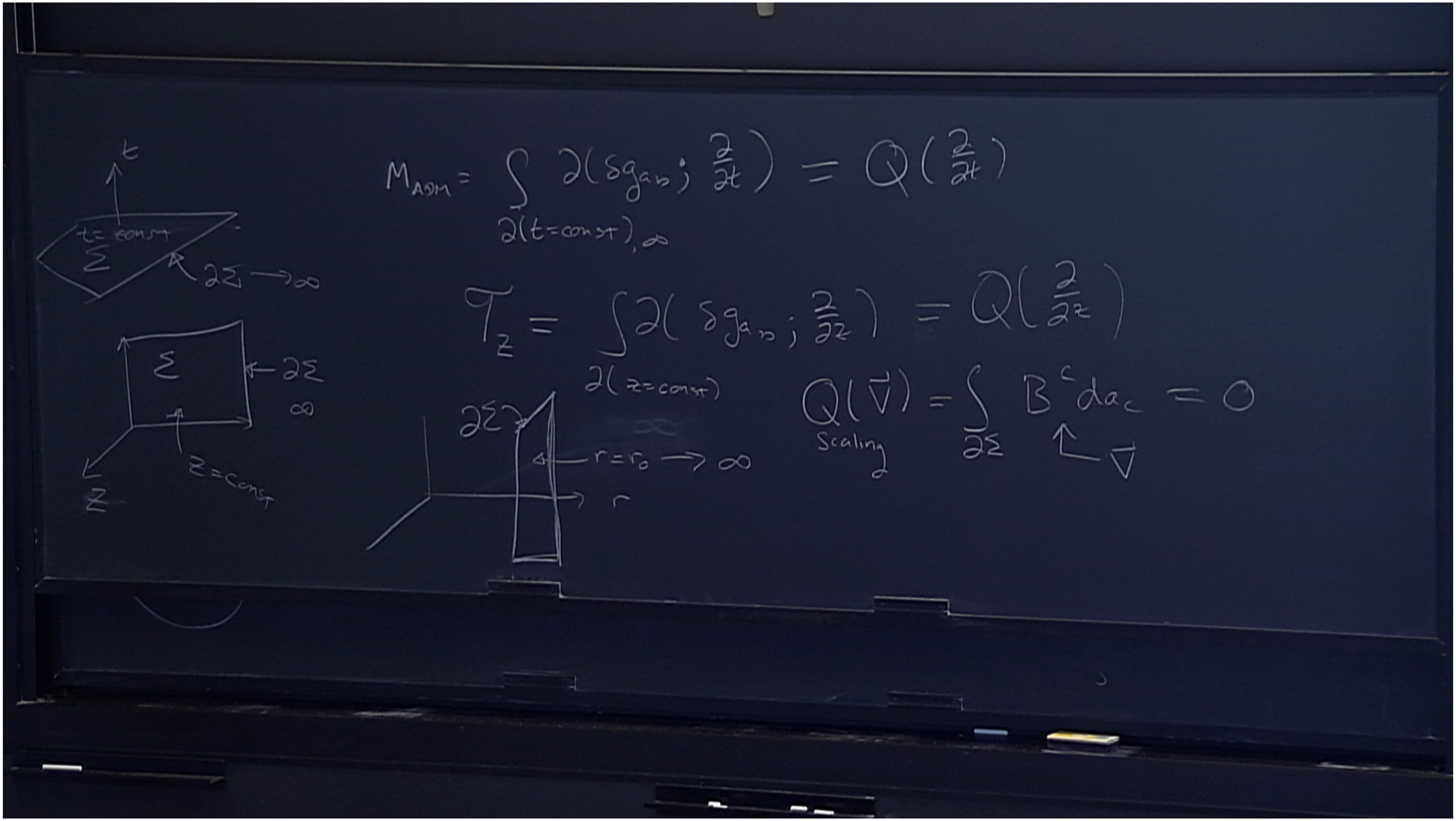

∂Σ
r = r₀ → ∞
r
z = const
z
0 = ∫ δT^a_b W^b w_a = ∫ D_a B^a + ∫ (PDEs)
Vol
on Sols
Vol
0

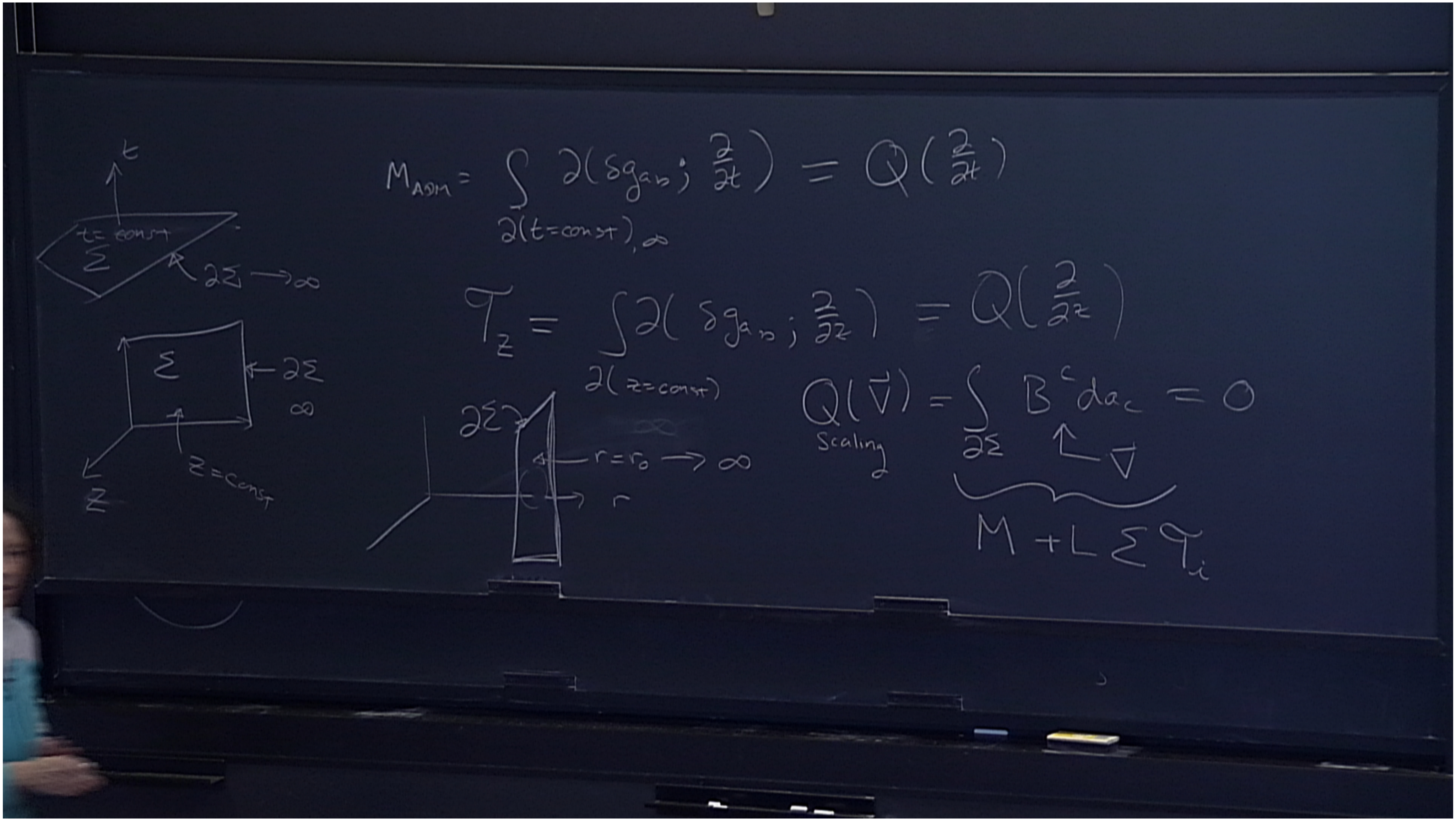

z = const
r = r₀ → ∞
0 = ∫ δT^a_b W^b w_a = ∫ D_a B^a + ∫ (PDEs)
Vol
Vol
on sols
⇒ ∫ B^c da_c = 0
∂Σ_TOT

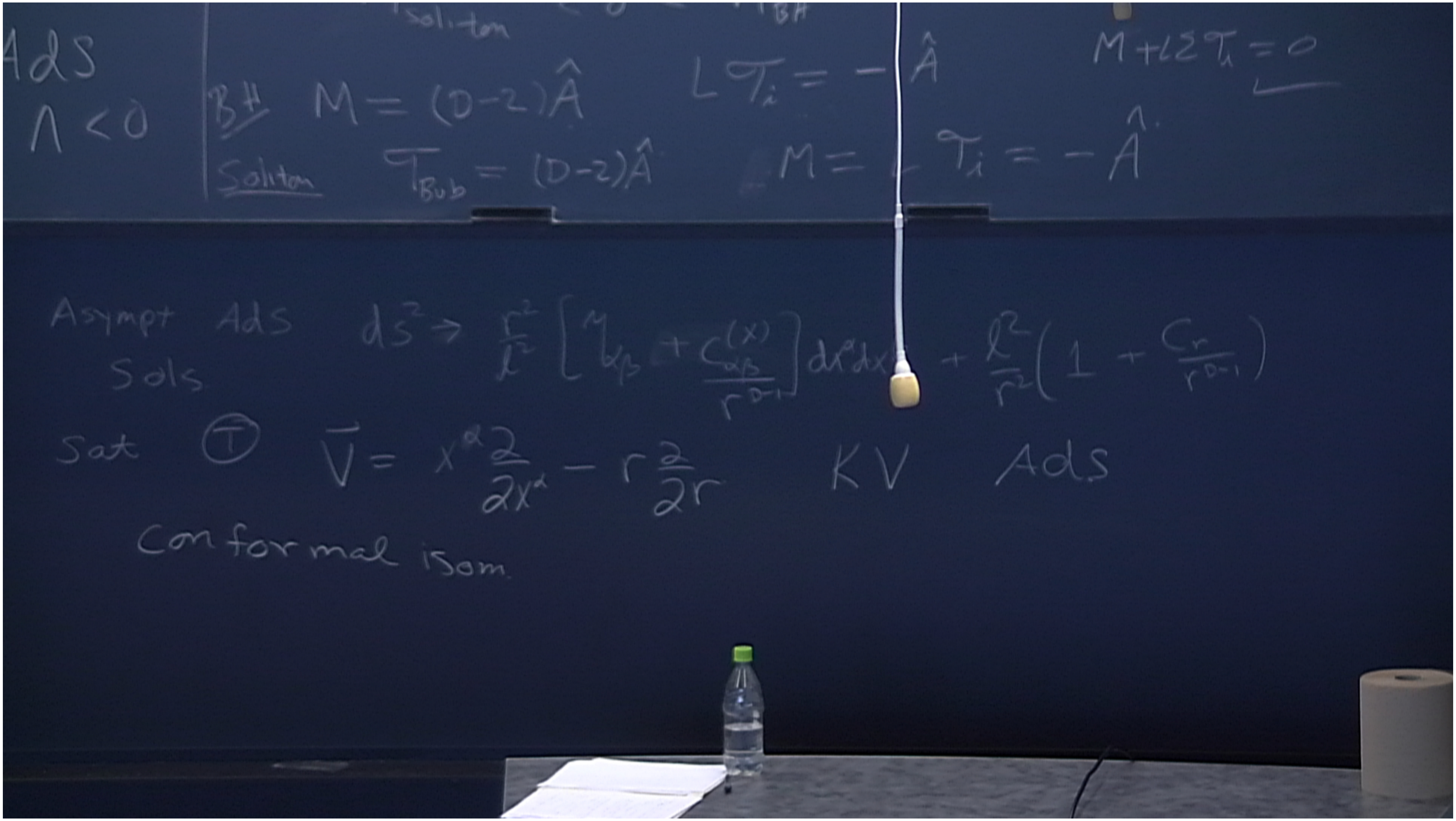

r = r₀ ⟶ ∞
z = const
0 = ∫ δT^a_b W^b w_a = ∫ D_a B^a + ∫ (PDEs)
Vol
on sols
W KV for
Vac, or Λ
⟹ ∫ B^c da_c = 0
∂Σ_Tot

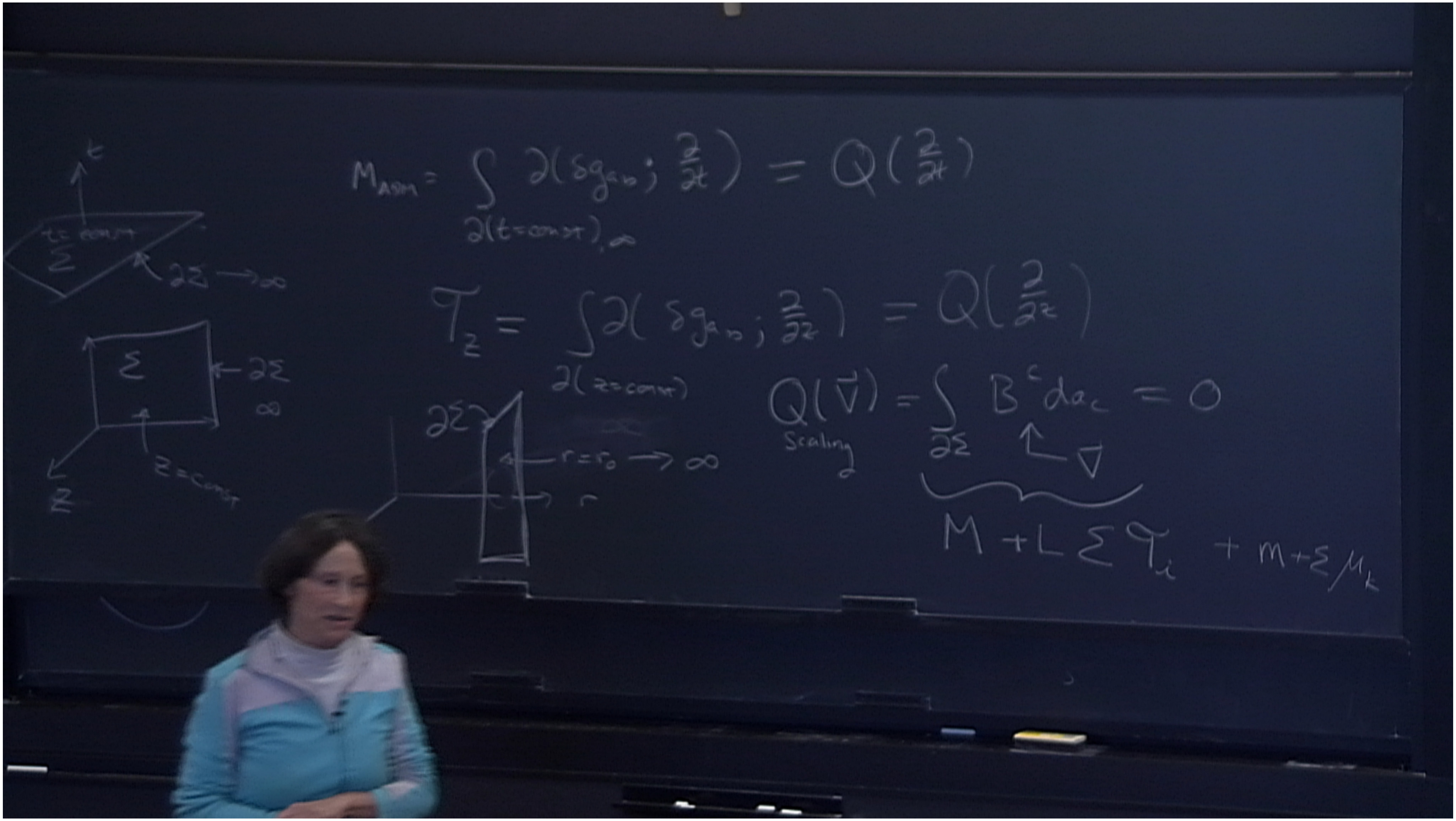

M_ADM = ∫ ∂(δg_ab ; ∂/∂t) = Q(∂/∂t)
∂(t=const),∞
t = const
Σ
∂Σ → ∞
T_z = ∫ ∂(δg_ab ; ∂/∂z) = Q(∂/∂z)
∂(z=const)
∂Σ
r = r_0 → ∞

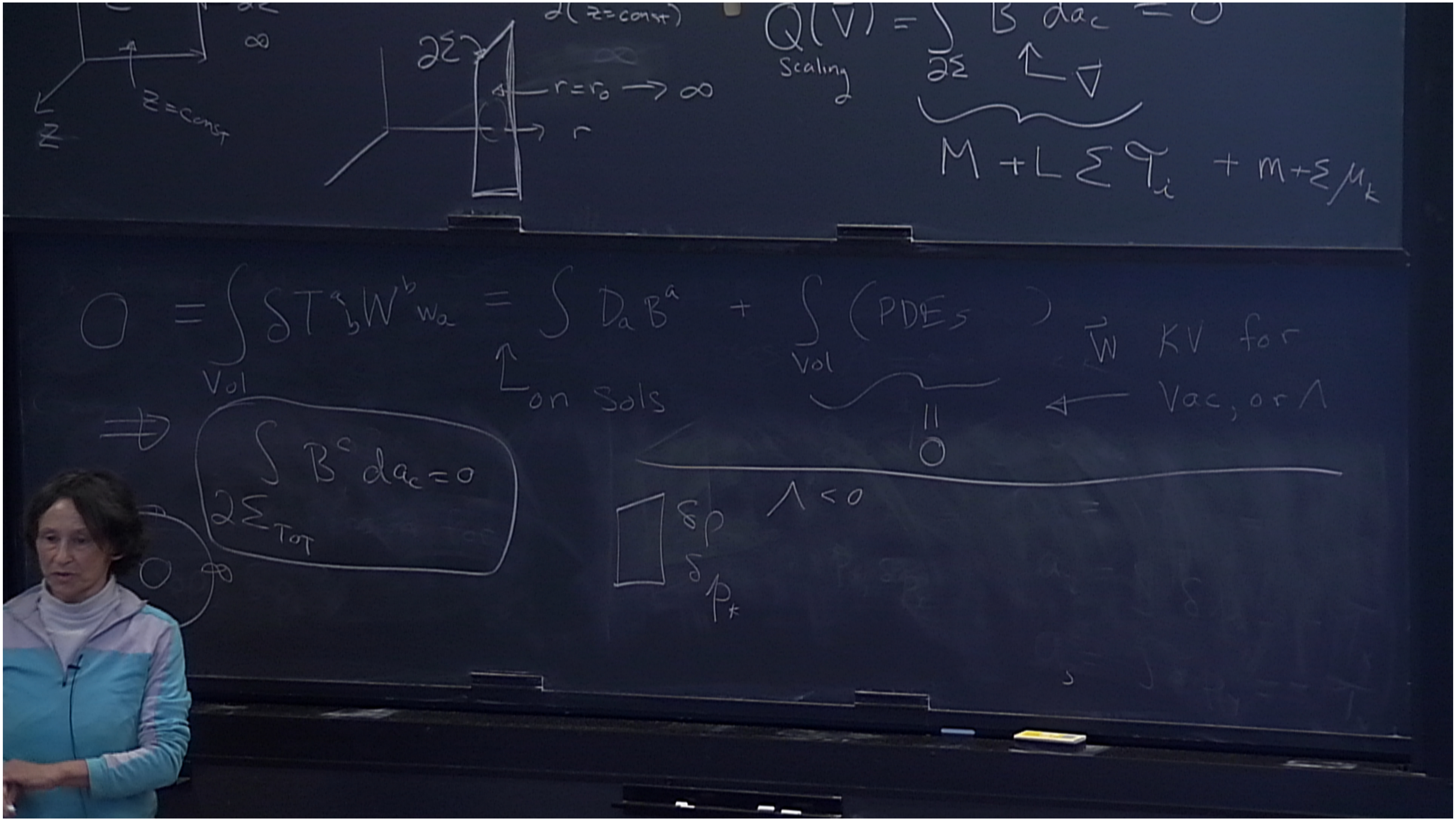

M_ADM = ∫ ∂(δg_ab ; ∂/∂t) = Q(∂/∂t)
∂(t=const),∞
T_z = ∫ ∂(δg_ab ; ∂/∂z) = Q(∂/∂z)
∂(z=const)
∫ B^c da_c = 0
∂Σ
t=const
Σ
∂Σ → ∞
z=const
r=r₀ → ∞

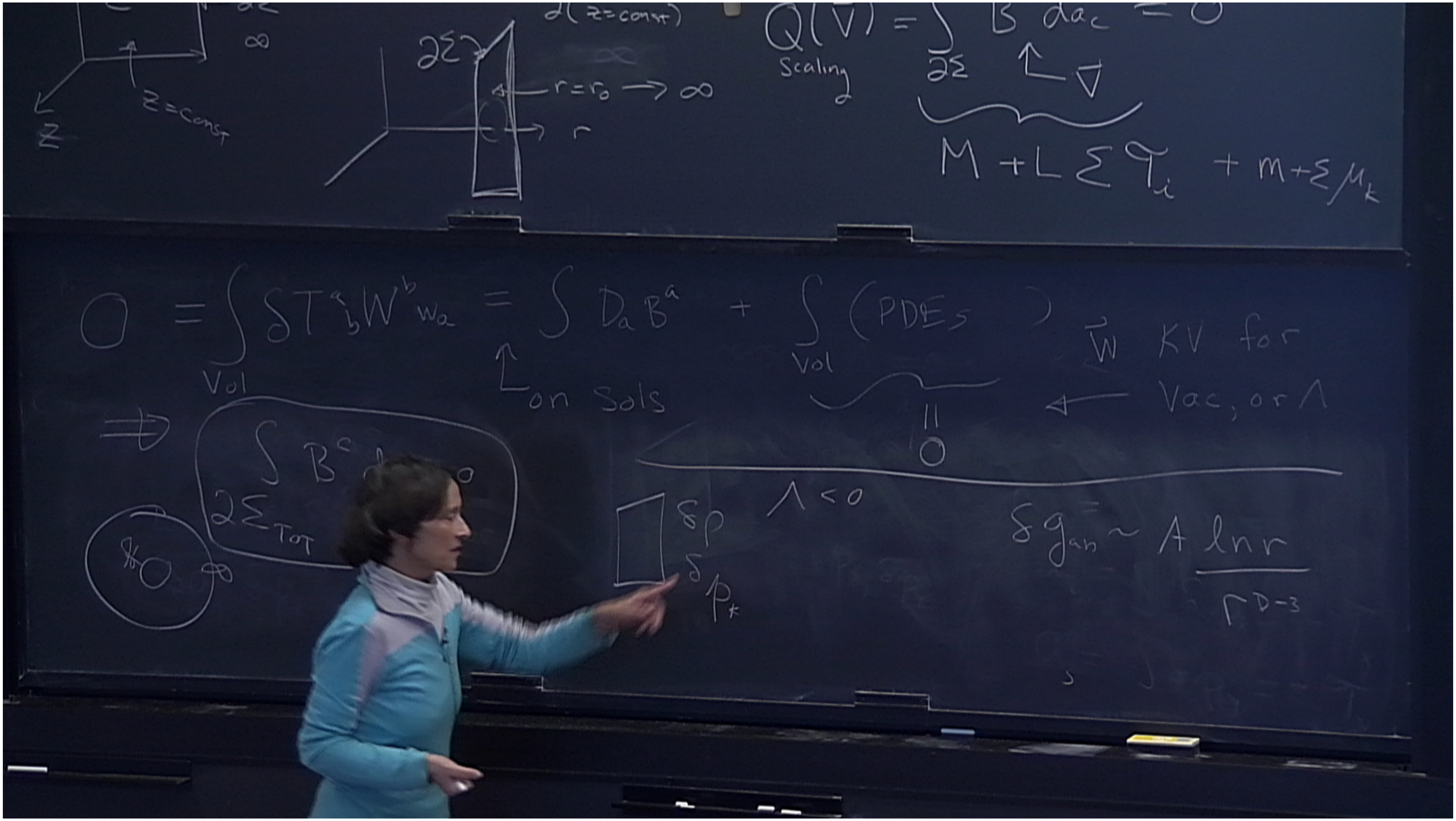

$M_{ADM} = \int_{\partial(t=const),\infty} \partial(\delta g_{ab}; \frac{\partial}{\partial t}) = Q(\frac{\partial}{\partial t})$
$T_z = \int_{\partial(z=const)} \partial(\delta g_{ab}; \frac{\partial}{\partial z}) = Q(\frac{\partial}{\partial z})$
$Q(\vec{\nabla}) = \int_{\partial\Sigma} B^c da_c = 0$
Scaling
t
t = const
Σ
∂Σ → ∞
∂Σ
∞
z = const
z
r = r₀ → ∞
r

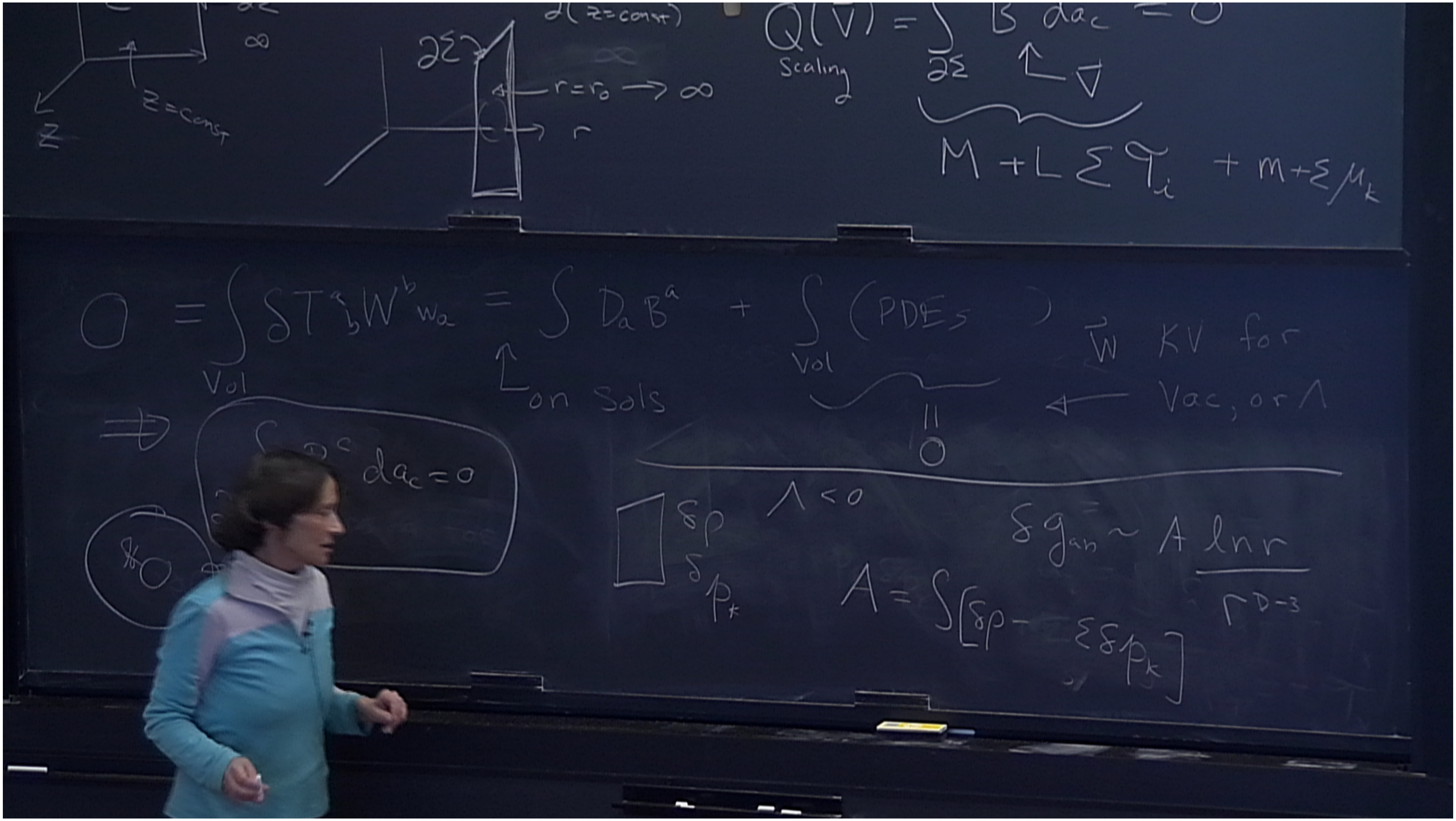

M_ADM = ∫ ∂(δg_ab ; ∂/∂t) = Q(∂/∂t)
∂(t=const),∞
T_z = ∫ ∂(δg_ab ; ∂/∂z) = Q(∂/∂z)
∂(z=const)
Q(V) = ∫ B^c da_c = 0
Scaling
∂Σ
M + L Σ T_i
t=const
Σ
∂Σ → ∞
z=const
r=r_0 → ∞


AdS
Λ < 0
BH M = (D−2)Â
Soliton τ_Bub = (D−2)Â
L τ_i = − Â
M = τ_i = − Â
M + L Σ τ_i = 0
Asympt AdS Sols
Sat (T)
KV AdS
conformal isom.


M_ADM = ∫ ∂(δg_ab ; ∂/∂t) = Q(∂/∂t)
∂(t=const),∞
t = const
Σ
∂Σ → ∞
T_z = ∫ ∂(δg_ab ; ∂/∂z) = Q(∂/∂z)
∂(z=const)
Q(V) = ∫ B^c da_c = 0
Scaling
∂Σ
r = r_0 → ∞
M + L Σ q_i + m + Σ μ_k
z = const


z = const
∂(z=const)
r = r0 → ∞
Q(V) = ∫ B dac = 0
Scaling
M + L Σ qi + m + Σ μk
0 = ∫ δT W wa = ∫ Da B + ∫ (PDEs)
Vol
on sols
W KV for
Vac, or Λ
∫ B dac = 0
∂Σ TOT
Λ < 0
δρ
δp


Q(V) = ∫ B dac = 0
Scaling
∂Σ
M + L Σ qi + m + Σ μk
∂Σ
r = r0 → ∞
r
z = const
0 = ∫ δT W w = ∫ Da B + ∫ (PDEs)
Vol
on Sols
W KV for
Vac, or Λ
Λ < 0
δp
δpk
δgab ~ A ln r / r^(D-3)
∂ΣTOT



z = const
∂Σ
r = r0 → ∞
Scaling
M + L Σ qi + m + Σ μk
Vol
on Sols
(PDEs)
W KV for
Vac, or Λ
Λ < 0
δp
δpk
δgab ~ A ln r / r^(D-3)
A = ∫[δp − Σ δpk]