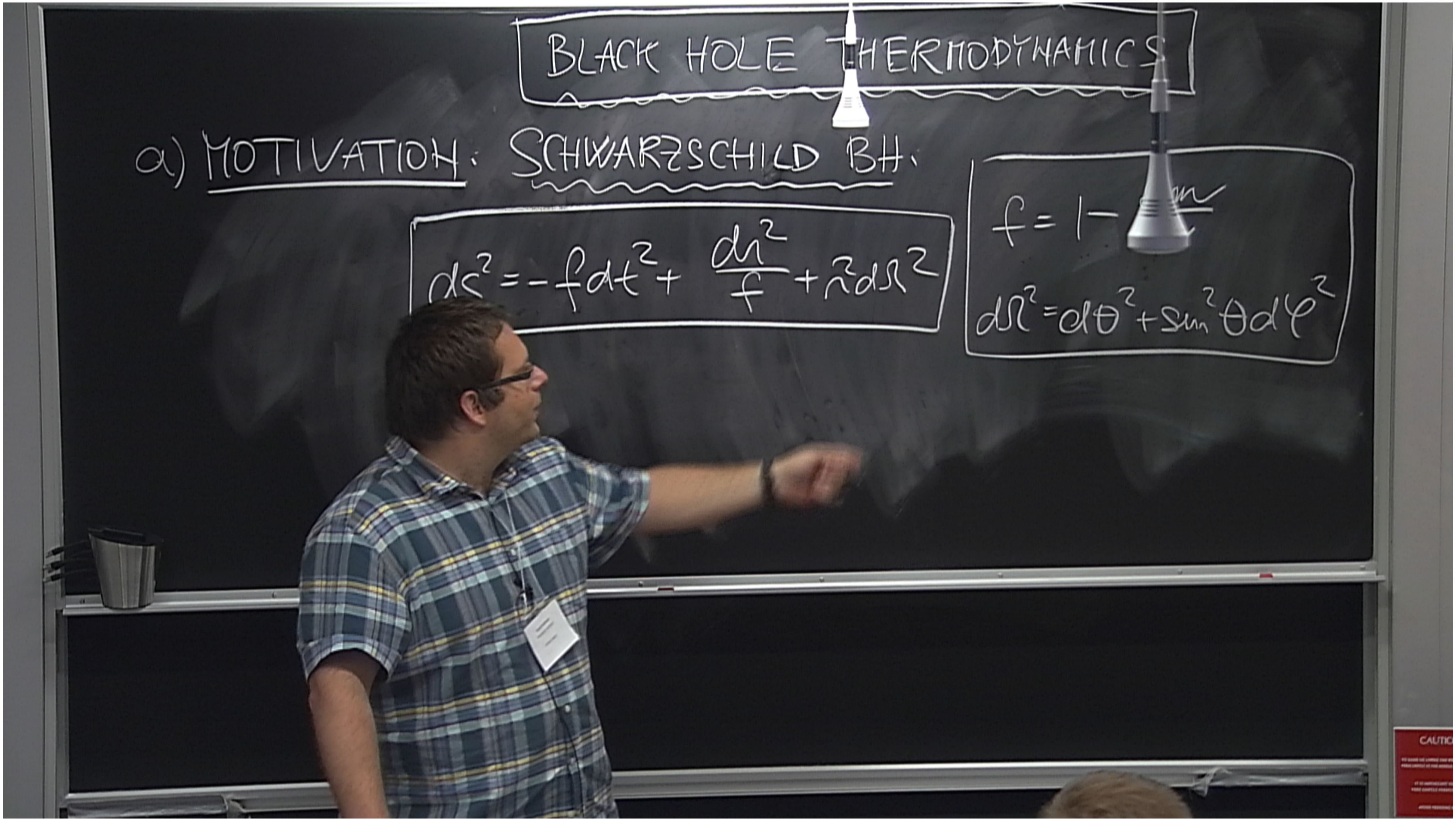
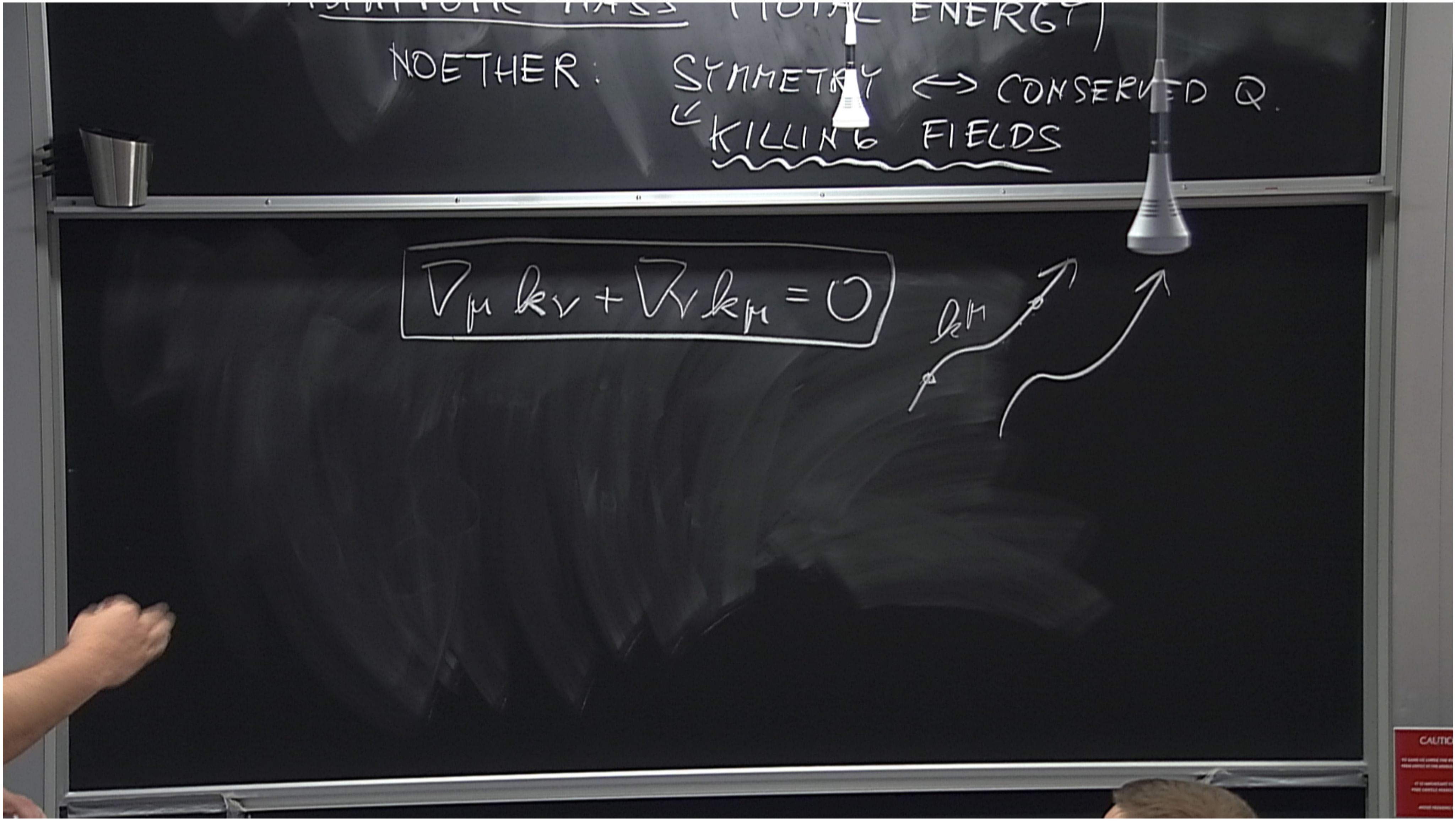
Title: Focus Lecture

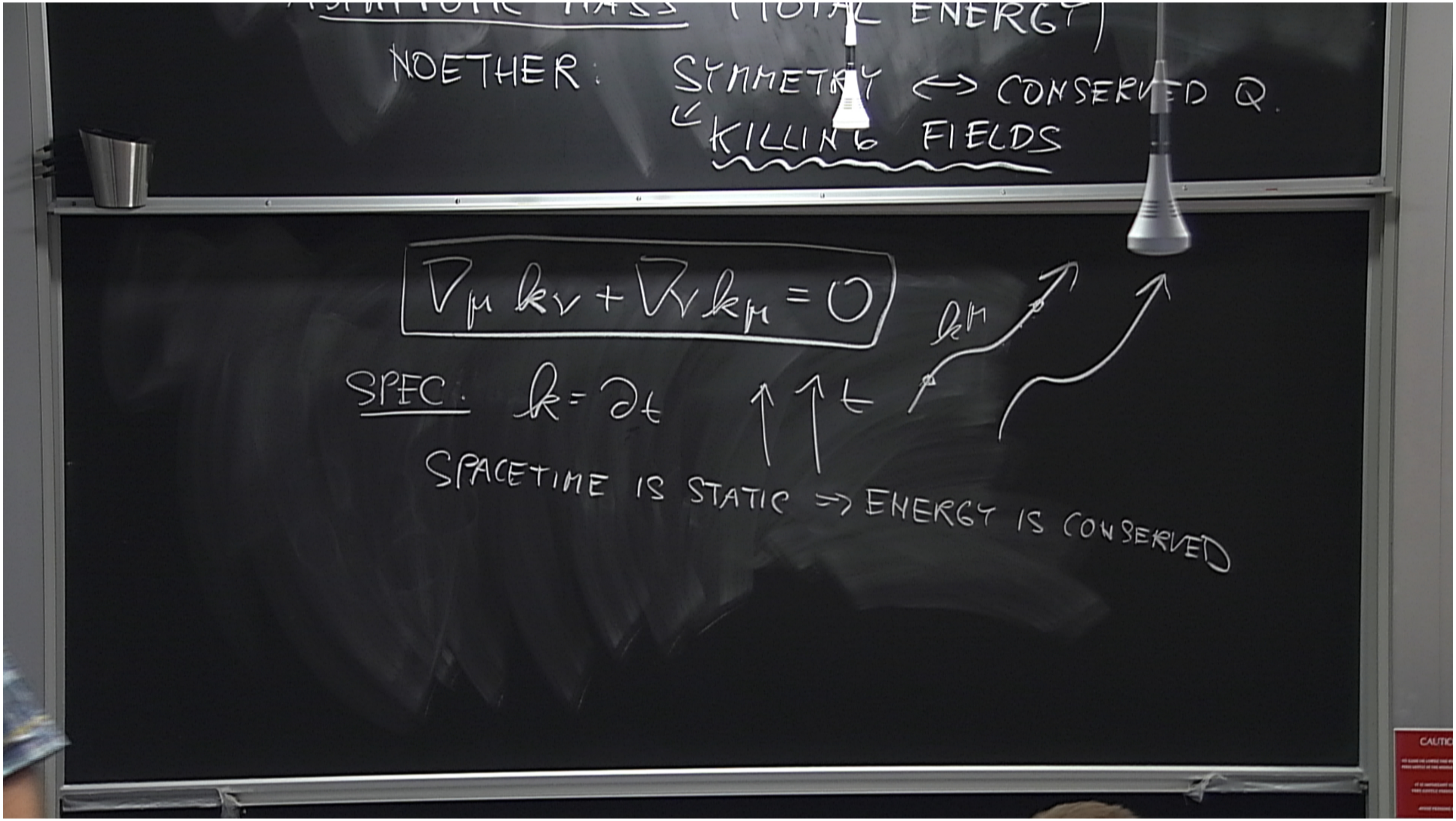
Date: Jul 20, 2016 05:00 PM

URL: http://pirsa.org/16070021

Abstract:


BLACK HOLE THERMODYNAMICS
a) MOTIVATION: SCHWARZSCHILD BH.
ds² = −f dt² + dr²/f + r² dΩ²
f = 1 −
dΩ² = dθ² + sin²θ dφ²


NOETHER: SYMMETRY ⟷ CONSERVED Q.
KILLING FIELDS
$\nabla_\mu k_\nu + \nabla_\nu k_\mu = 0$
k^μ

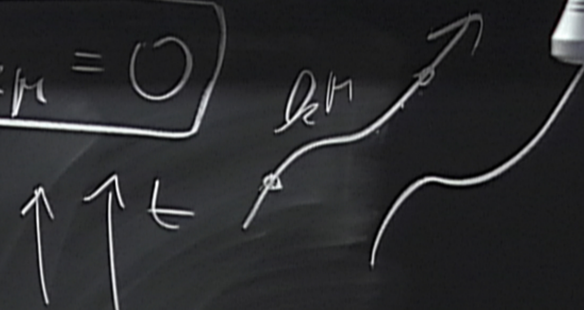

NOETHER: SYMMETRY ⟺ CONSERVED Q.
KILLING FIELDS
$\nabla_\mu k_\nu + \nabla_\nu k_\mu = 0$
k^μ
SPEC: $k = \partial_t$
t
SPACETIME IS STATIC ⇒ ENERGY IS CONSERVED
CAUTION

ASYMPTOTIC MASS (TOTAL ENERGY)

NOETHER: SYMMETRY ⟺ CONSERVED Q.

↙ KILLING FIELDS

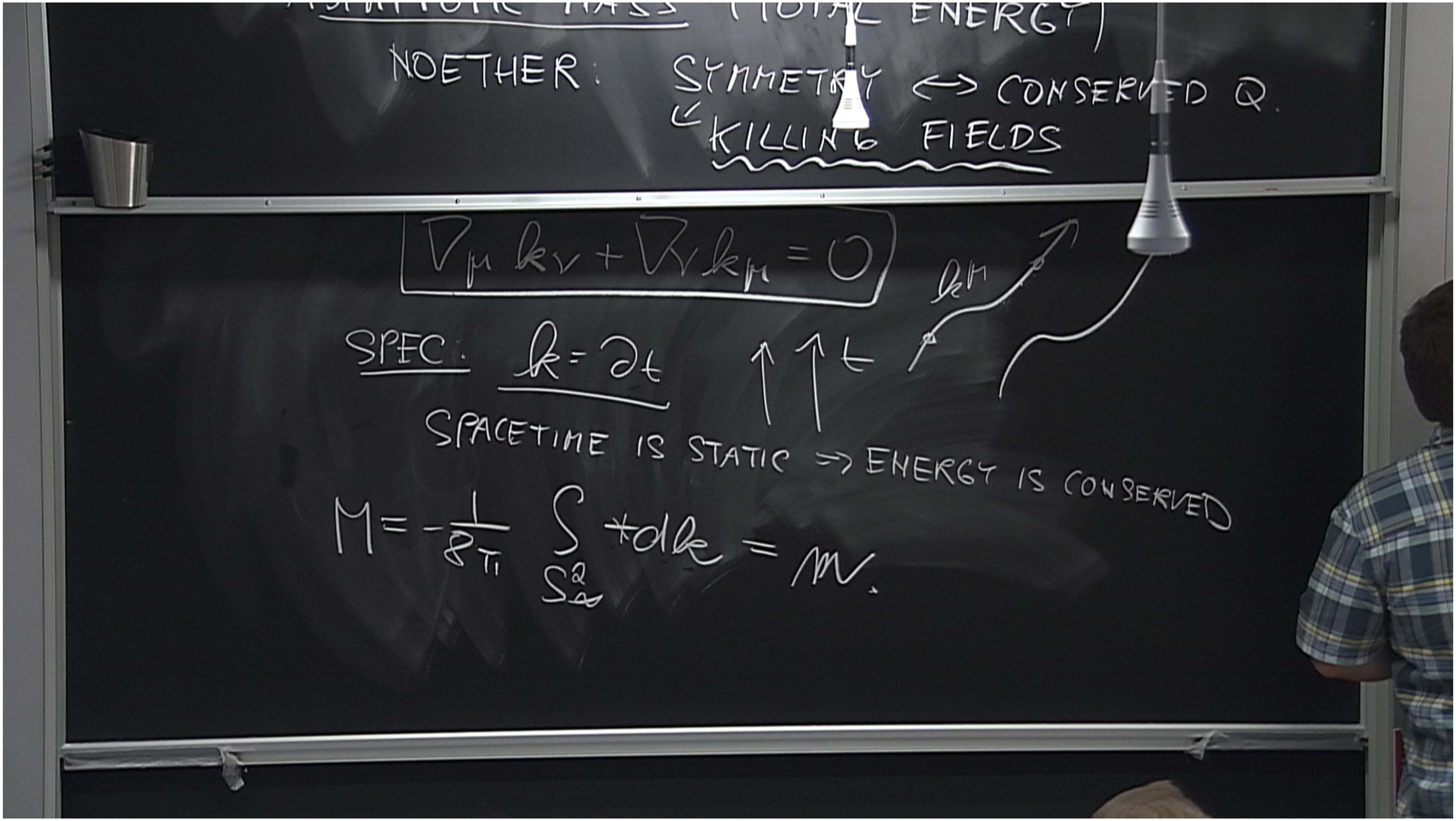
$$\boxed{\nabla_\mu k_\nu + \nabla_\nu k_\mu = 0}$$

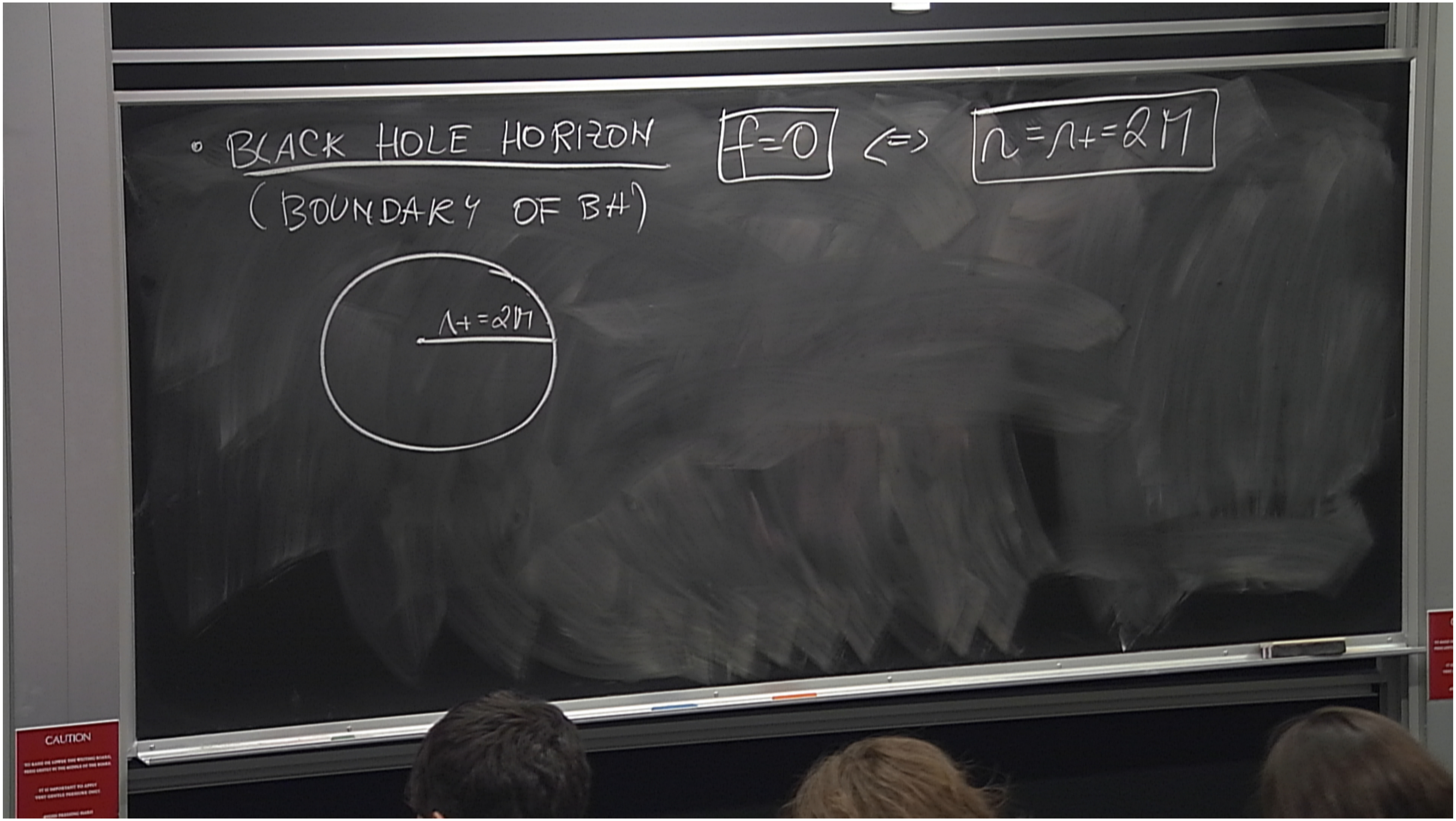


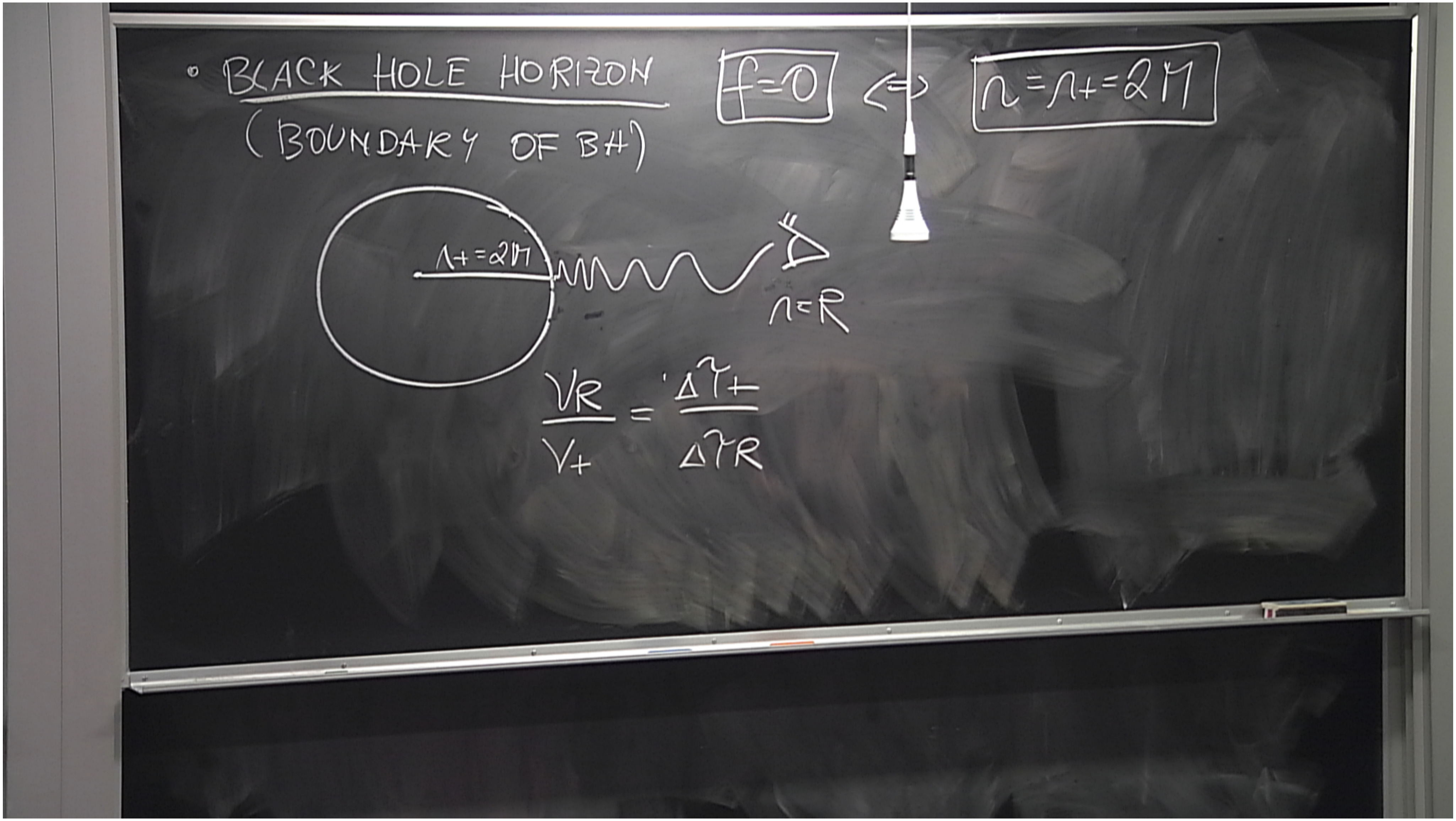
SPEC: $k = \partial_t$

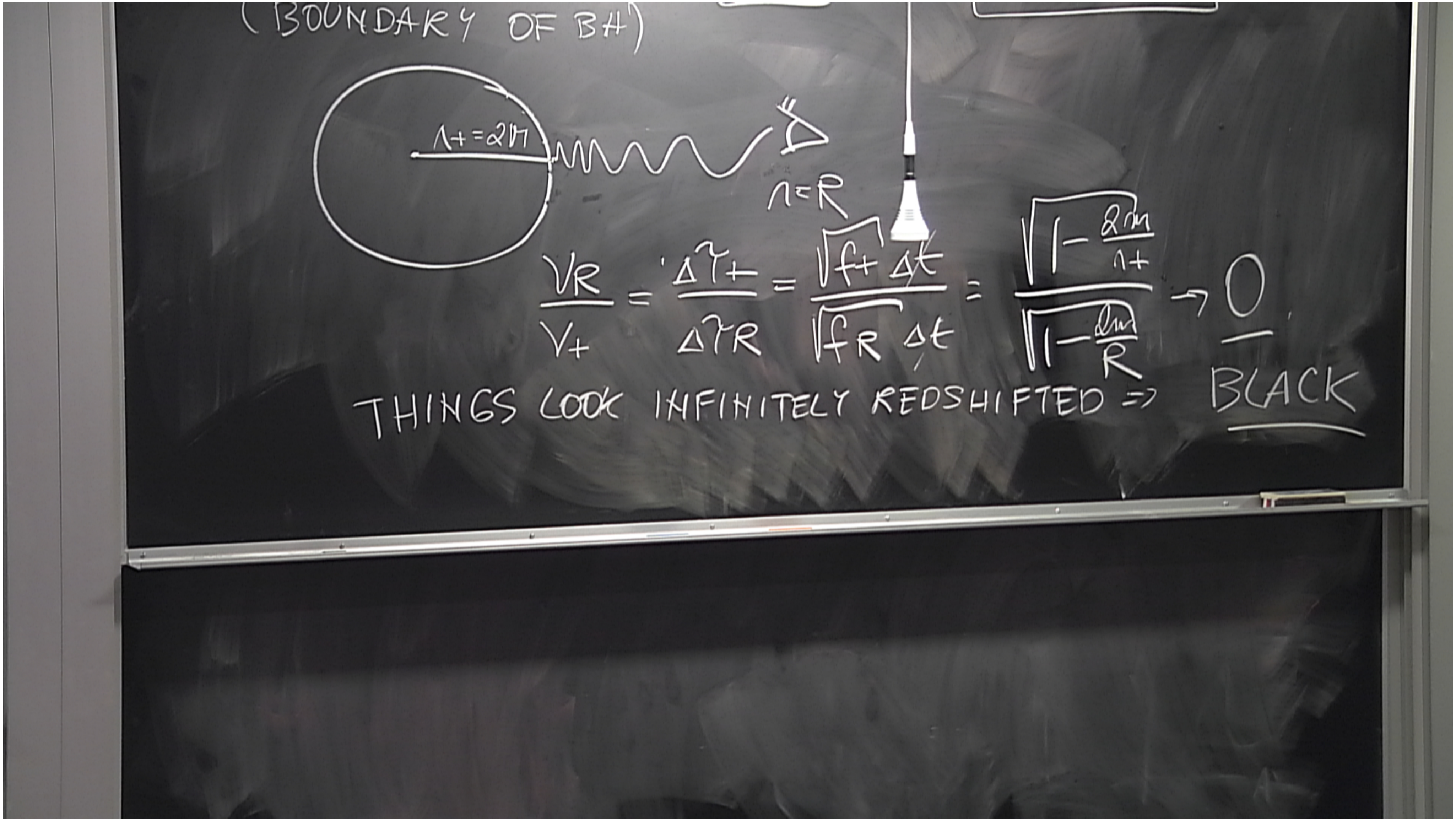
SPACETIME IS STATIC ⟹ ENERGY IS CONSERVED

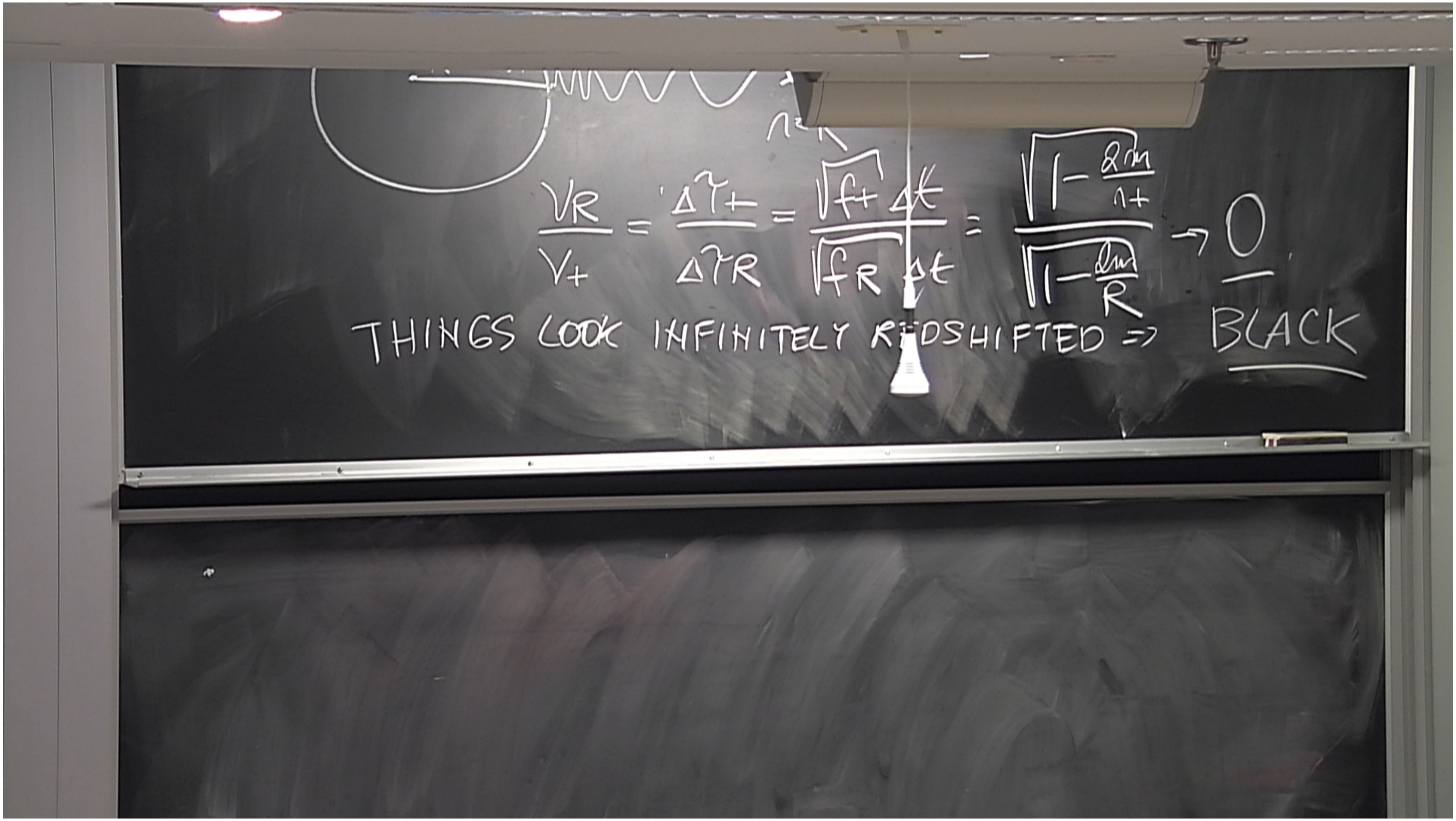
$$M = -\frac{1}{8\pi} \int_{S^2_\infty} \star dk = m.$$

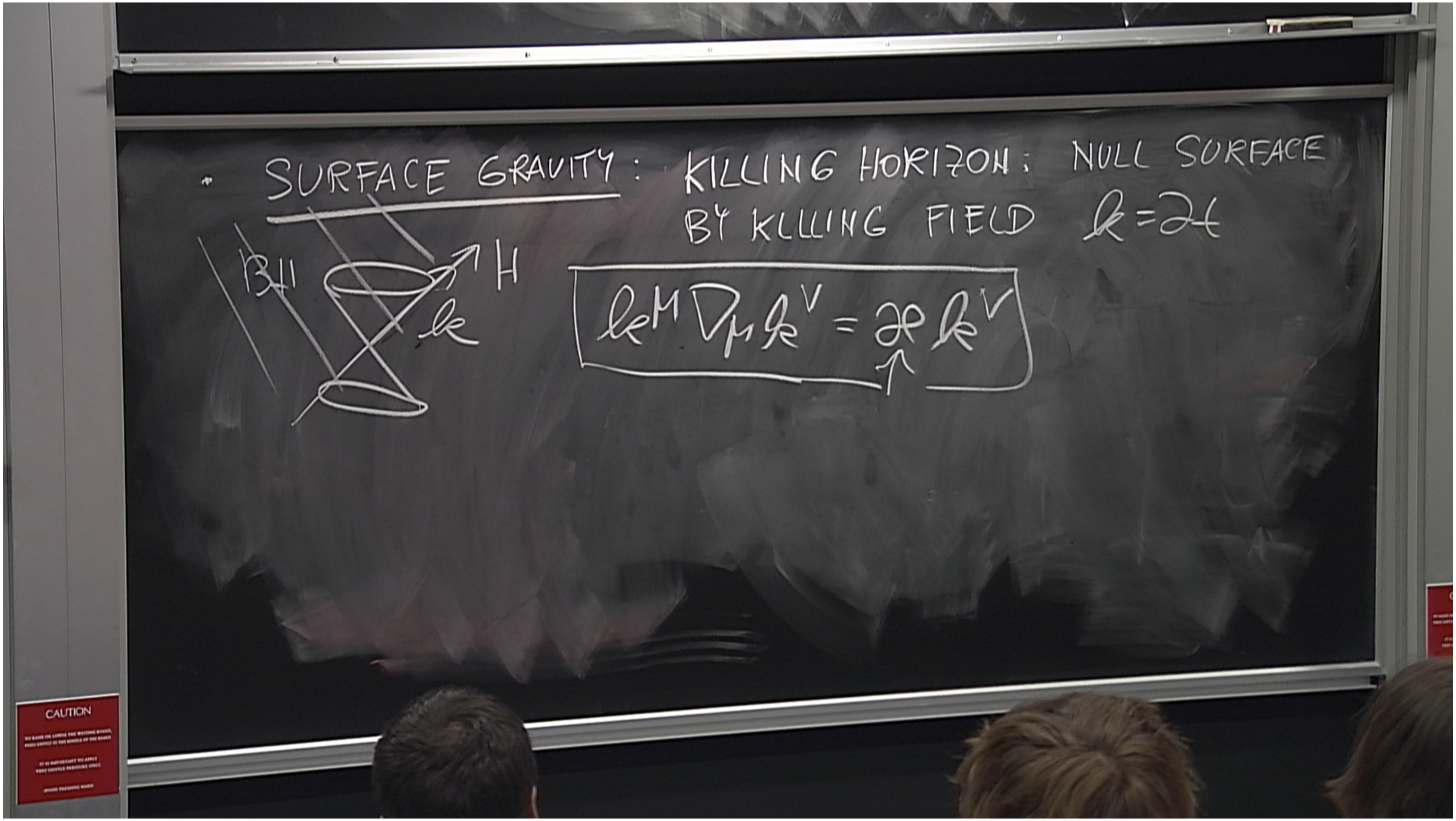

NOETHER: SYMMETRY $\leftrightarrow$ CONSERVED Q.
KILLING FIELDS
$\nabla_\mu k_\nu + \nabla_\nu k_\mu = 0$
k^μ
SPEC: $k = \partial_t$
t
SPACETIME IS STATIC $\Rightarrow$ ENERGY IS CONSERVED
$M = -\frac{1}{8\pi} \int_{S^2_\infty} * dk = m.$


• BLACK HOLE HORIZON
(BOUNDARY OF BH)
f=0 <=> r=r+=2M
r+=2M
CAUTION

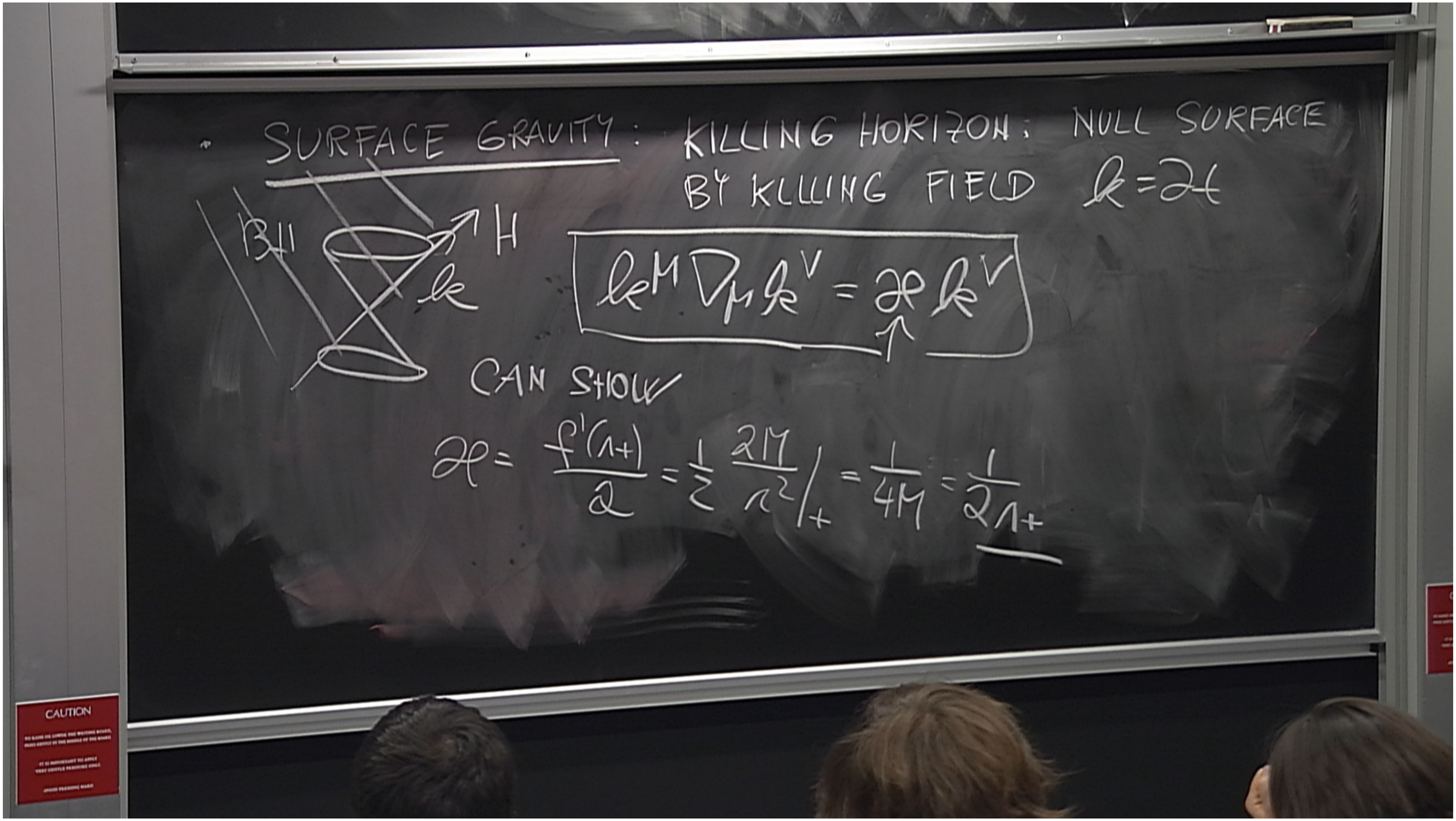

BLACK HOLE HORIZON
(BOUNDARY OF BH)
f=0
r=r+=2M
r+=2M
r=R
VR / V+ = Δτ+ / ΔτR

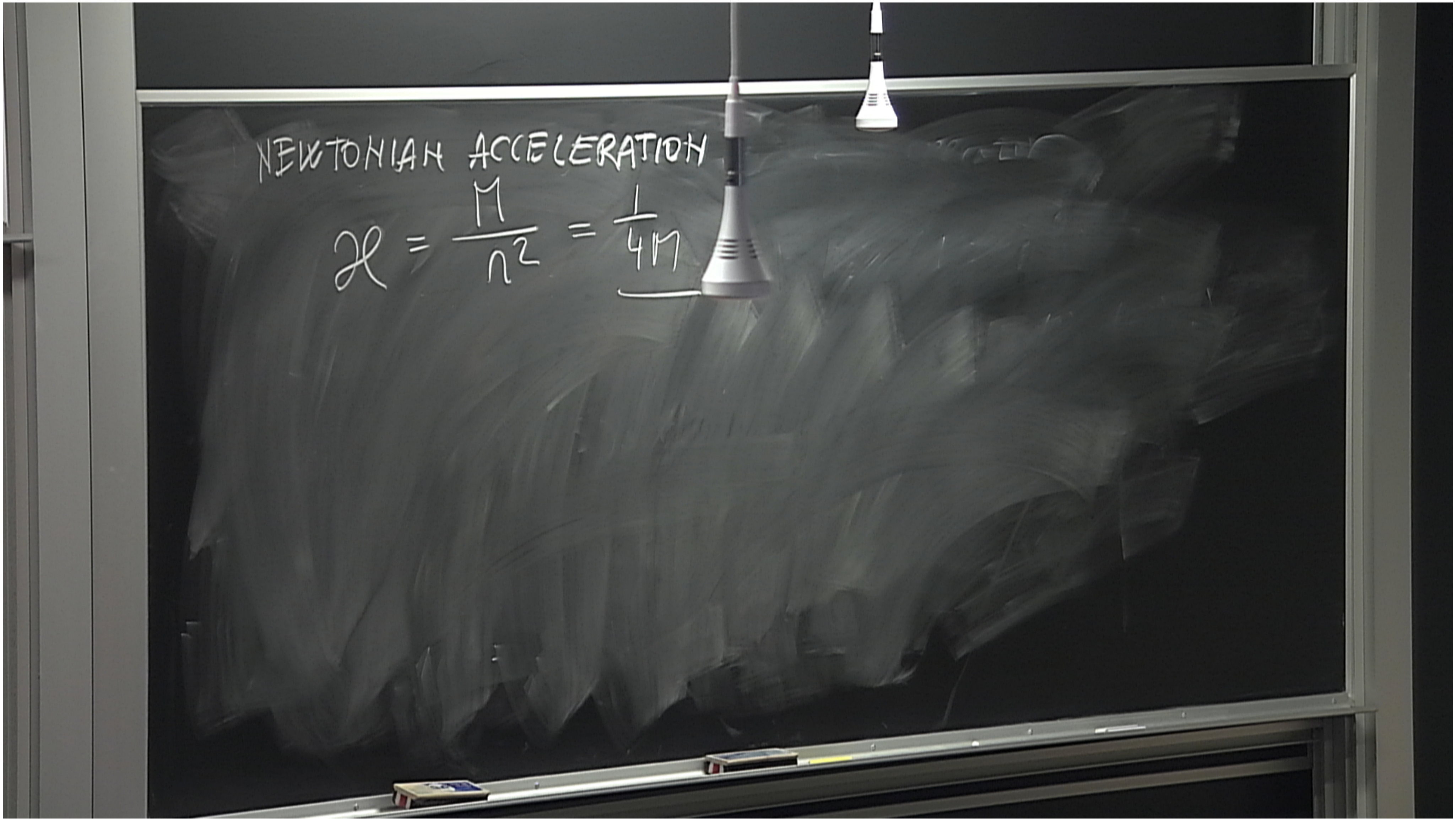

(BOUNDARY OF BH)
$r_+ = 2M$
$r = R$
$\frac{\nu_R}{\nu_+} = \frac{\Delta\tau_+}{\Delta\tau_R} = \frac{\sqrt{f_+}\,\Delta t}{\sqrt{f_R}\,\Delta t} = \frac{\sqrt{1-\frac{2m}{r_+}}}{\sqrt{1-\frac{2m}{R}}} \to 0$
THINGS LOOK INFINITELY REDSHIFTED ⇒ BLACK

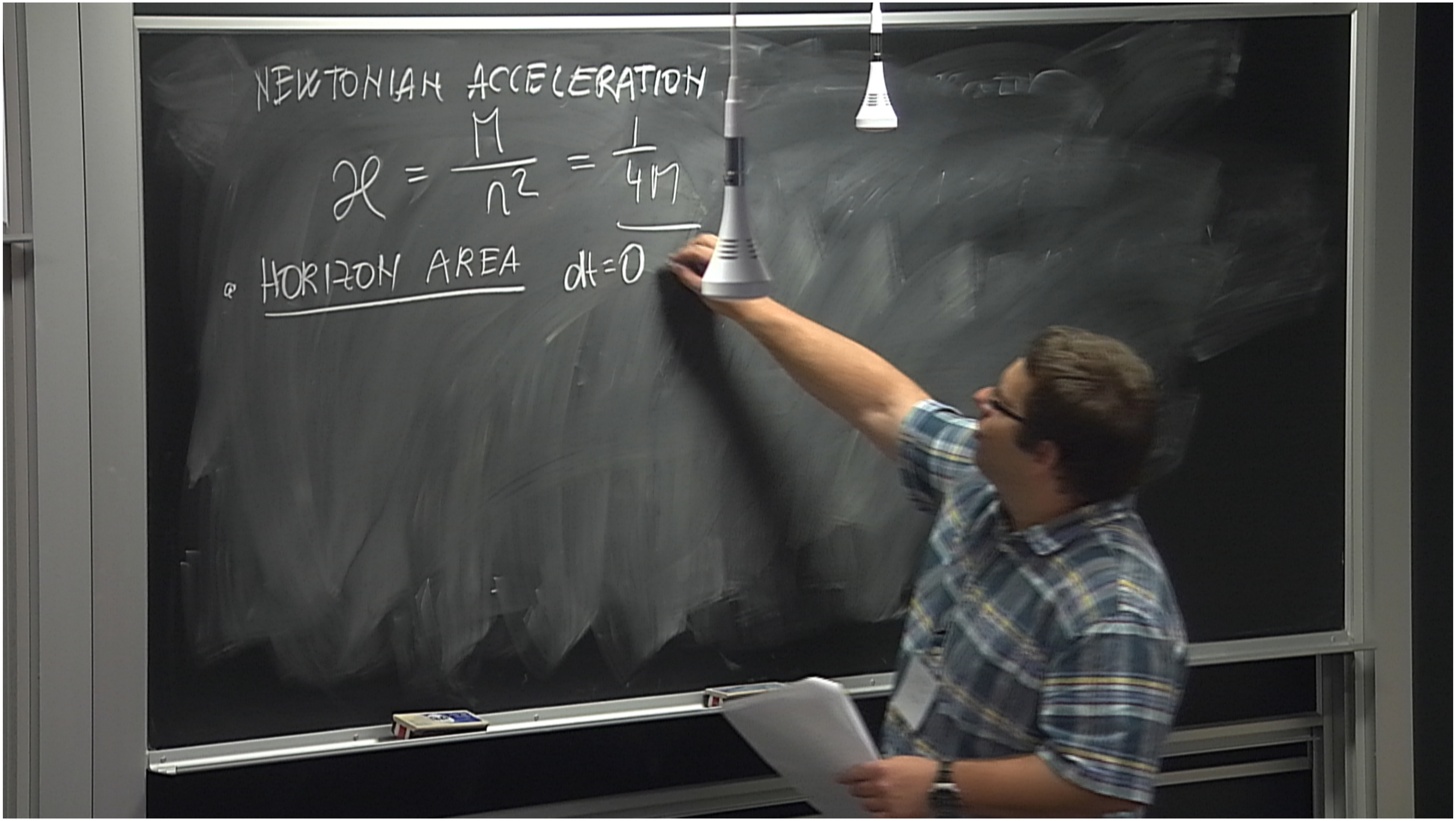

THINGS LOOK INFINITELY REDSHIFTED =>
BLACK

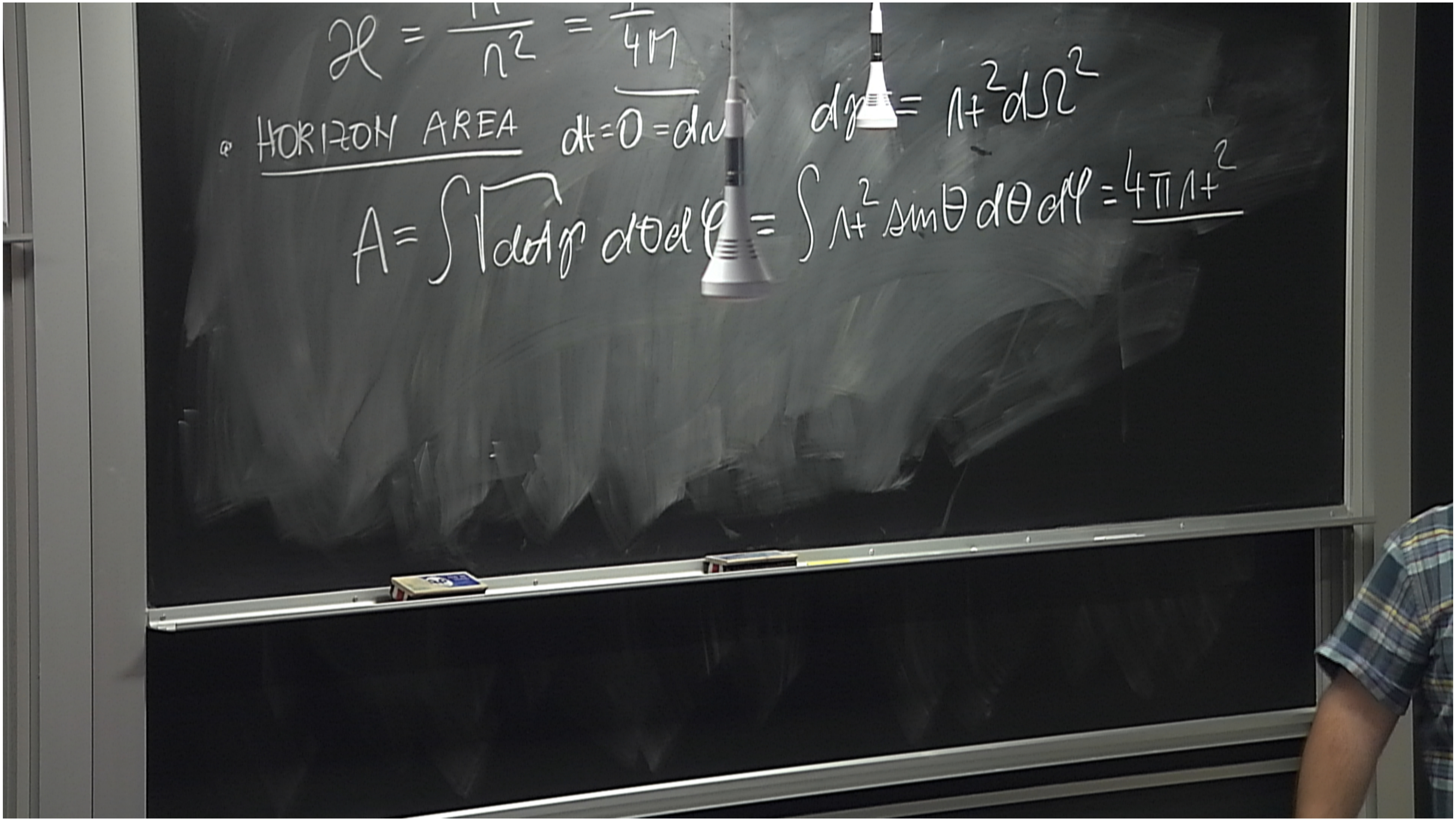


SURFACE GRAVITY: KILLING HORIZON: NULL SURFACE
BY KILLING FIELD $k = \partial_t$
BH
H
k
$k^\mu D_\mu k^\nu = \kappa k^\nu$
CAUTION


SURFACE GRAVITY: KILLING HORIZON: NULL SURFACE
BY KILLING FIELD $k = \partial_t$
BH
H
k
$k^\mu D_\mu k^\nu = \kappa k^\nu$
CAN SHOW
$\kappa = \frac{f'(r_+)}{2} = \frac{1}{2}\frac{2M}{r^2}\Big|_+ = \frac{1}{4M} = \frac{1}{2r_+}$


NEWTONIAN ACCELERATION
$\kappa = \frac{M}{r^2} = \frac{1}{4M}$


NEWTONIAN ACCELERATION
HORIZON AREA
dt=0

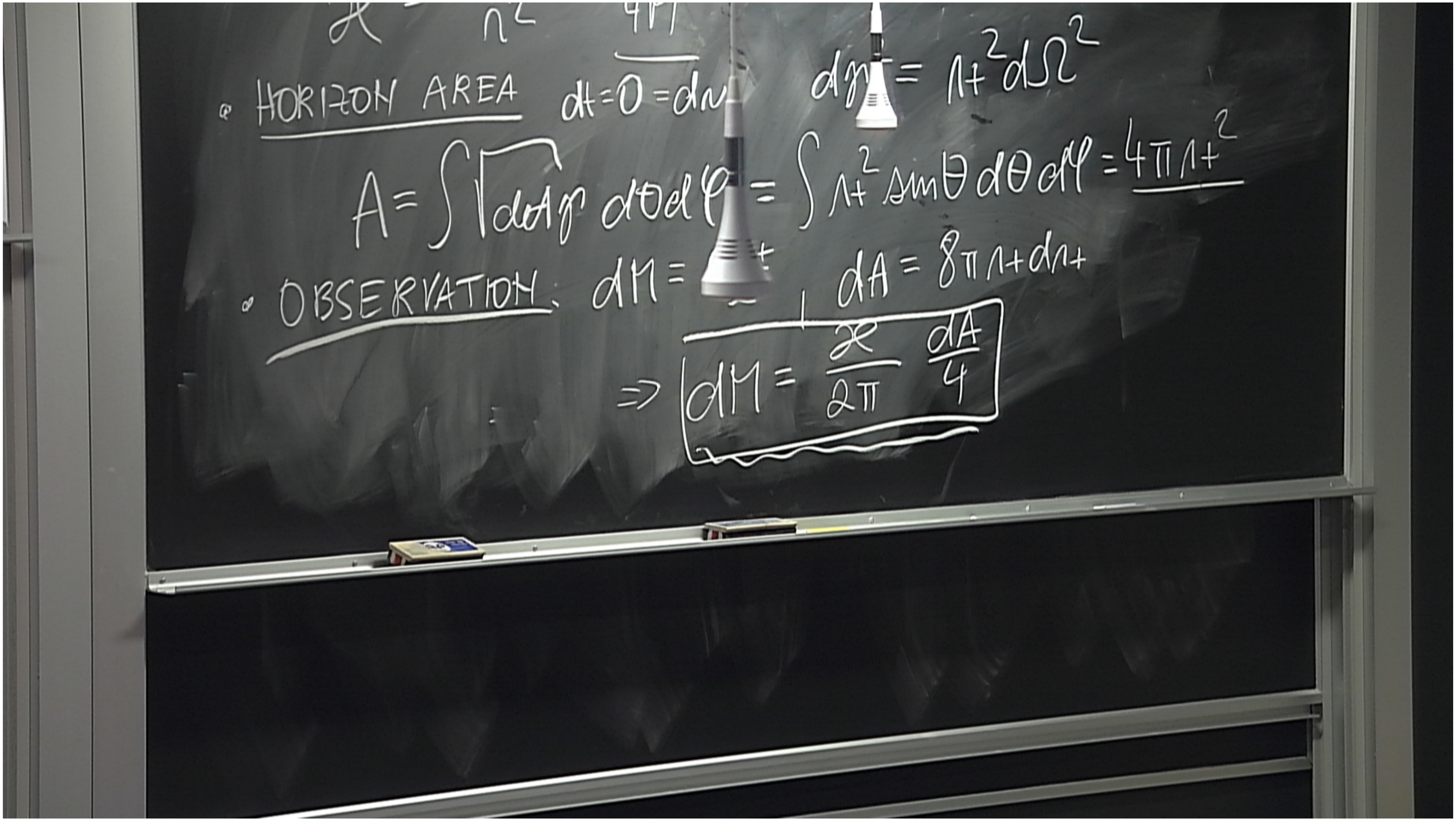

HORIZON AREA
dt = 0 = dr
dγ = r+² dΩ²
A = ∫ √det γ dθ dφ = ∫ r+² sinθ dθ dφ = 4π r+²

- **HORIZON AREA** $dt = 0 = dr$ $\quad d\sigma^2 = r_+^2 d\Omega^2$

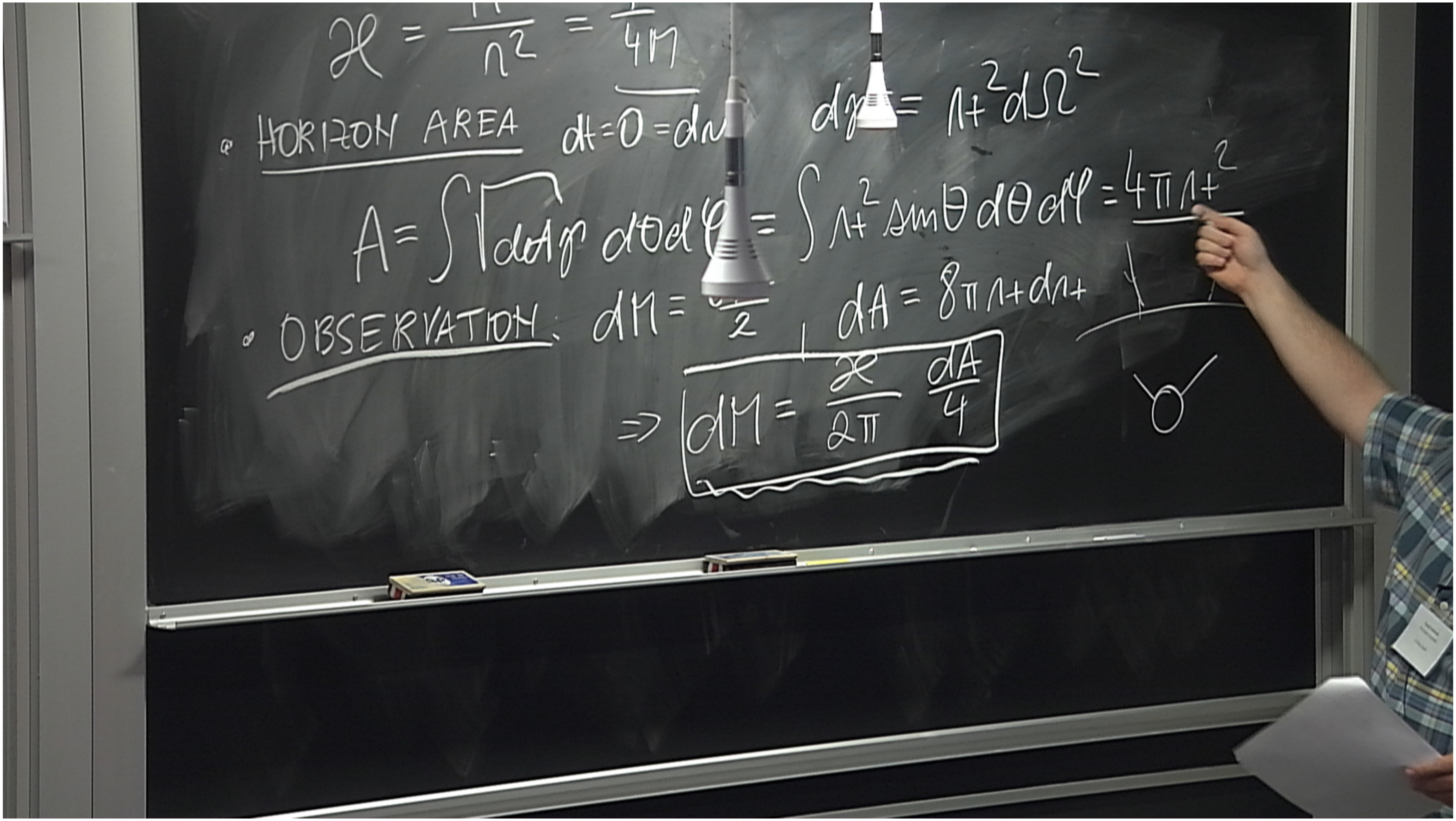
$$A = \int \sqrt{\det g}\, d\theta\, d\varphi = \int r_+^2 \sin\theta\, d\theta\, d\varphi = 4\pi r_+^2$$

- **OBSERVATION**: $dM = \ldots$ $\quad dA = 8\pi r_+ dr_+$

$$\Rightarrow \boxed{dM = \frac{\varkappa}{2\pi} \frac{dA}{4}}$$



HORIZON AREA
dt = 0 = dr
A = ∫√det γ dθ dφ = ∫ r+² sinθ dθ dφ = 4π r+²
OBSERVATION:
dM =
dA = 8π r+ dr+
⇒ dM = κ/2π dA/4



HORIZON AREA
dt = 0 = dr
dΣ² = r+² dΩ²
A = ∫ √det g dθ dφ = ∫ r+² sinθ dθ dφ = 4π r+²
OBSERVATION:
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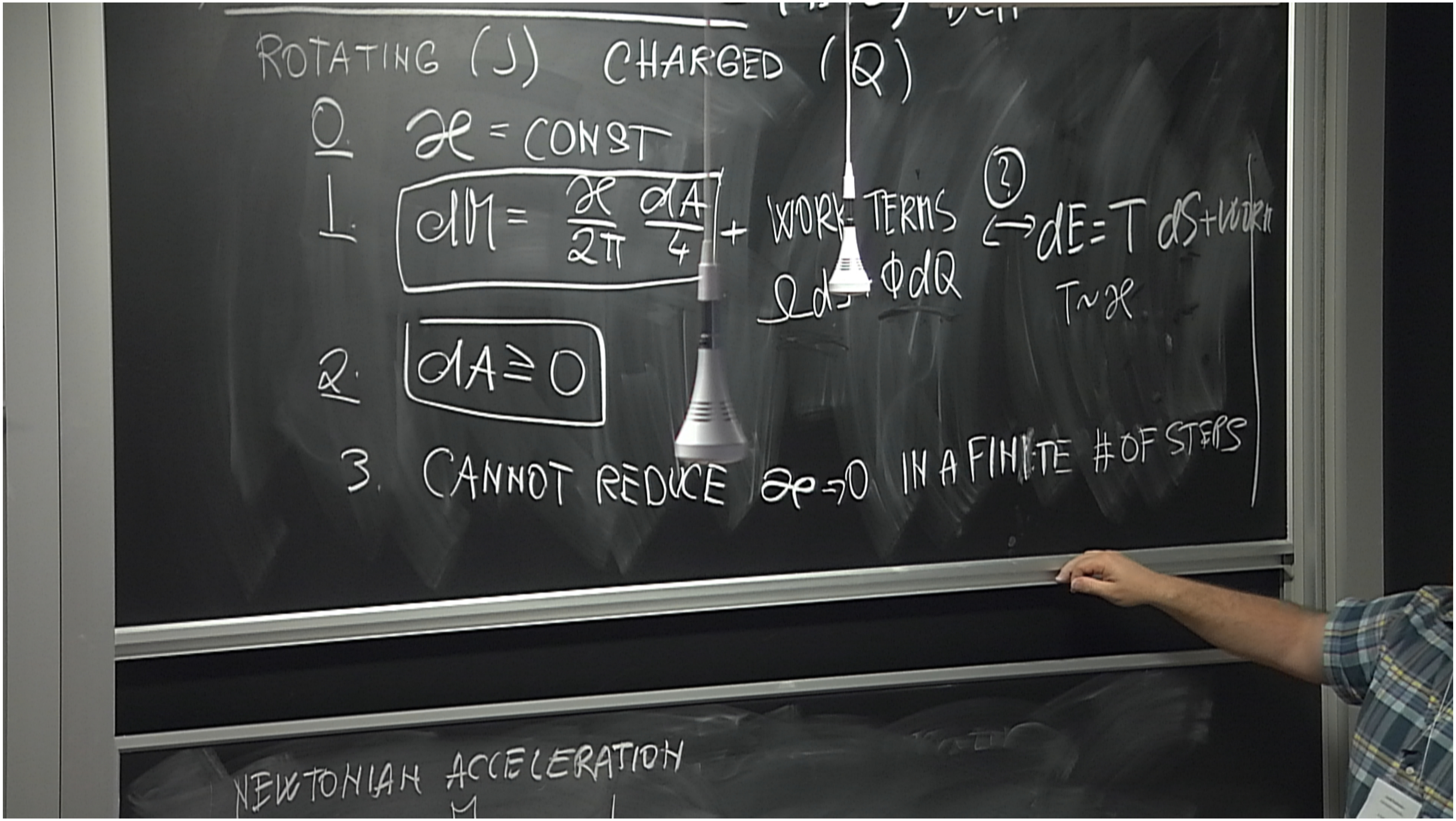
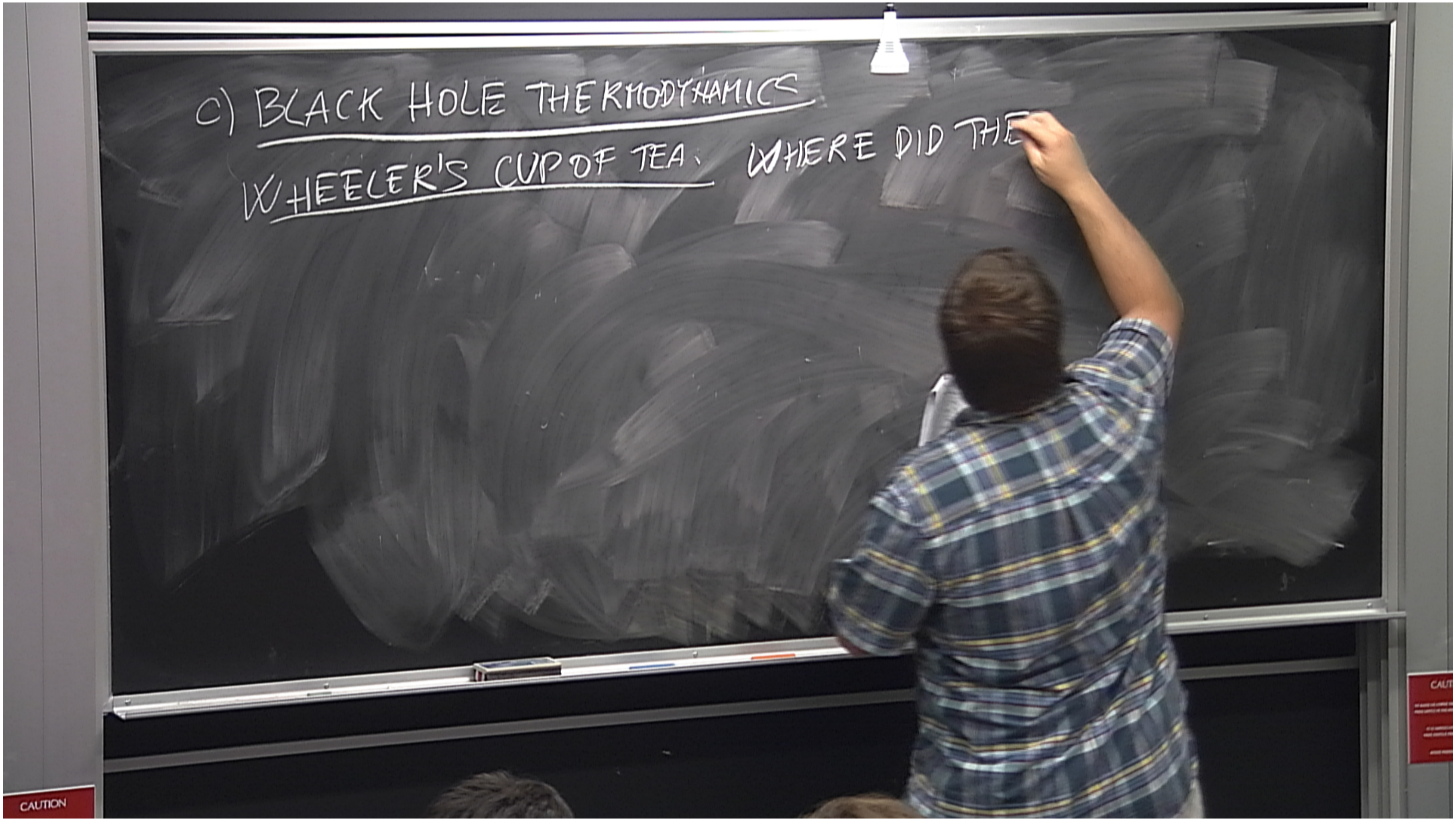
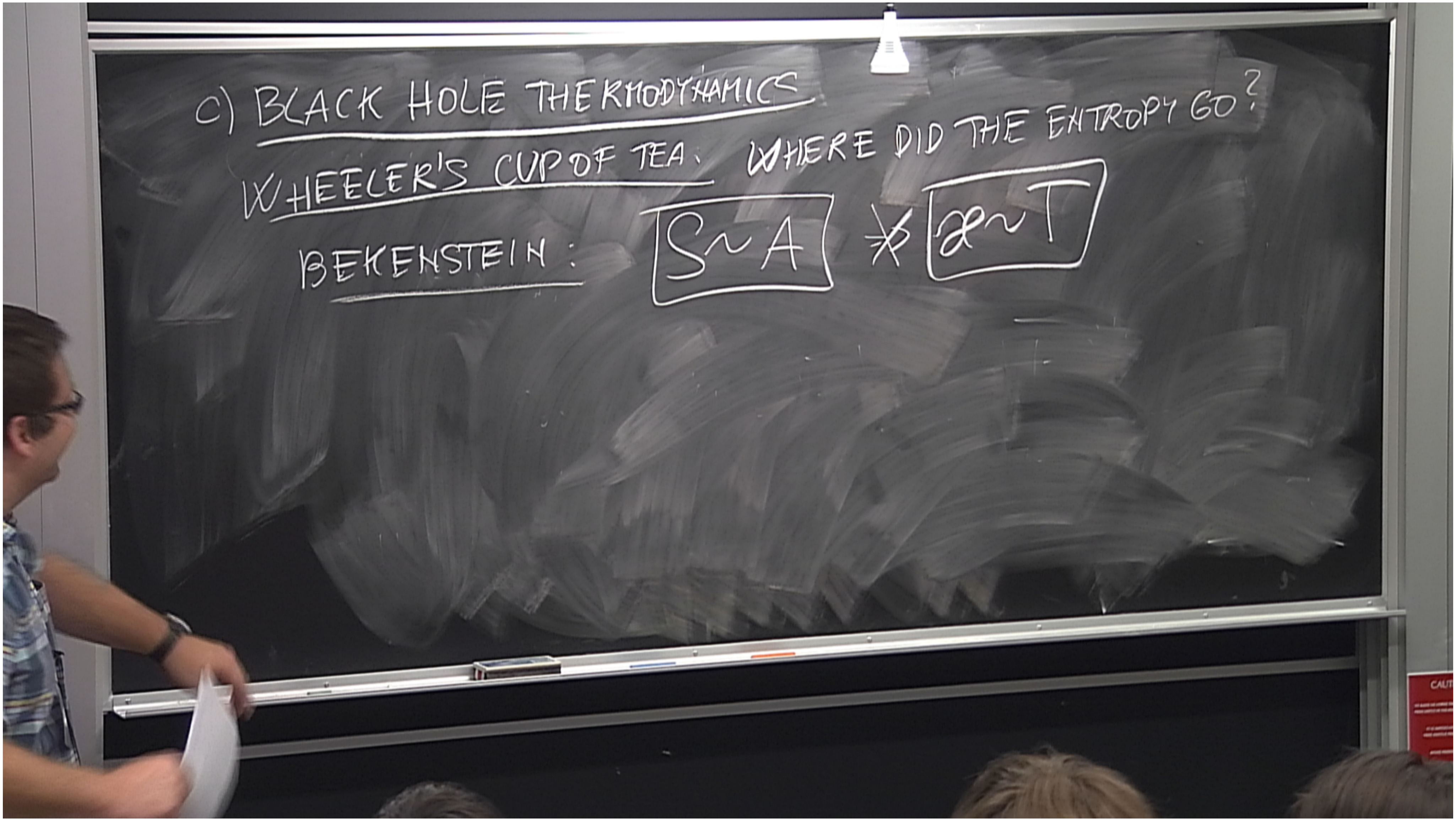
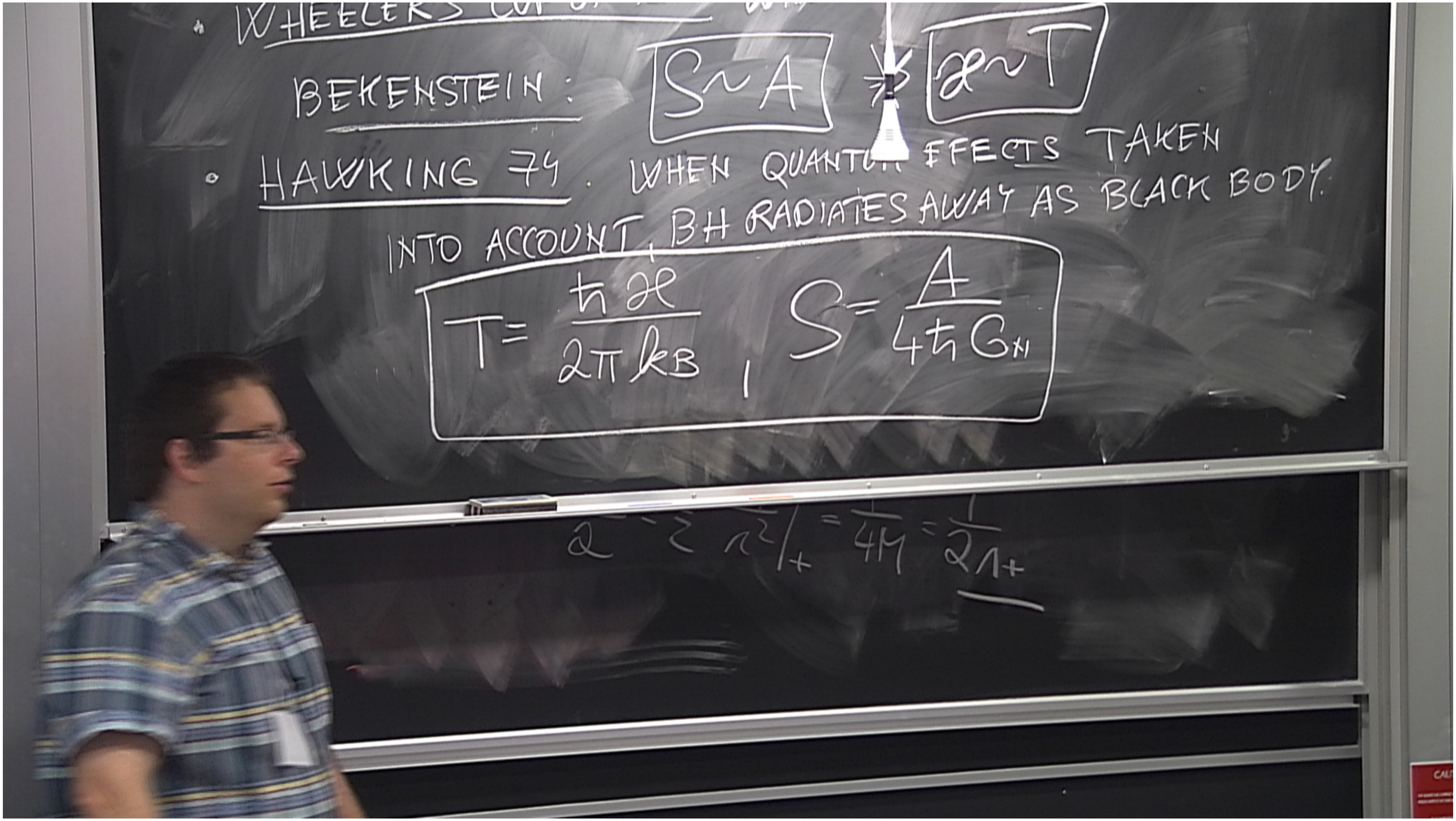
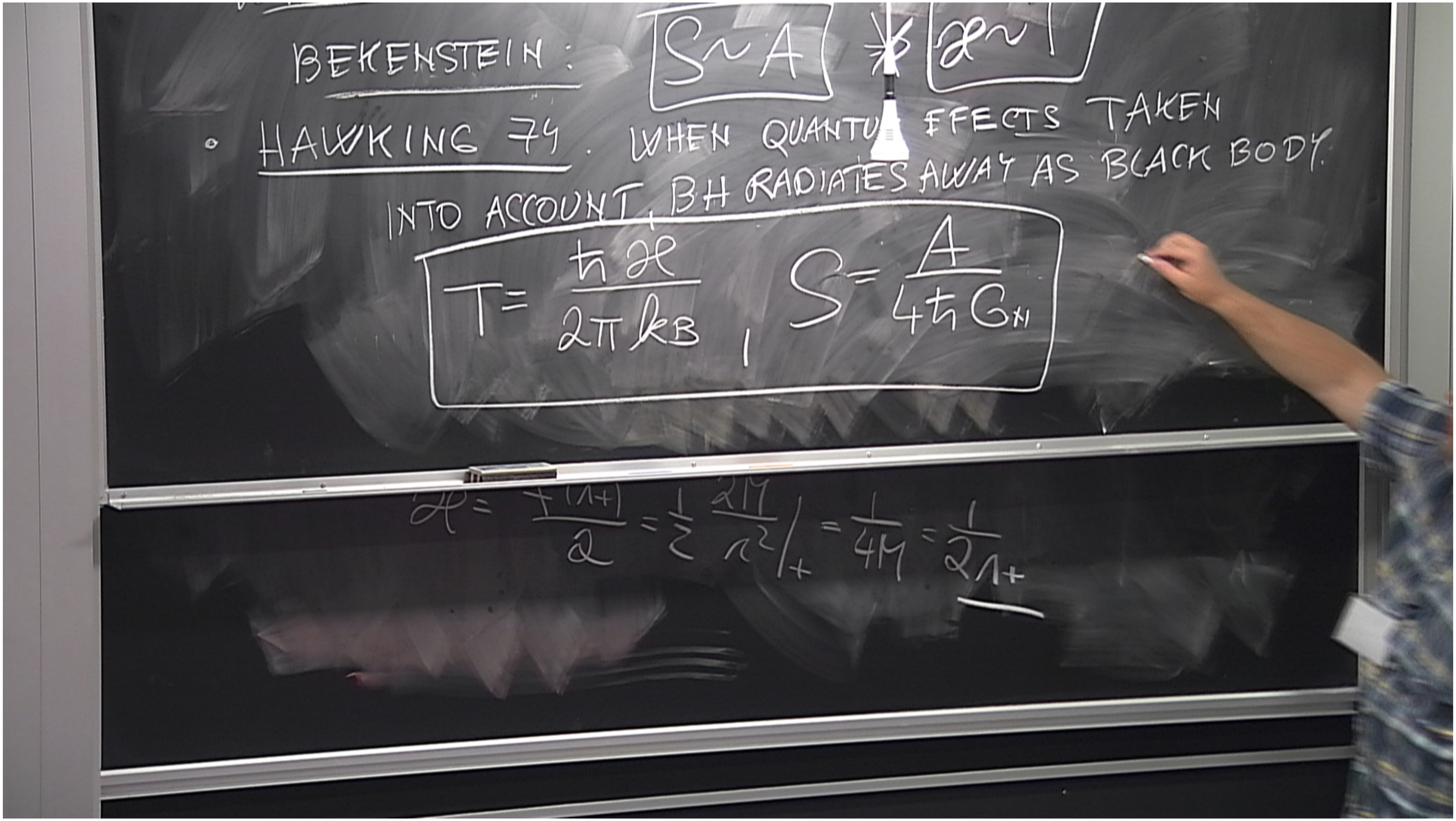

ROTATING (J) CHARGED (Q)
0. ϰ = CONST
1. dM = ϰ/2π dA/4 + WORK TERMS
ΩdJ + ΦdQ
② ⟷ dE = T dS + WORK
T~ϰ
2. dA ≥ 0
3. CANNOT REDUCE ϰ→0 IN A FINITE # OF STEPS
NEWTONIAN ACCELERATION


C) BLACK HOLE THERMODYNAMICS
WHEELER'S CUP OF TEA. WHERE DID THE


c) BLACK HOLE THERMODYNAMICS
WHEELER'S CUP OF TEA: WHERE DID THE ENTROPY GO?
BEKENSTEIN:
S~A
κ~T


BEKENSTEIN: S ~ A & ϰ ~ T
HAWKING 74. WHEN QUANTUM EFFECTS TAKEN
INTO ACCOUNT, BH RADIATES AWAY AS BLACK BODY.
$T = \frac{\hbar \varkappa}{2\pi k_B}$, $S = \frac{A}{4\hbar G_N}$

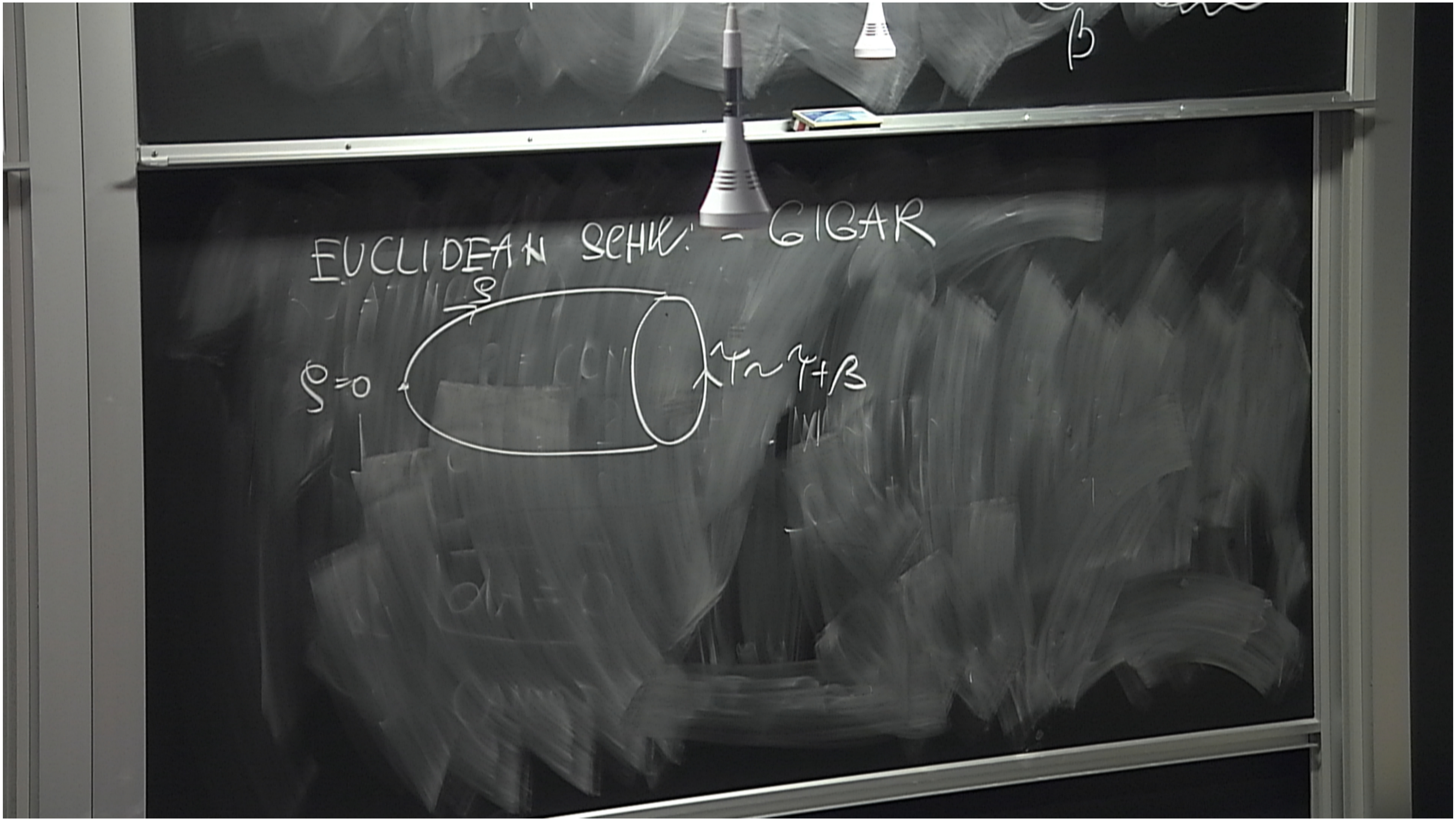

BEKENSTEIN :
S ~ A
HAWKING 74. WHEN QUANTUM EFFECTS TAKEN INTO ACCOUNT, BH RADIATES AWAY AS BLACK BODY.
T = ħκ / 2π kB , S = A / 4ħ GN
= 1/4M = 1/2r+

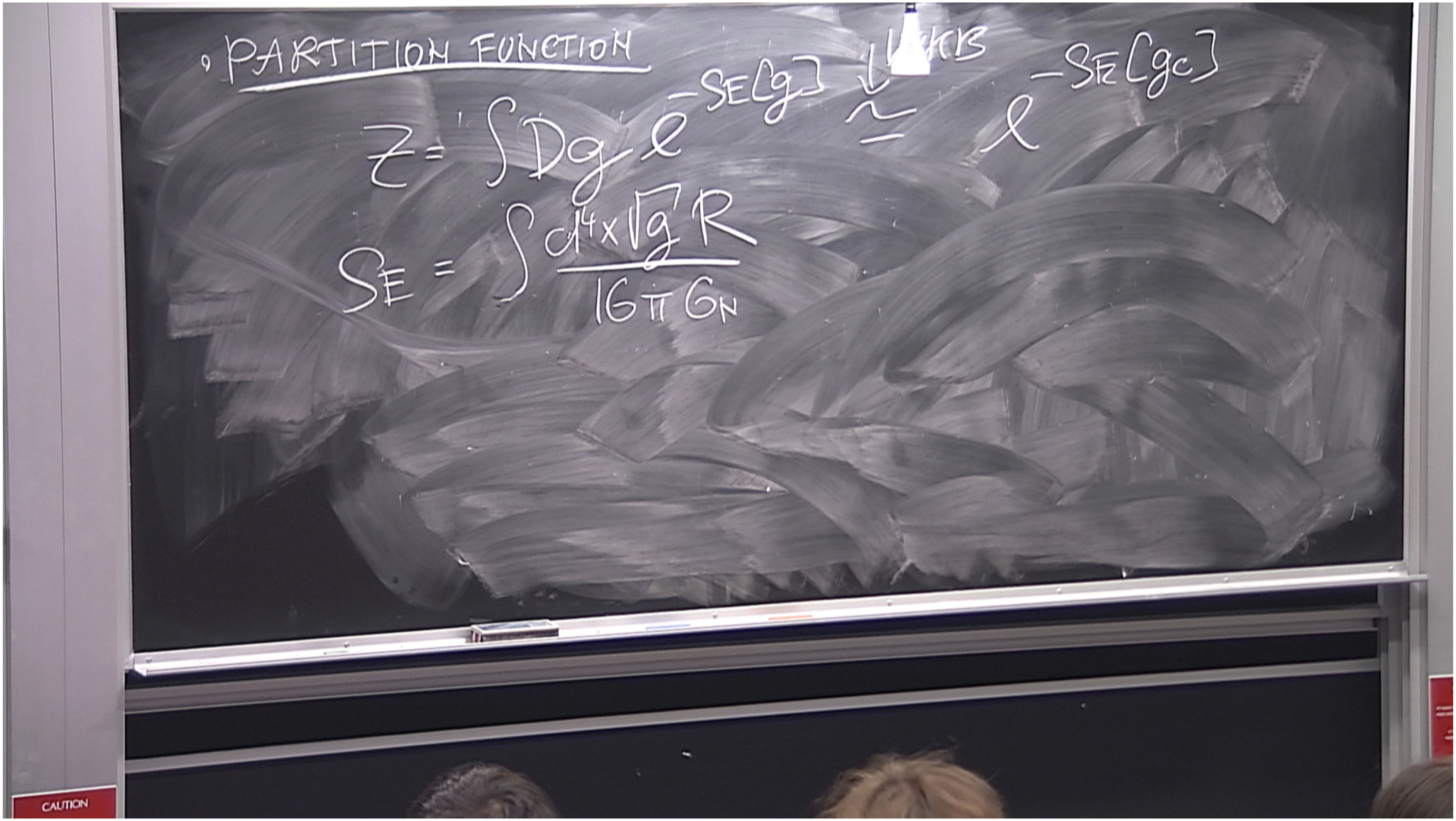
$$T = \frac{\hbar \kappa}{2\pi k_B}, \quad S = \frac{A}{4\hbar G_N}$$

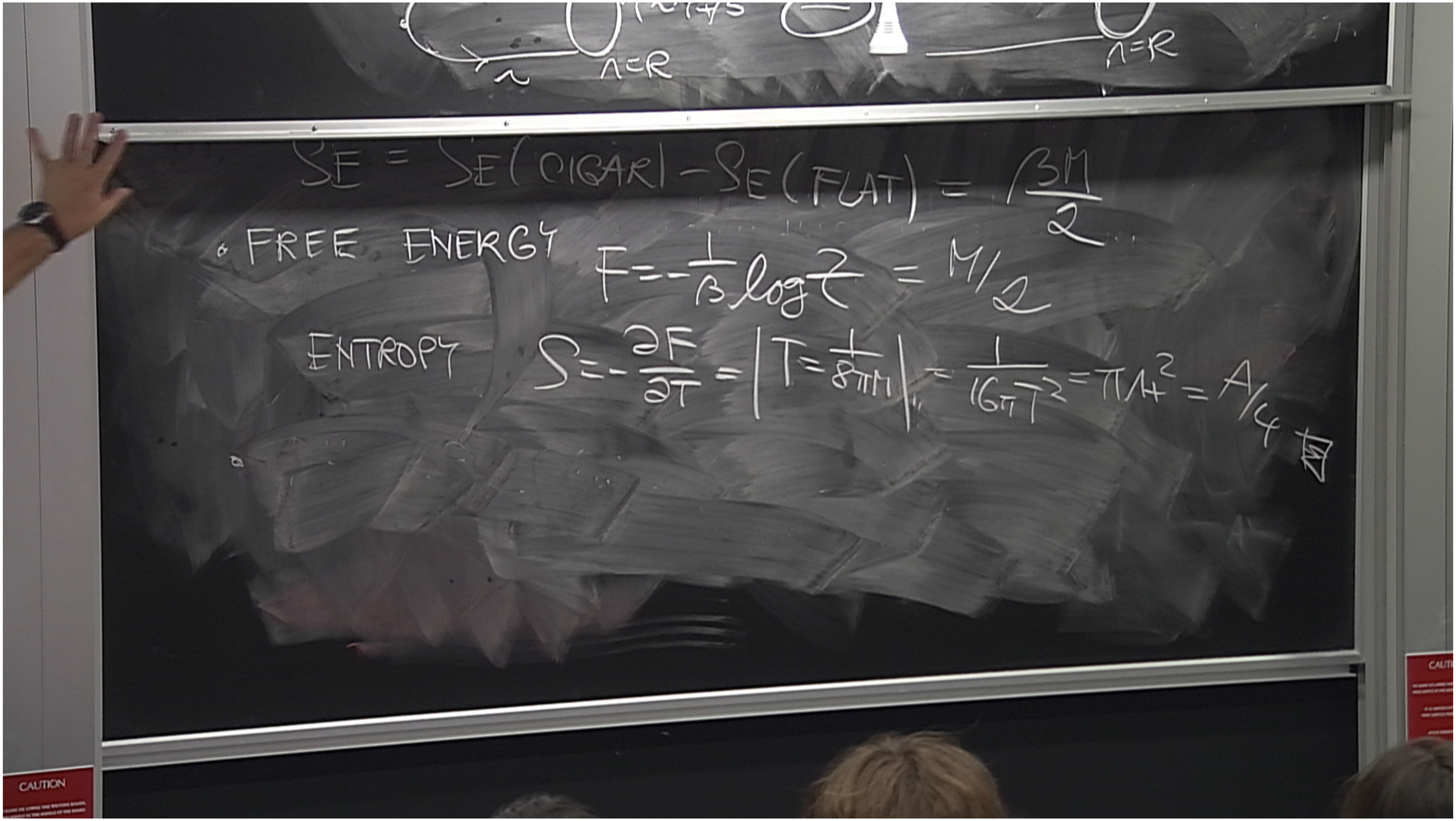
DER.

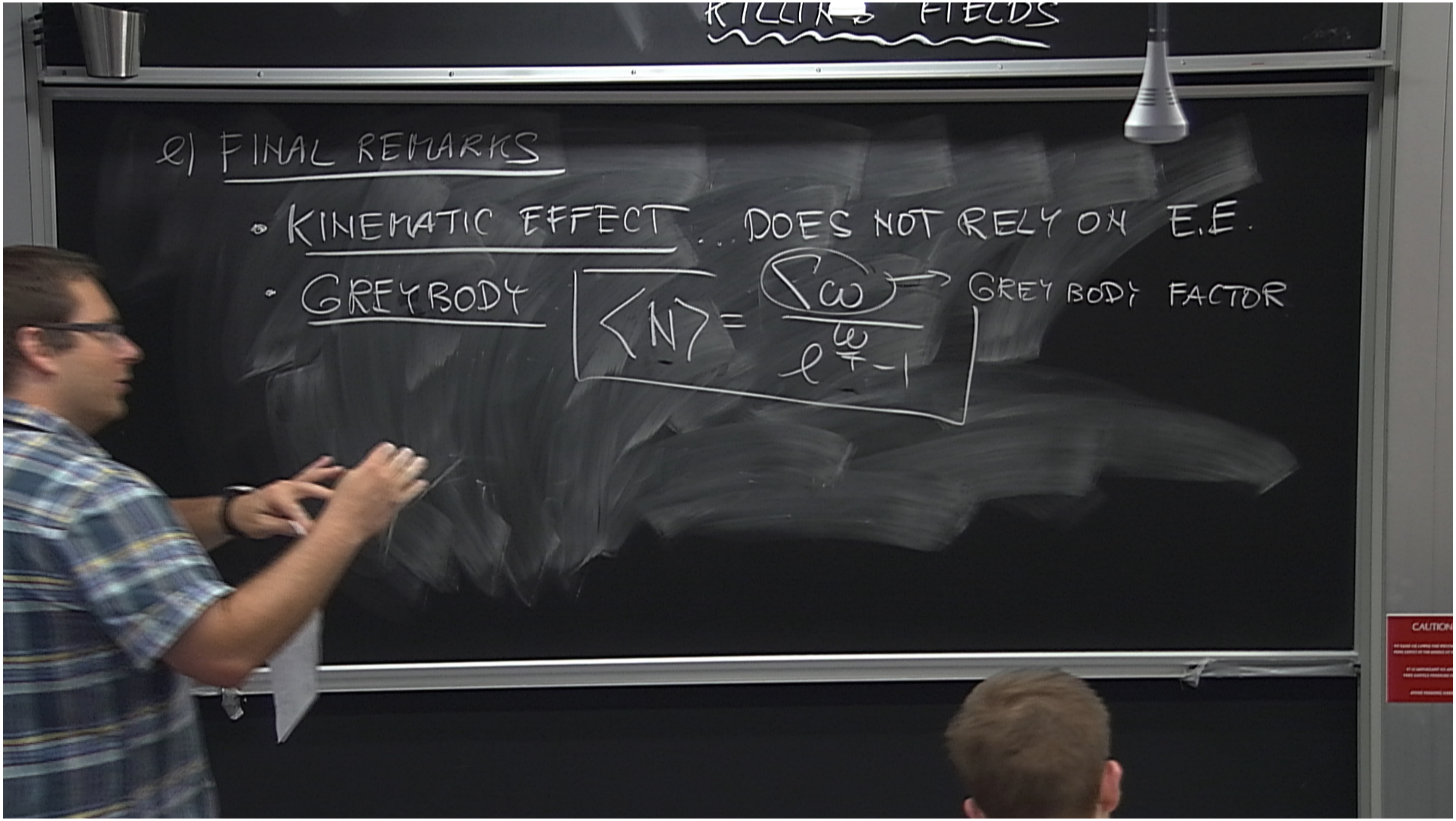
- EUCLIDEAN PI, TUNNELLING, LQG, STRING T.

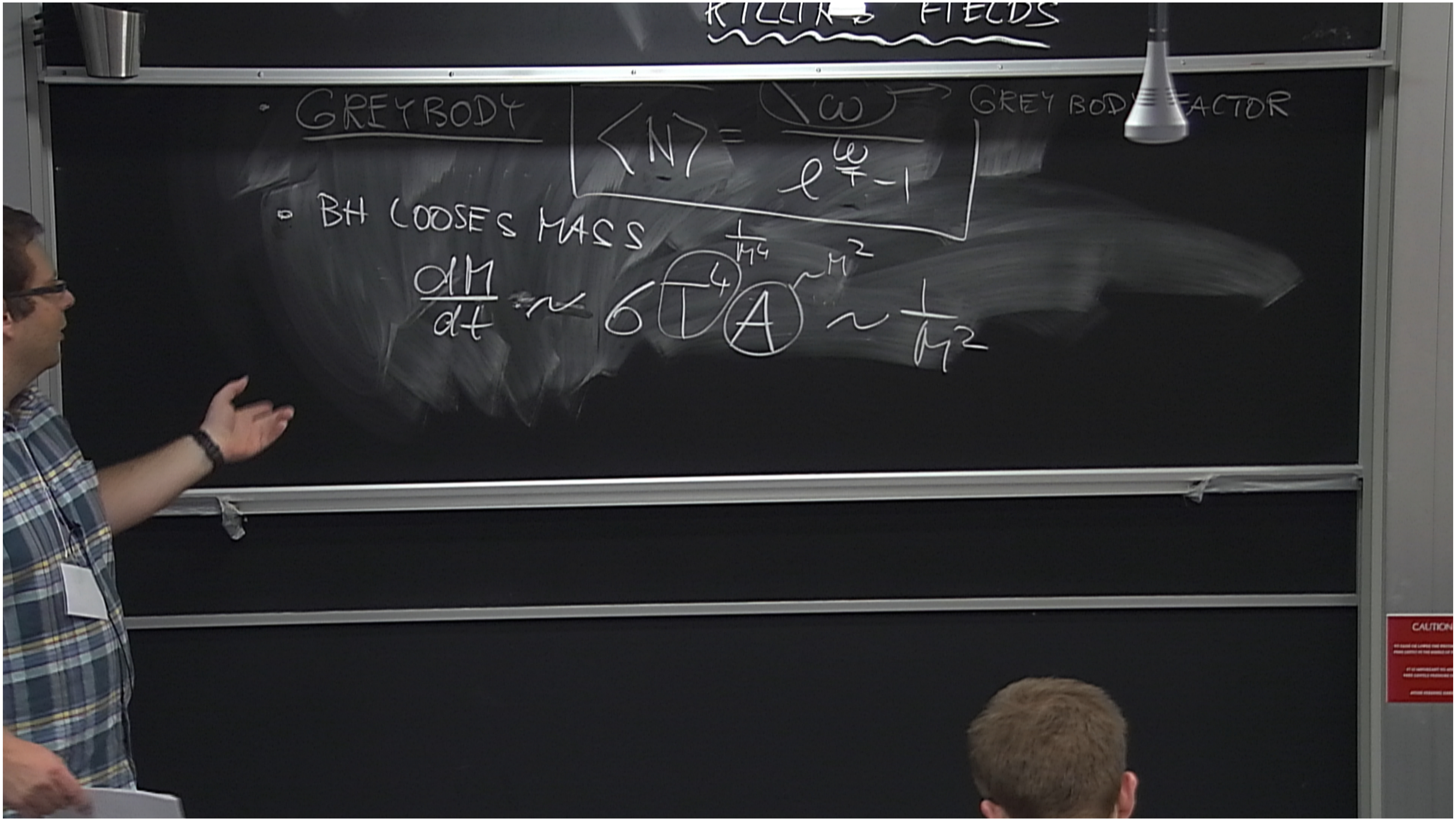
d) EUCLIDEAN TRICK

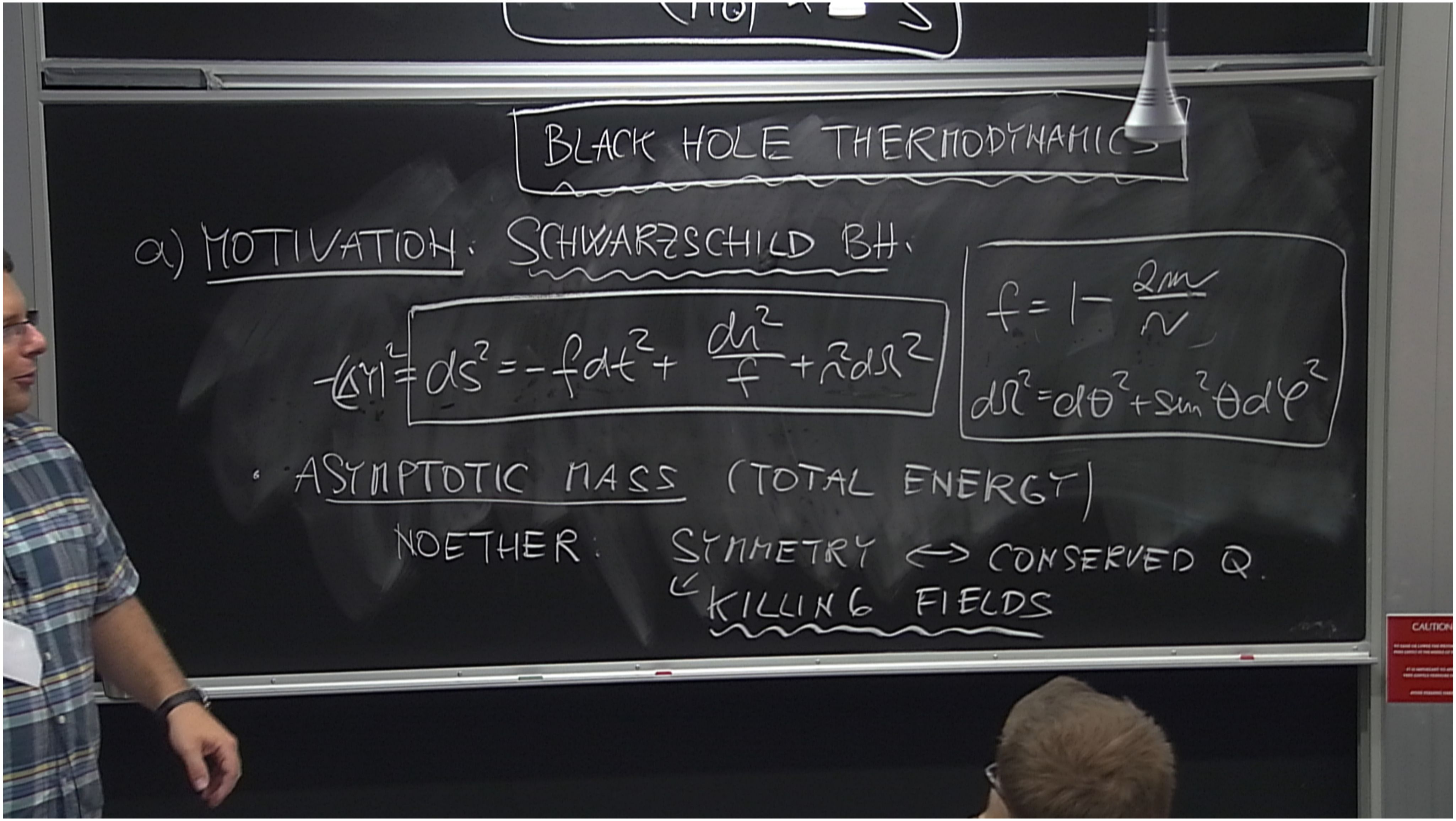

EUCLIDEAN SCHW: - CIGAR
ρ
ρ=0
τ~τ+β
β

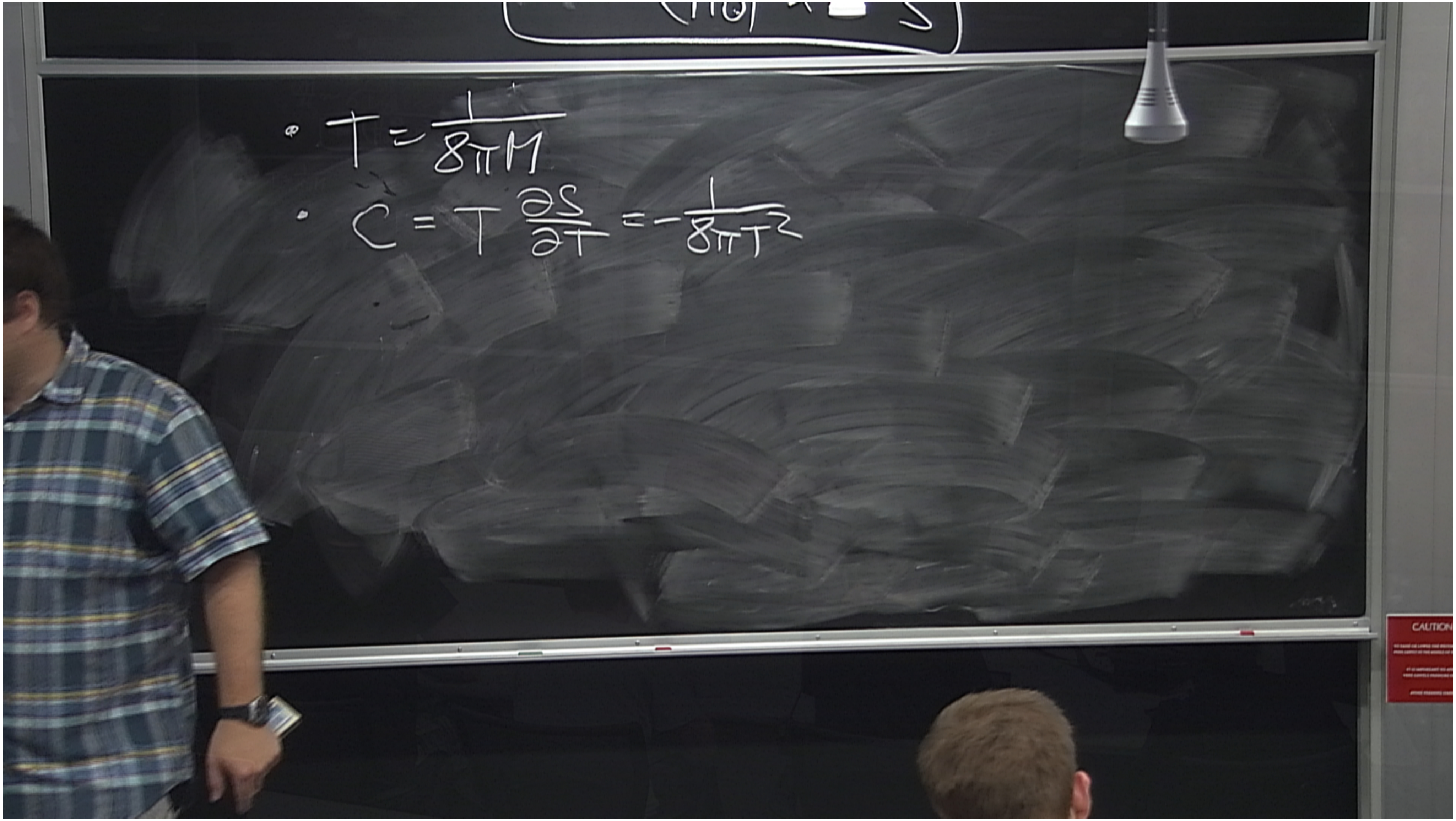

PARTITION FUNCTION
$Z = \int Dg\, e^{-S_E[g]} \simeq e^{-S_E[g_c]}$
$S_E = \int \frac{d^4x \sqrt{g}\, R}{16\pi G_N}$
CAUTION

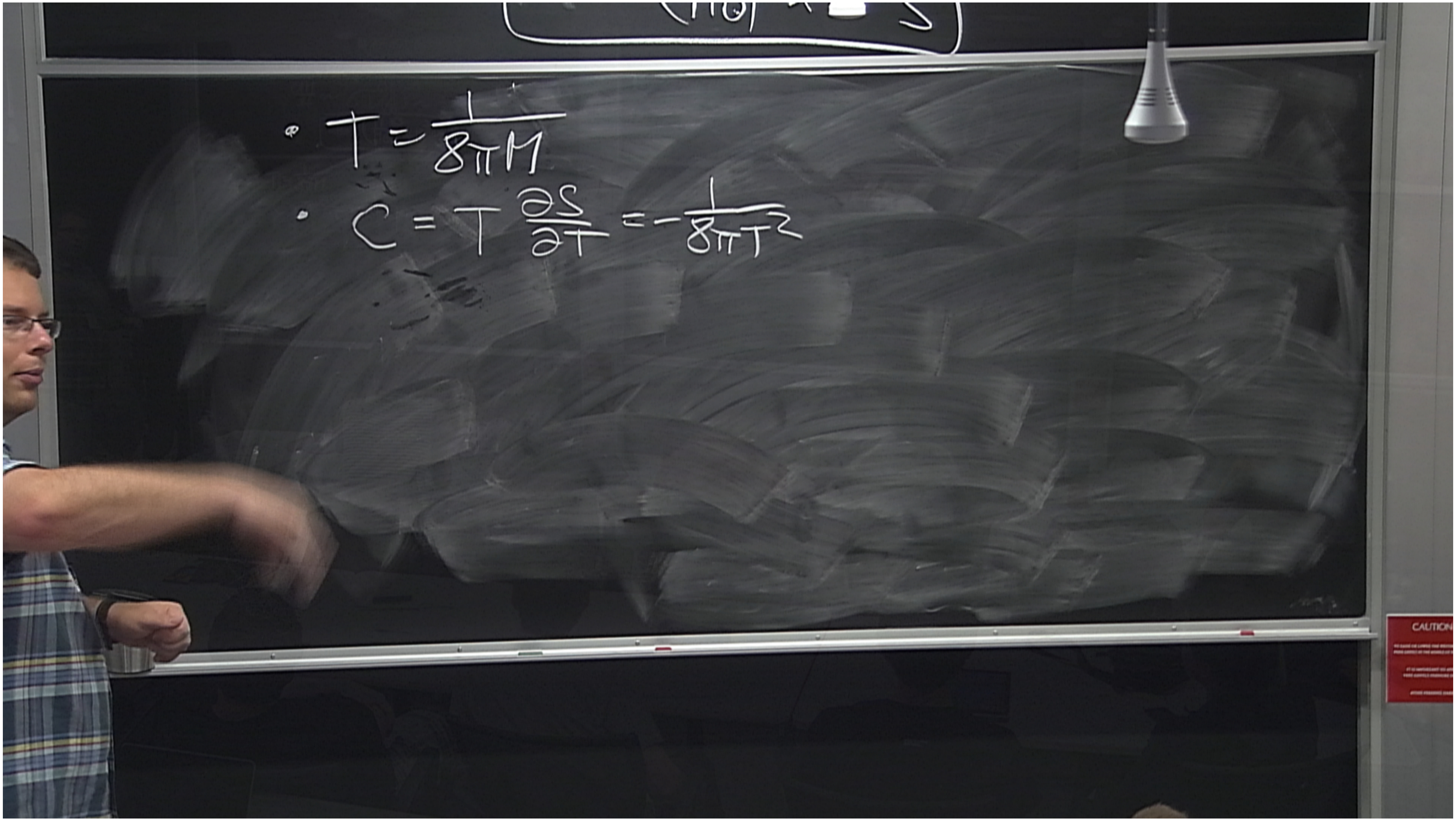

r = R
r = R
S_E = S_E(CIGAR) − S_E(FLAT) = βM/2
FREE ENERGY F = −(1/β) log Z = M/2
ENTROPY S = −∂F/∂T = |_{T = 1/8πM} = 1/(16πT²) = πr_H² = A/4
CAUTION

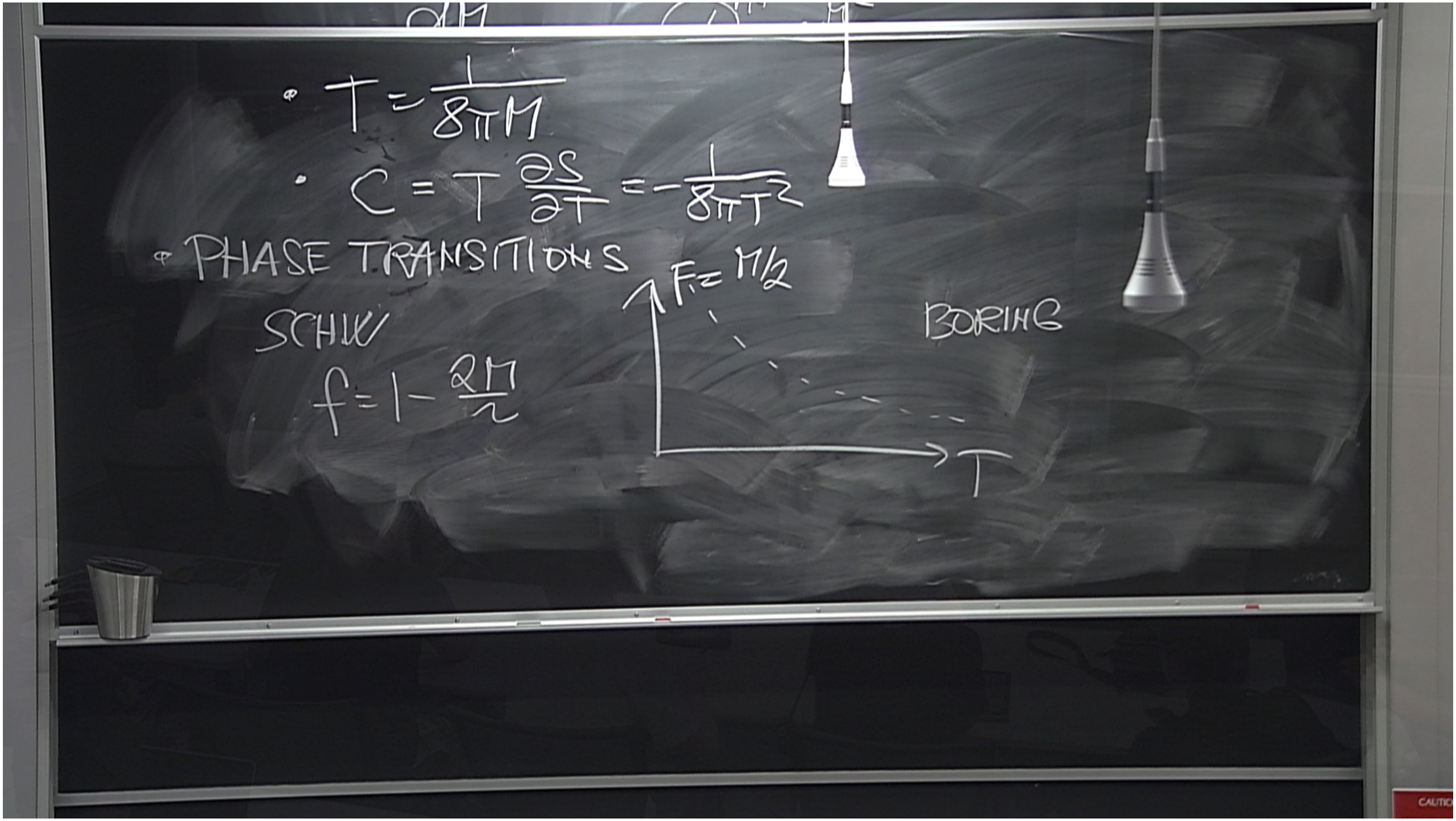

e) FINAL REMARKS
• KINEMATIC EFFECT ... DOES NOT RELY ON E.E.
• GREYBODY
$\langle N \rangle = \frac{\Gamma_\omega}{e^{\frac{\omega}{T}}-1}$
GREYBODY FACTOR
CAUTION


GREYBODY
⟨N⟩ = Γω / (e^{ω/T} − 1)
GREY BODY FACTOR
BH LOOSES MASS
dM/dt ~ σ T^4 A ~ 1/M^2
CAUTION


BLACK HOLE THERMODYNAMICS
a) MOTIVATION: SCHWARZSCHILD BH.
$-(\Delta\tau)^2 = ds^2 = -f dt^2 + \frac{dr^2}{f} + r^2 d\Omega^2$
$f = 1 - \frac{2m}{r}$
$d\Omega^2 = d\theta^2 + \sin^2\theta d\varphi^2$
· ASYMPTOTIC MASS (TOTAL ENERGY)
NOETHER: SYMMETRY ⟷ CONSERVED Q.
KILLING FIELDS


T = 1/8πM
C = T ∂S/∂T = −1/8πT²


$T = \frac{1}{8\pi M}$
$C = T \frac{\partial S}{\partial T} = -\frac{1}{8\pi T^2}$


$T = \frac{1}{8\pi M}$
$C = T \frac{\partial S}{\partial T} = -\frac{1}{8\pi T^2}$
PHASE TRANSITIONS
SCHW
$f = 1 - \frac{2M}{r}$
$F = M/2$
T
BORING