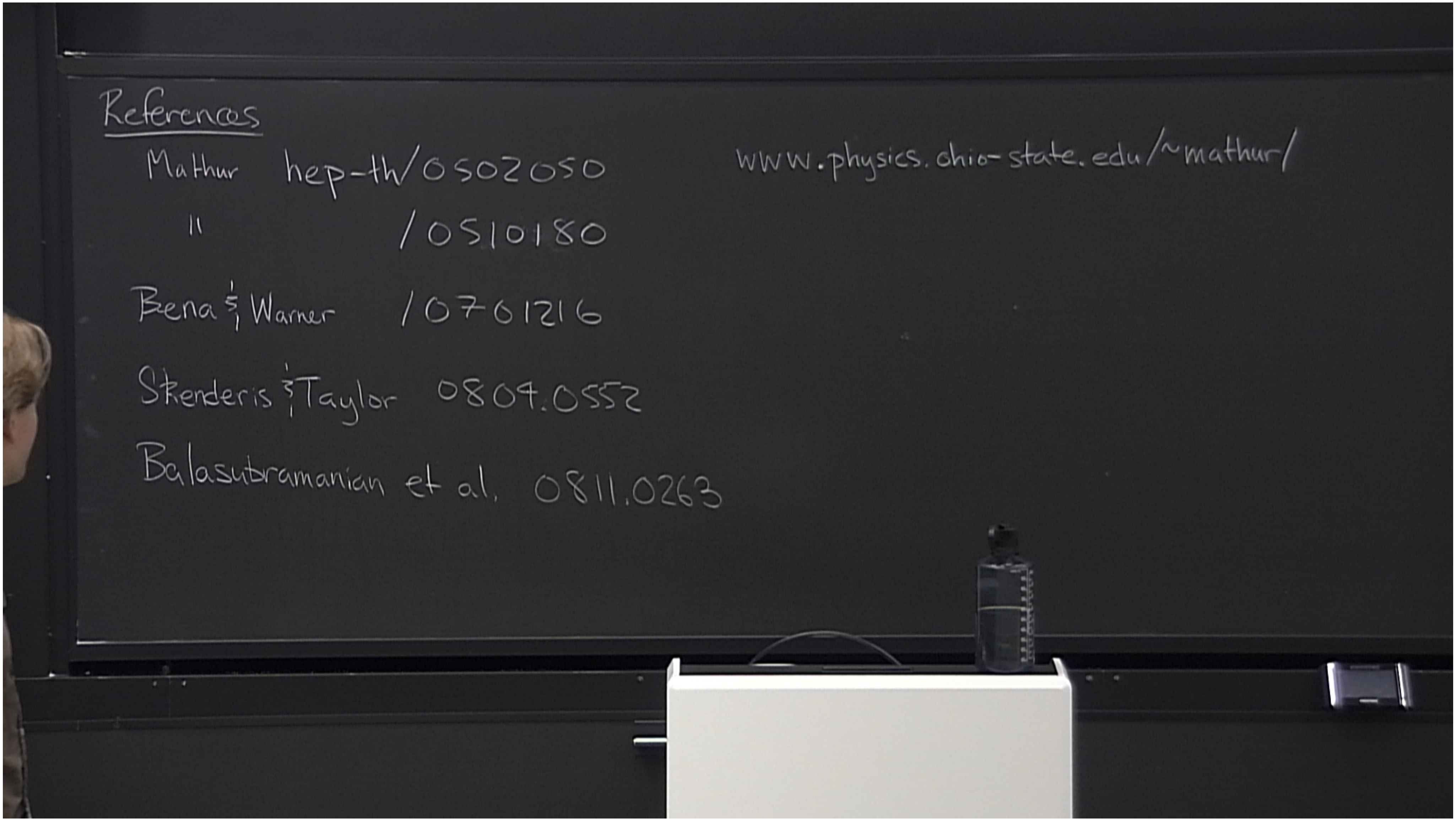
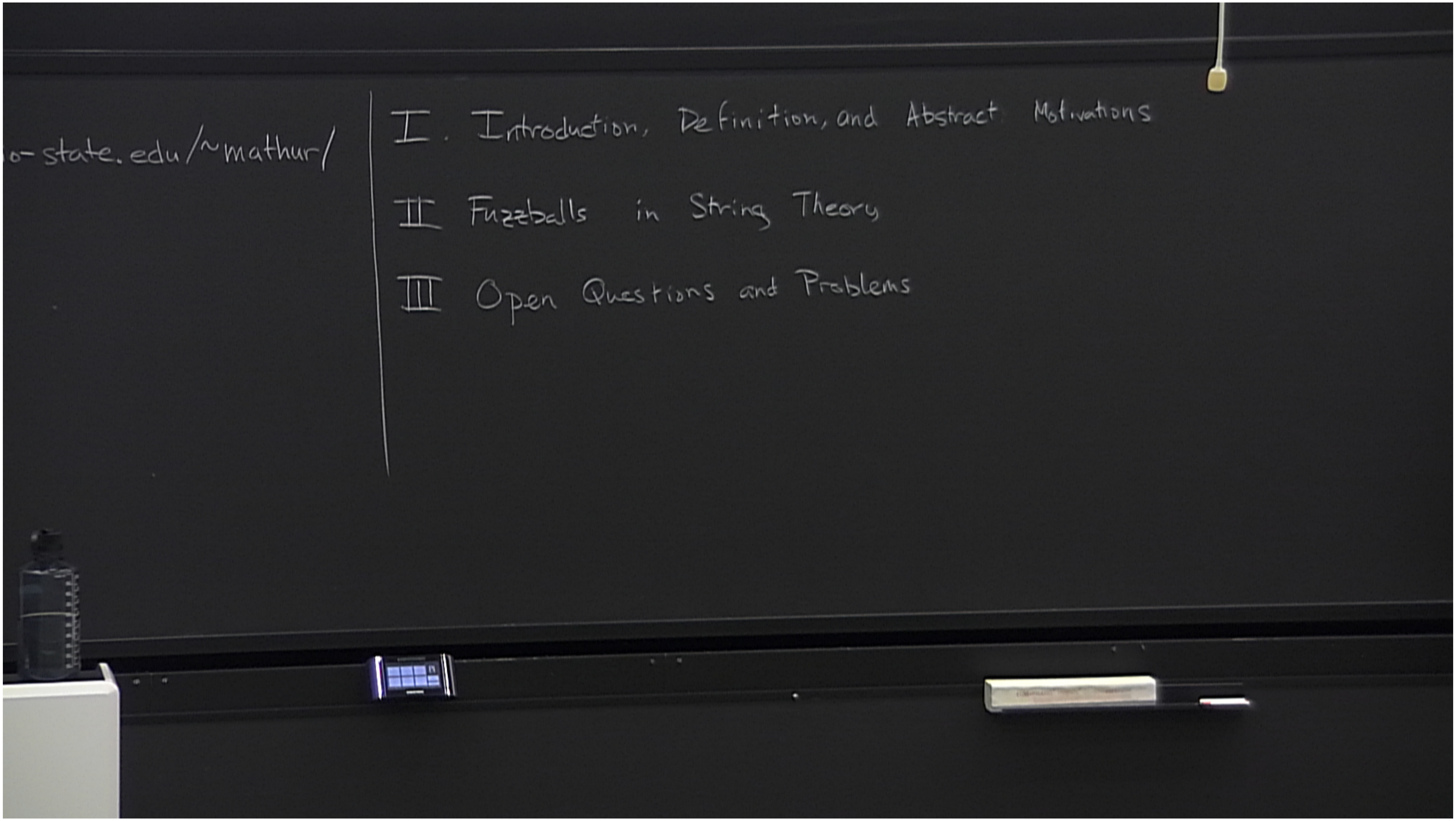
Title: Fuzzballs to Firewalls: A Post-Firewall Review of the Fuzzball Proposal: Lecture 1

Date: May 30, 2013 11:00 AM

URL: http://pirsa.org/13050087

Abstract: The fuzzball proposal makes a conjecture about the nature of black hole <br>microstates. Now, more than a decade old and including several different<br>
philosophies and perspectives, it is especially relevant after the recent<br>
firewall argument and ensuing debate. Over three lectures, I plan to start<br>with a very general discussion of the general ideas and motivations, then<br>review the theoretical evidence from string theory, and finally close by<br>discussing open questions, including the fate of a freely falling observer<br><br>as he/she passes through the black hole horizon.


References
Mathur hep-th/0502050
" /0510180
Bena & Warner /0701216
Skenderis & Taylor 0804.0552
Balasubramanian et al. 0811.0263
www.physics.ohio-state.edu/~mathur/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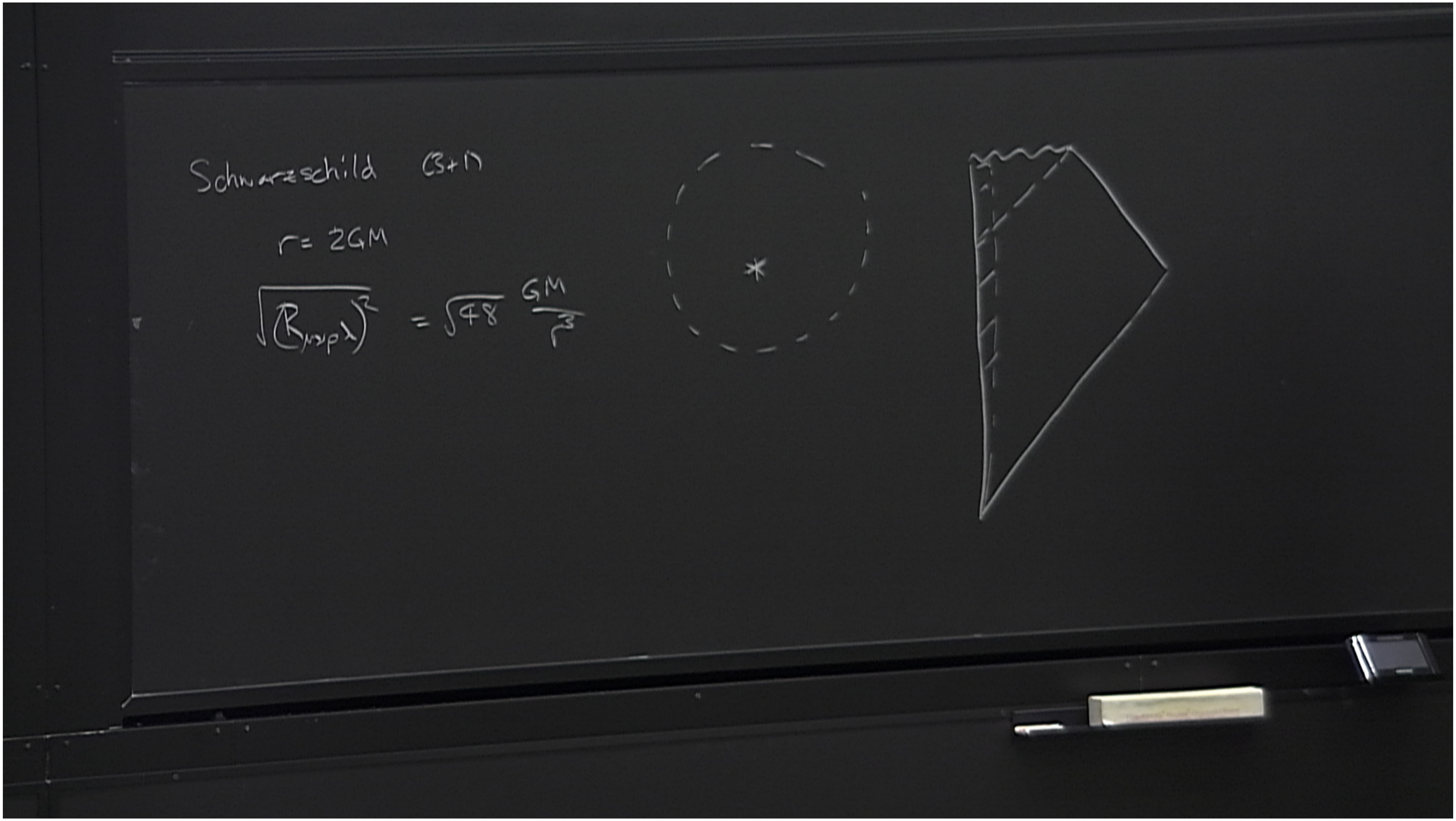
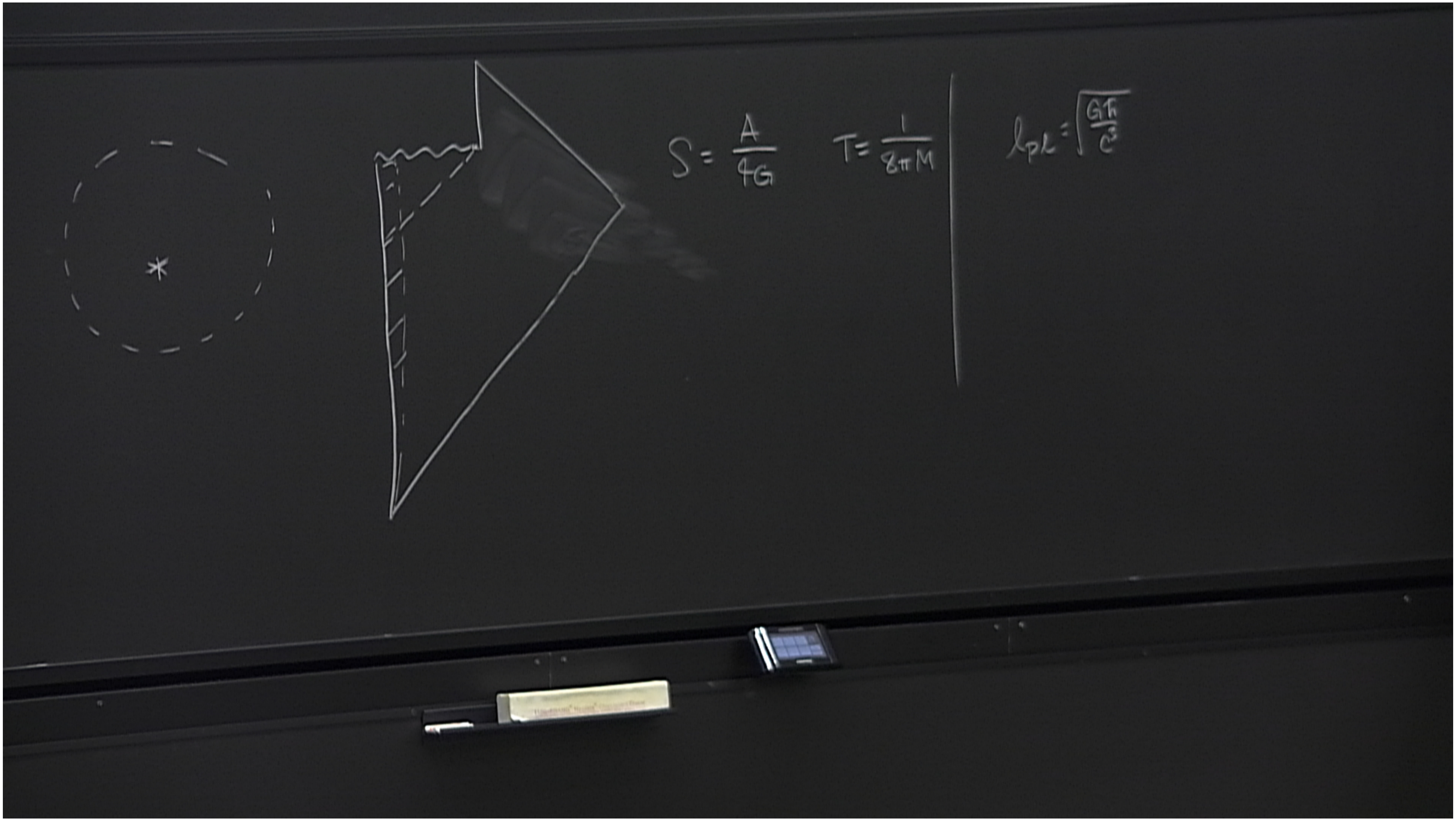
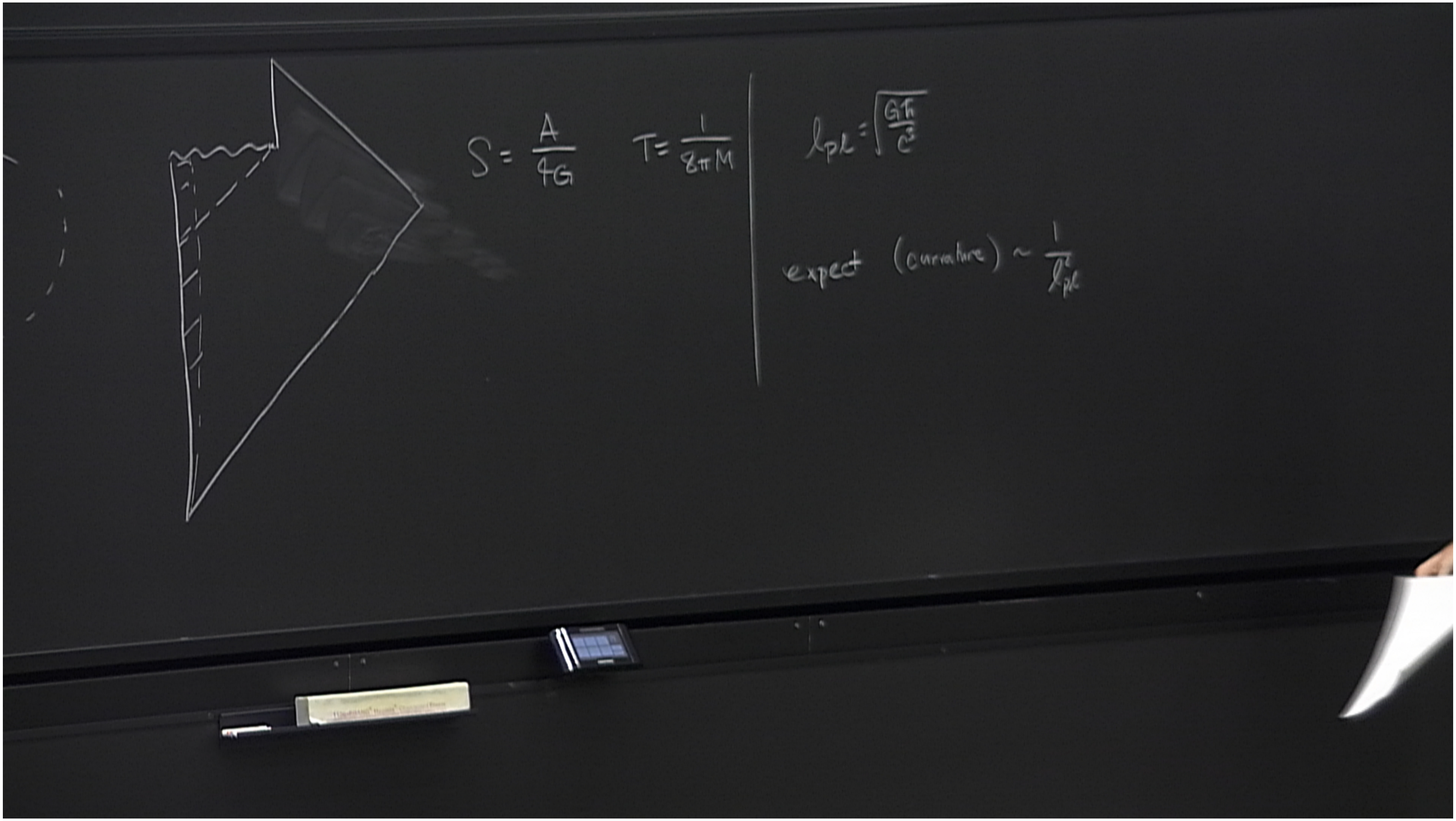
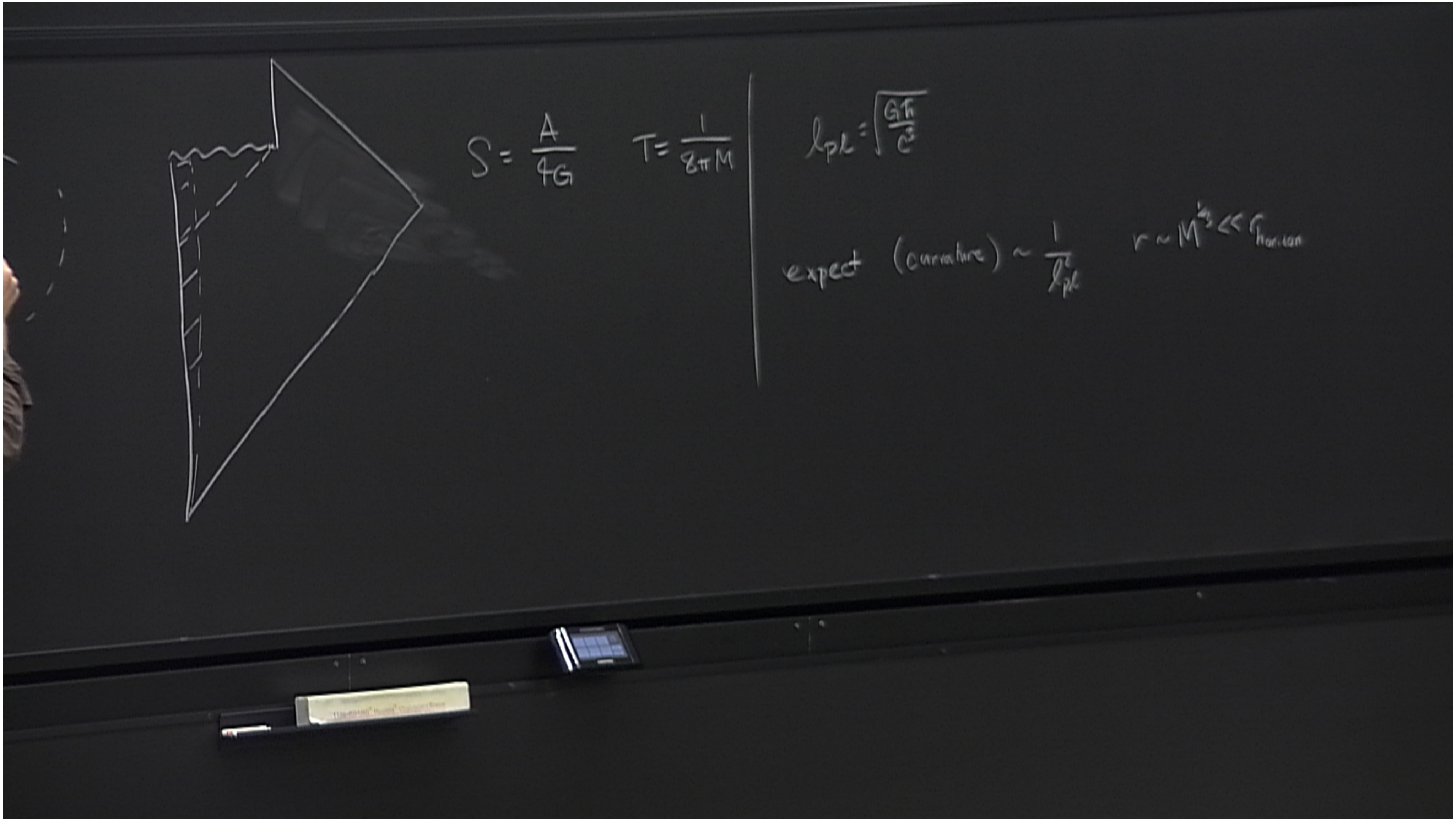
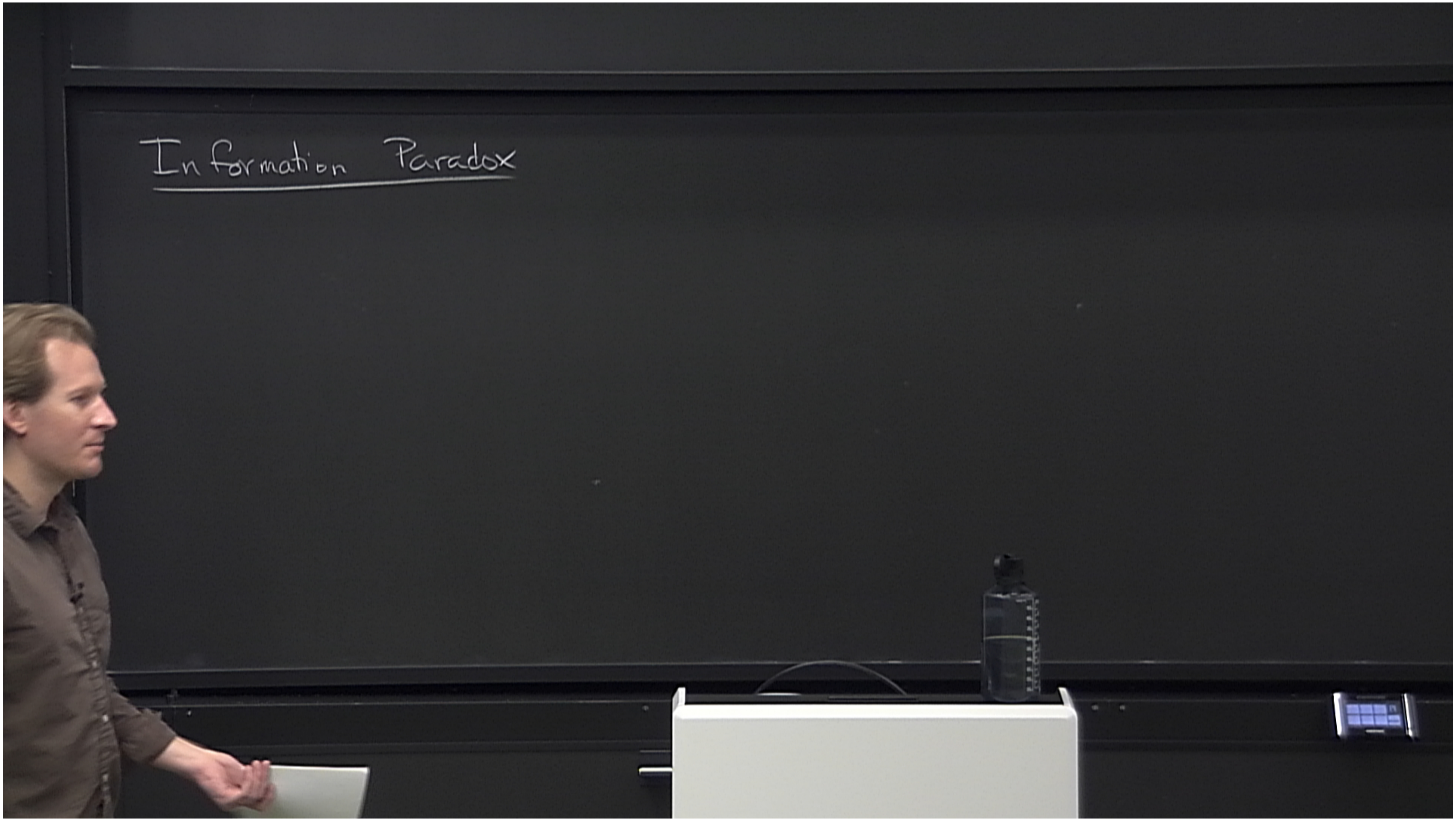
I. Introduction, Definition, and Abstract Motivations
II Fuzzballs in String Theory
III Open Questions and Problems

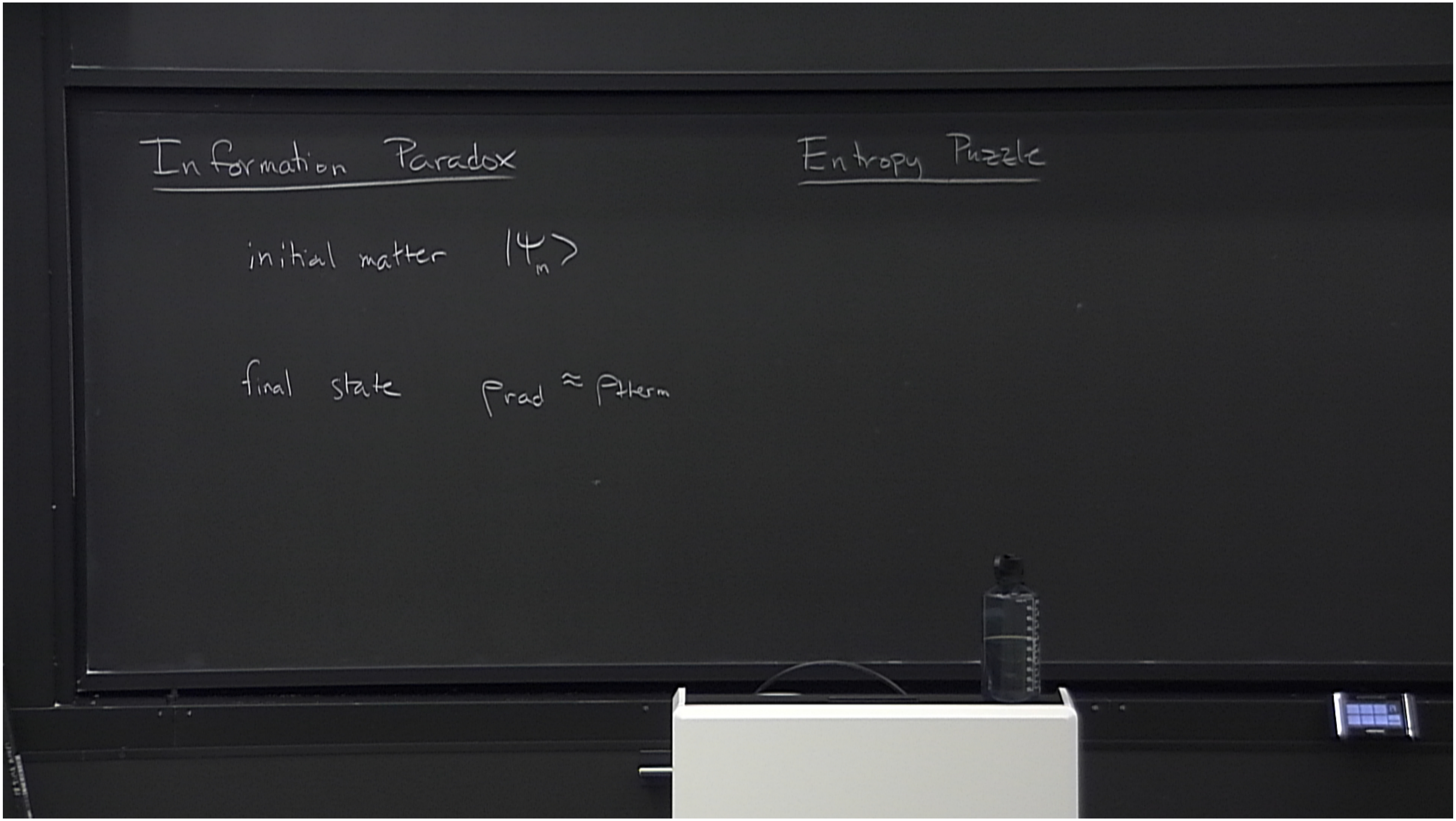

Schwarzschild (3+1)
r = 2GM
$\sqrt{(R_{\mu\nu\rho\lambda})^2} = \sqrt{48}\,\frac{GM}{r^3}$

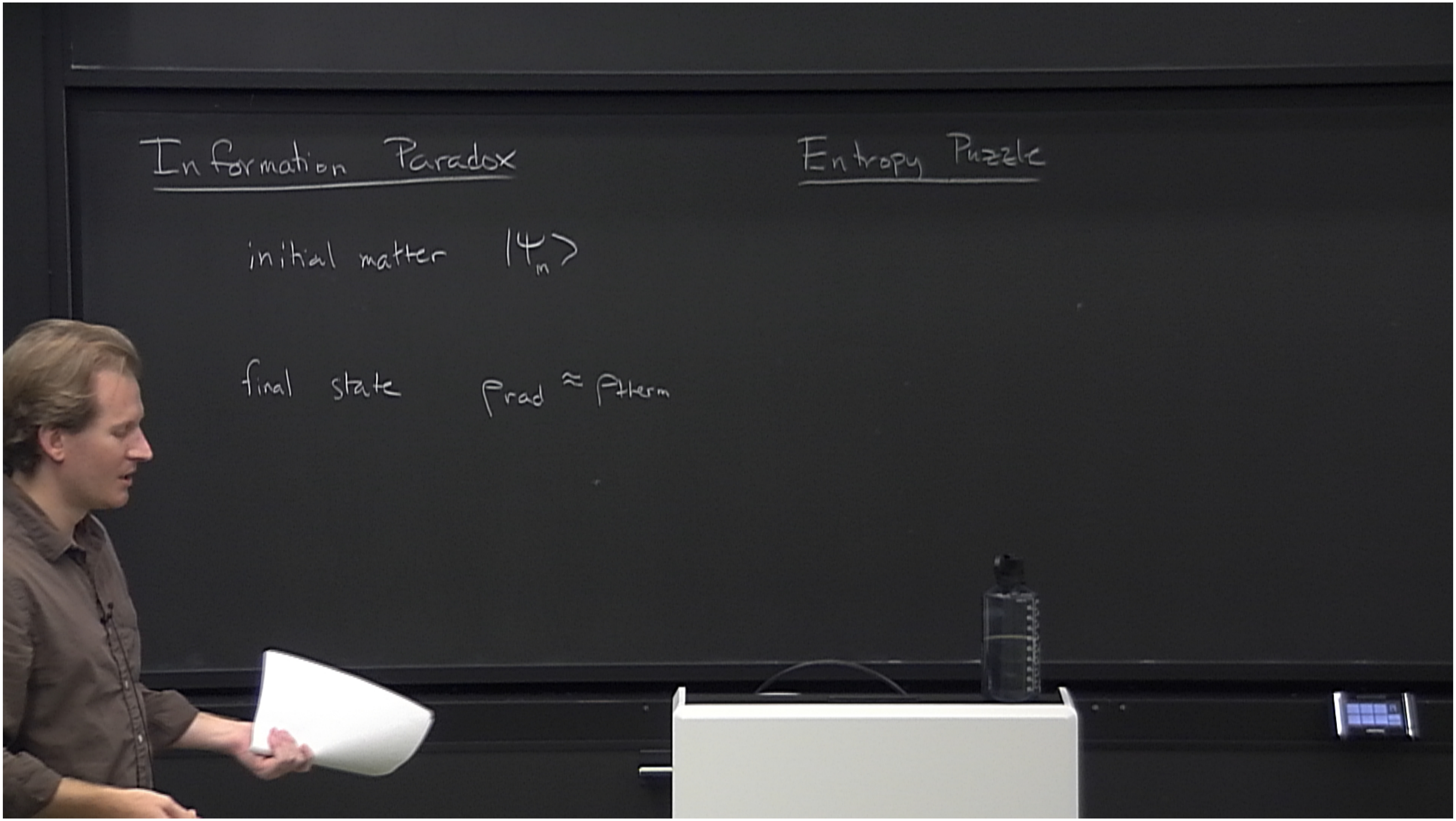

$S = \frac{A}{4G}$
$T = \frac{1}{8\pi M}$
$l_{pl} = \sqrt{\frac{G\hbar}{c^3}}$


$S = \frac{A}{4G}$
$T = \frac{1}{8\pi M}$
$l_{pl} = \sqrt{\frac{G\hbar}{c^3}}$
expect (curvature) $\sim \frac{1}{l_{pl}^2}$


S = A/4G
T = 1/8πM
l_pl = √(Għ/c³)
expect (curvature) ~ 1/l_pl²
r ~ M^(1/3) << r_horizon


Information Paradox


Information Paradox
initial matter $|\psi_m\rangle$
final state $\rho_{rad} \approx \rho_{therm}$
Entropy Puzzle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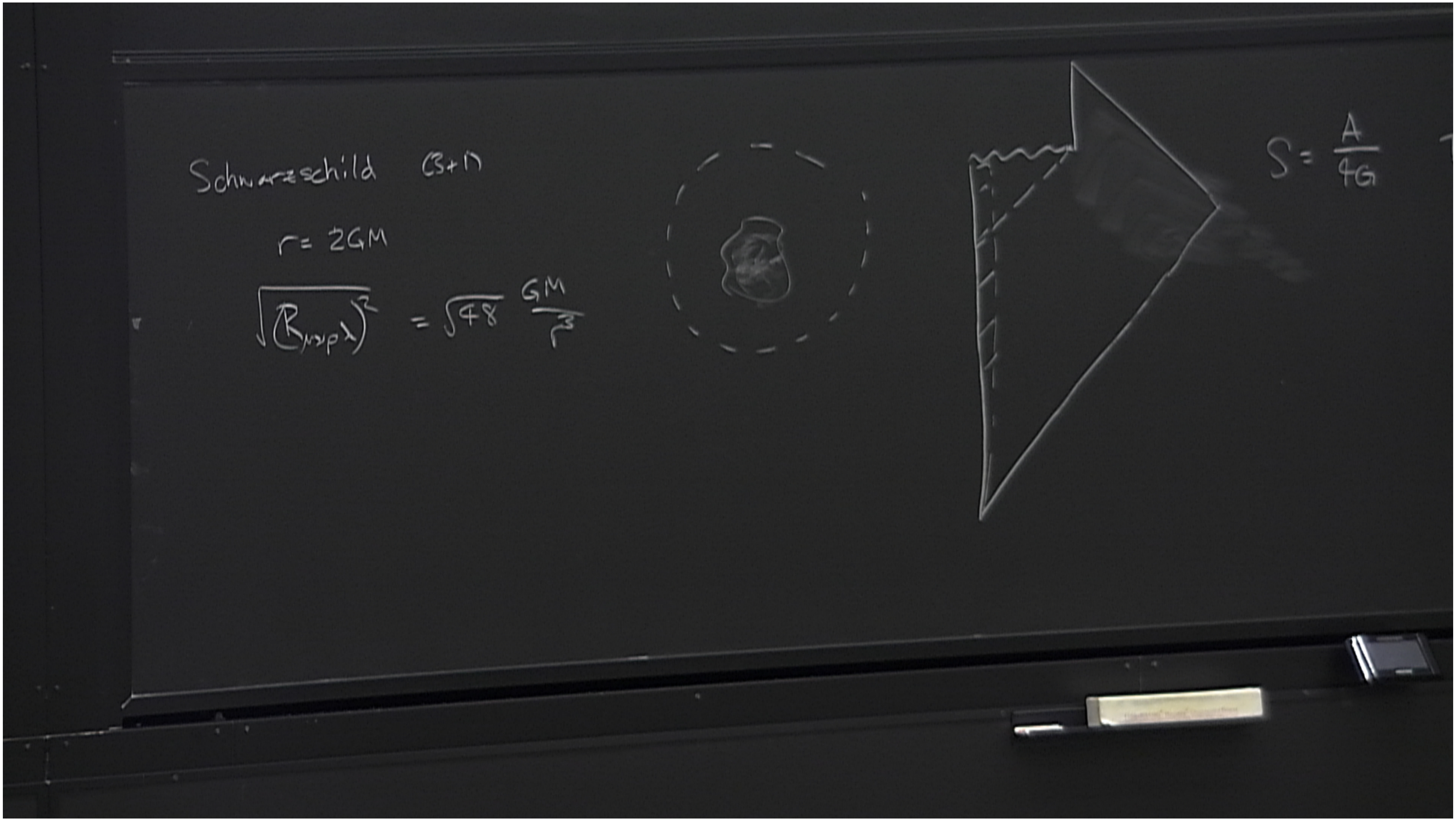
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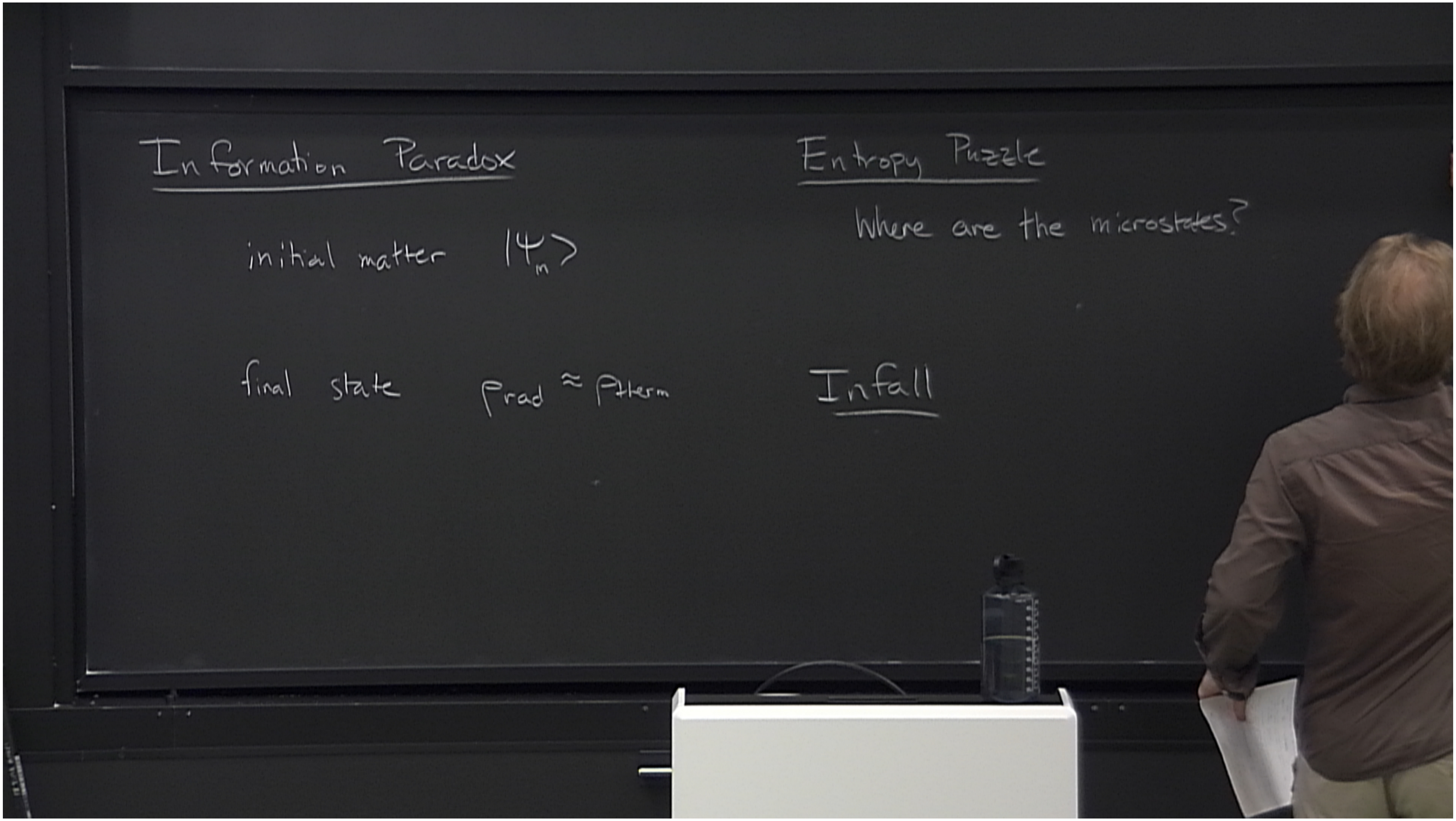
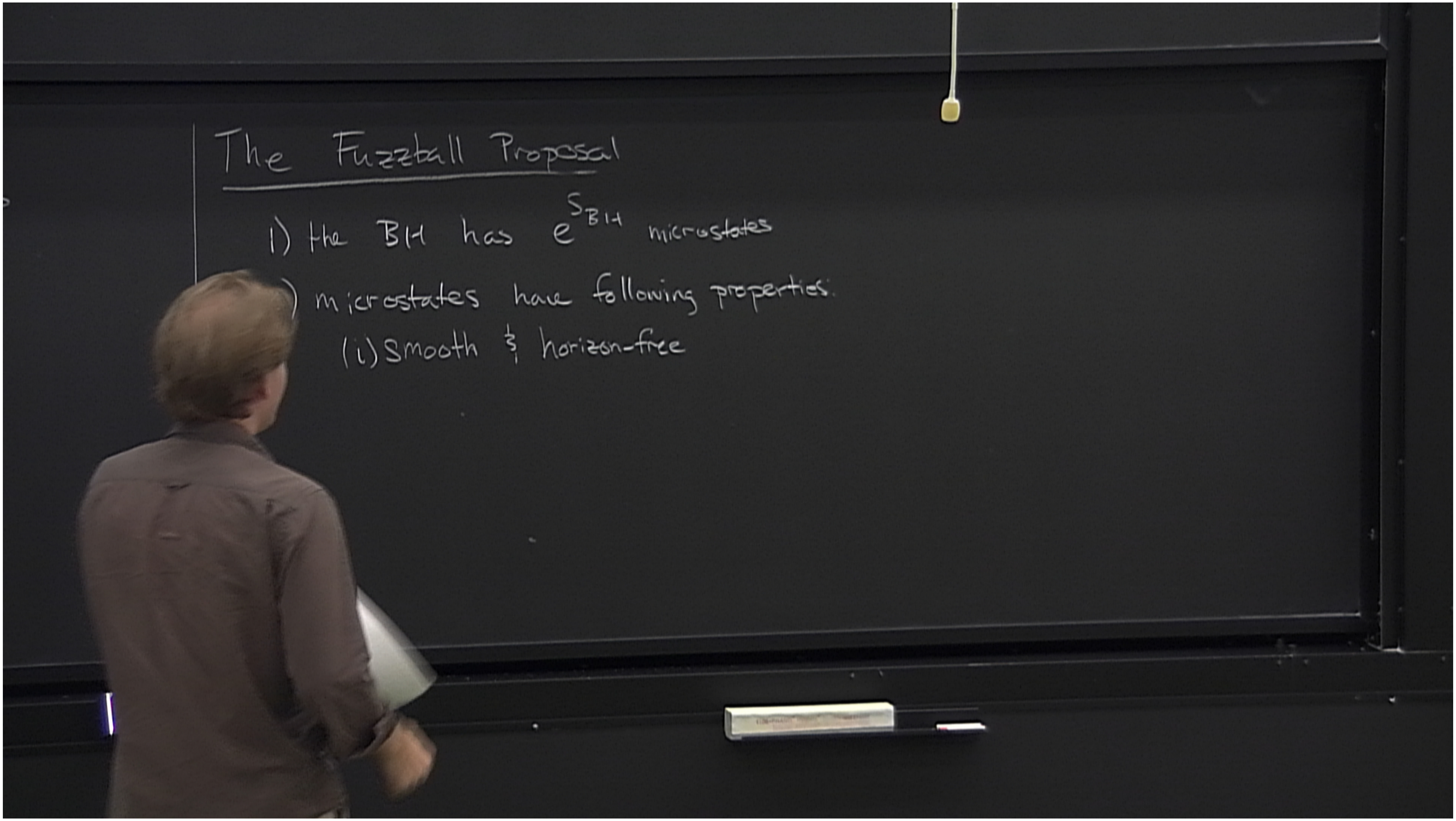
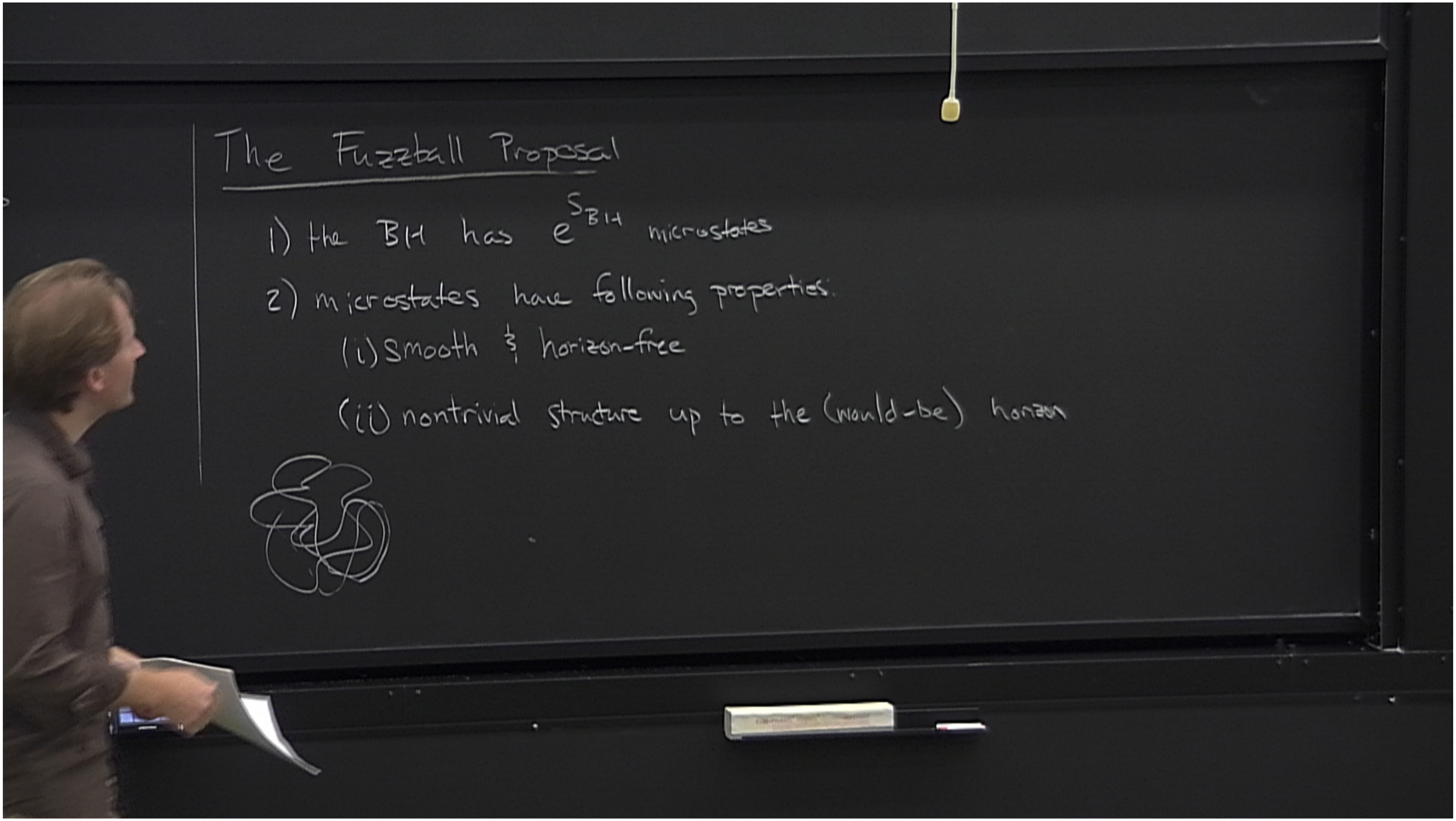
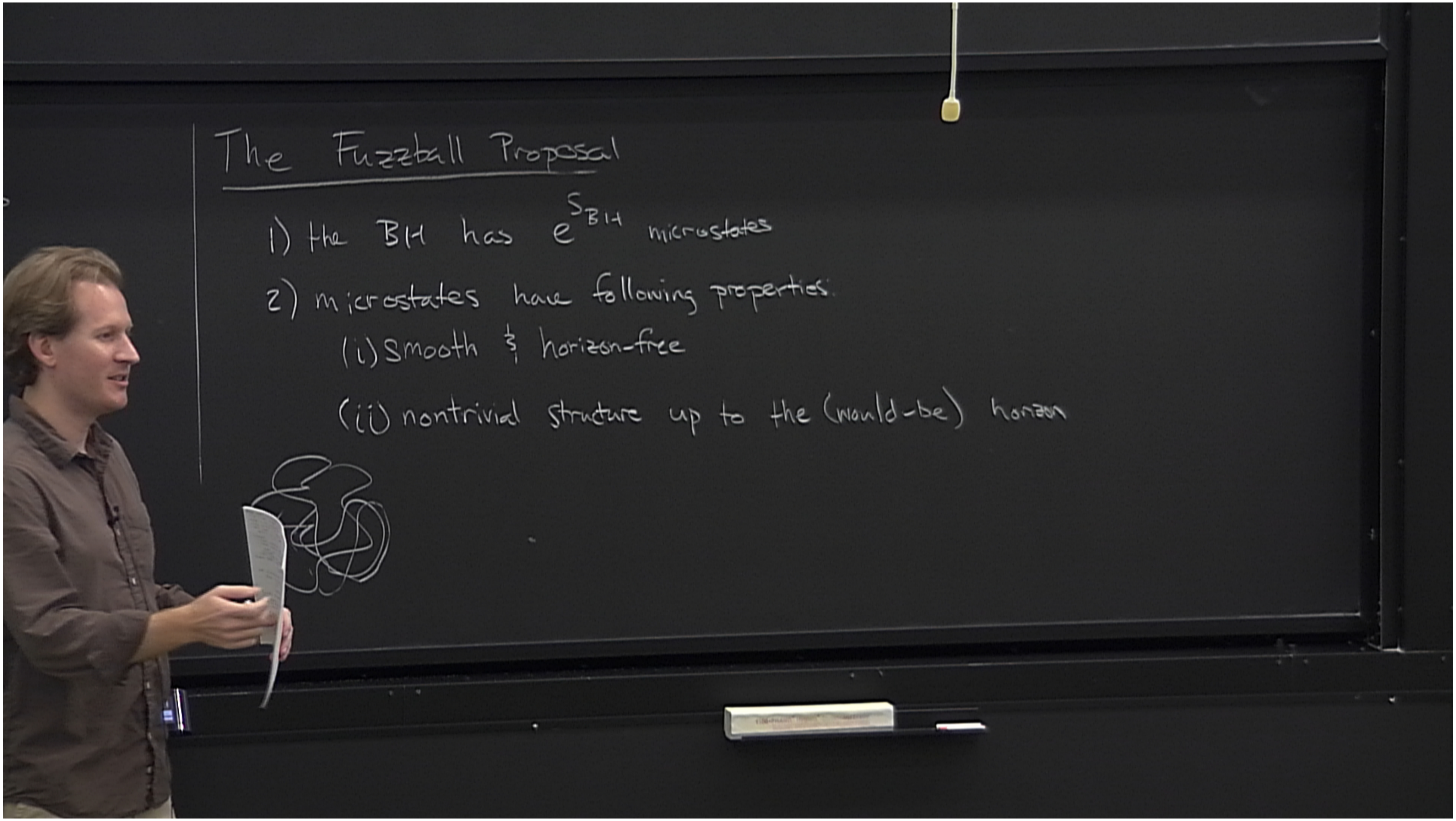

Information Paradox
initial matter $|\Psi_m\rangle$
final state $\rho_{rad} \approx \rho_{therm}$
Entropy Puzzle
Where are the microstates?
Infall


The Fuzzball Proposal
1) the BH has $e^{S_{BH}}$ microstates
) microstates have following properties:
(i) Smooth & horizon-free


The Fuzzball Proposal
1) the BH has $e^{S_{BH}}$ microstates
2) microstates have following properties:
(i) smooth & horizon-free
(ii) nontrivial structure up to the (would-be) horizon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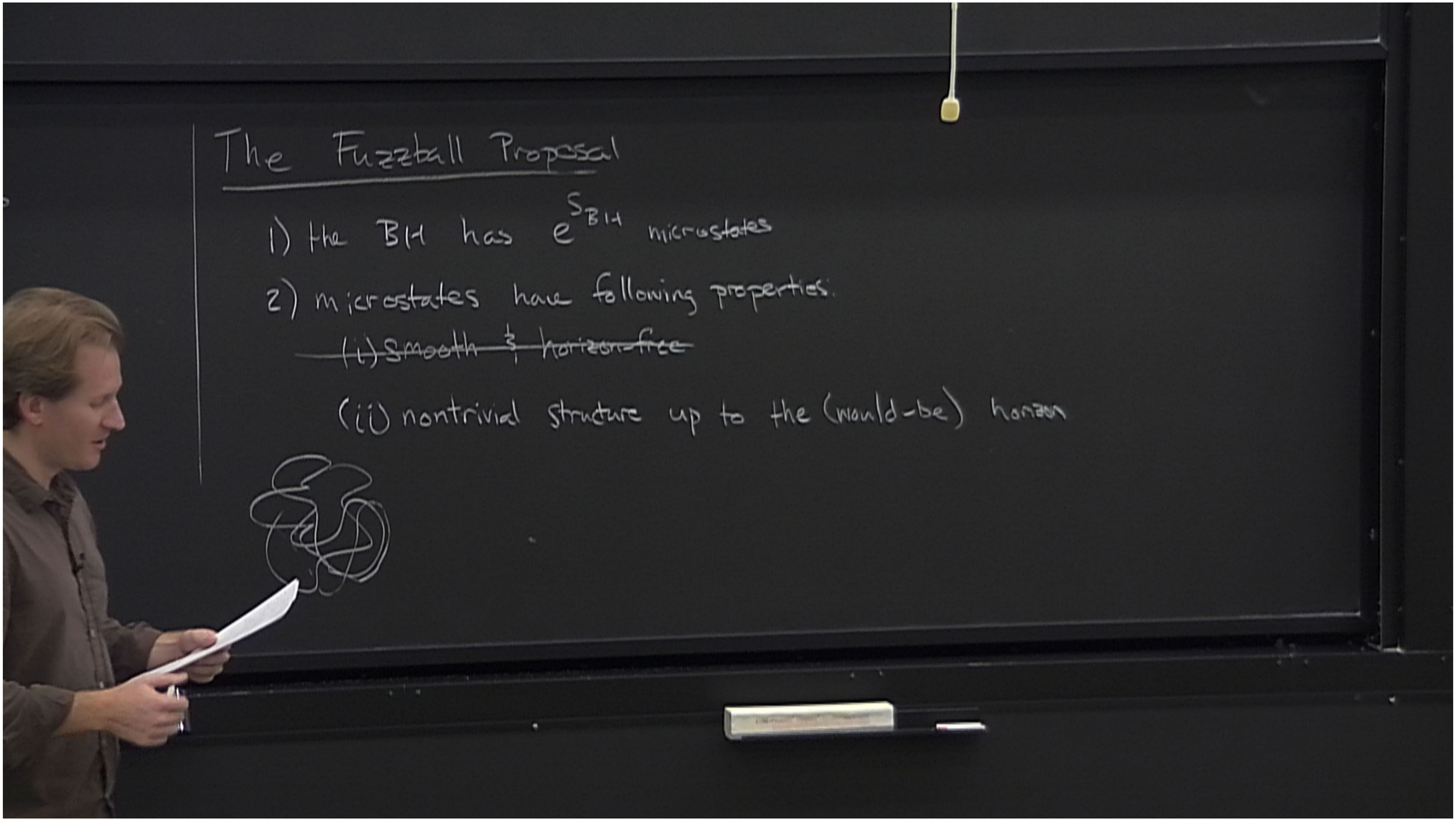
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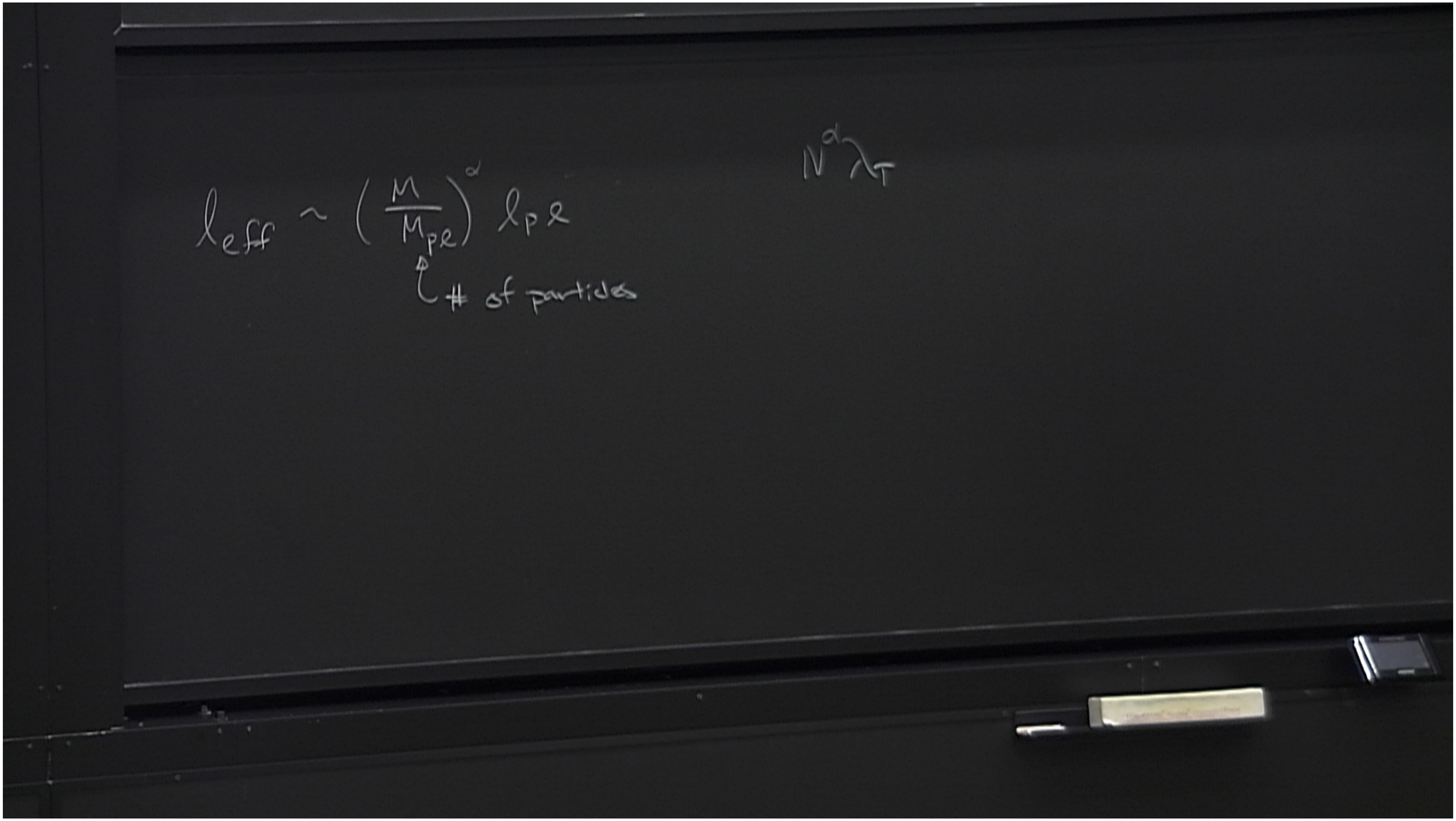
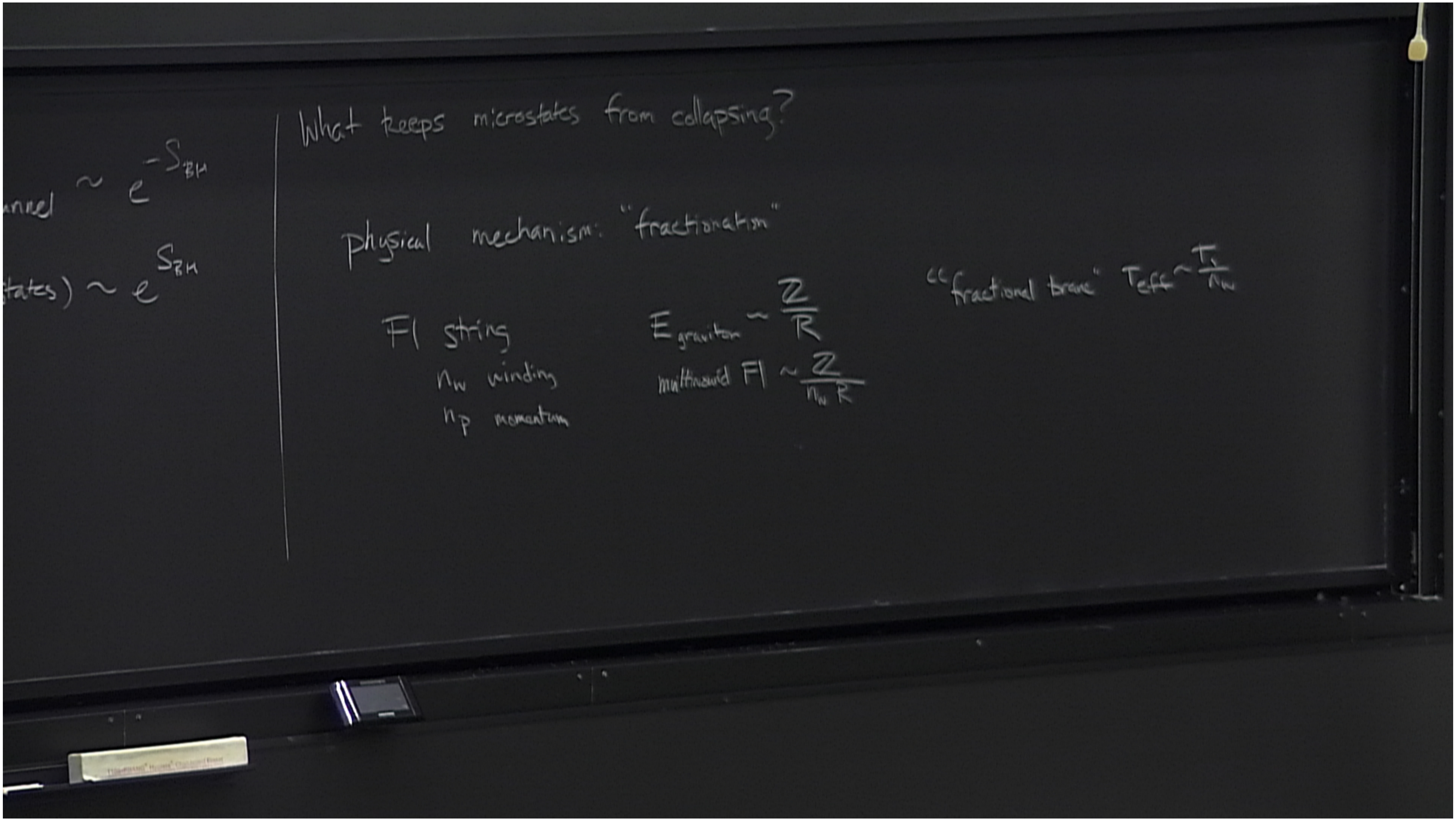
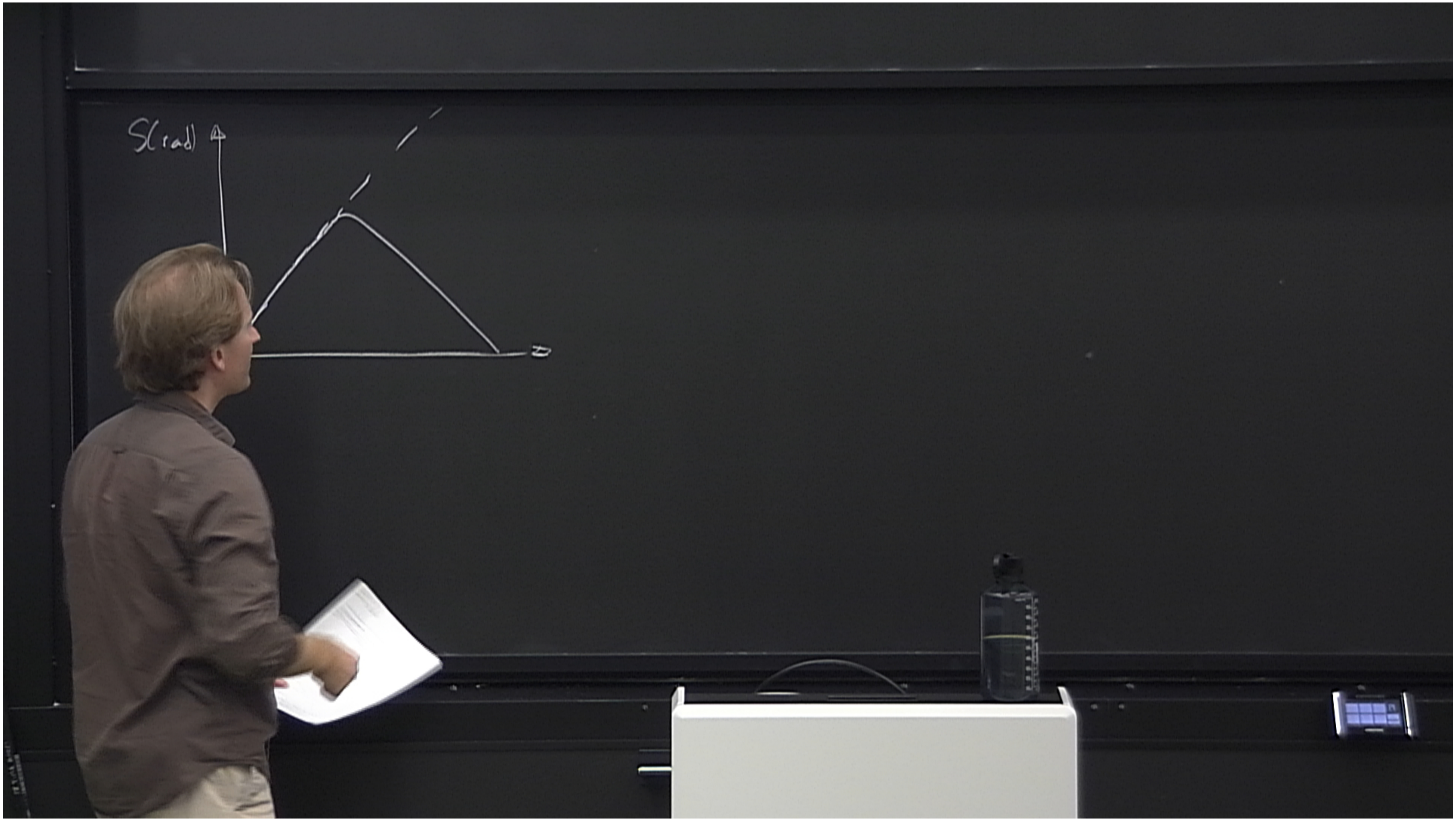
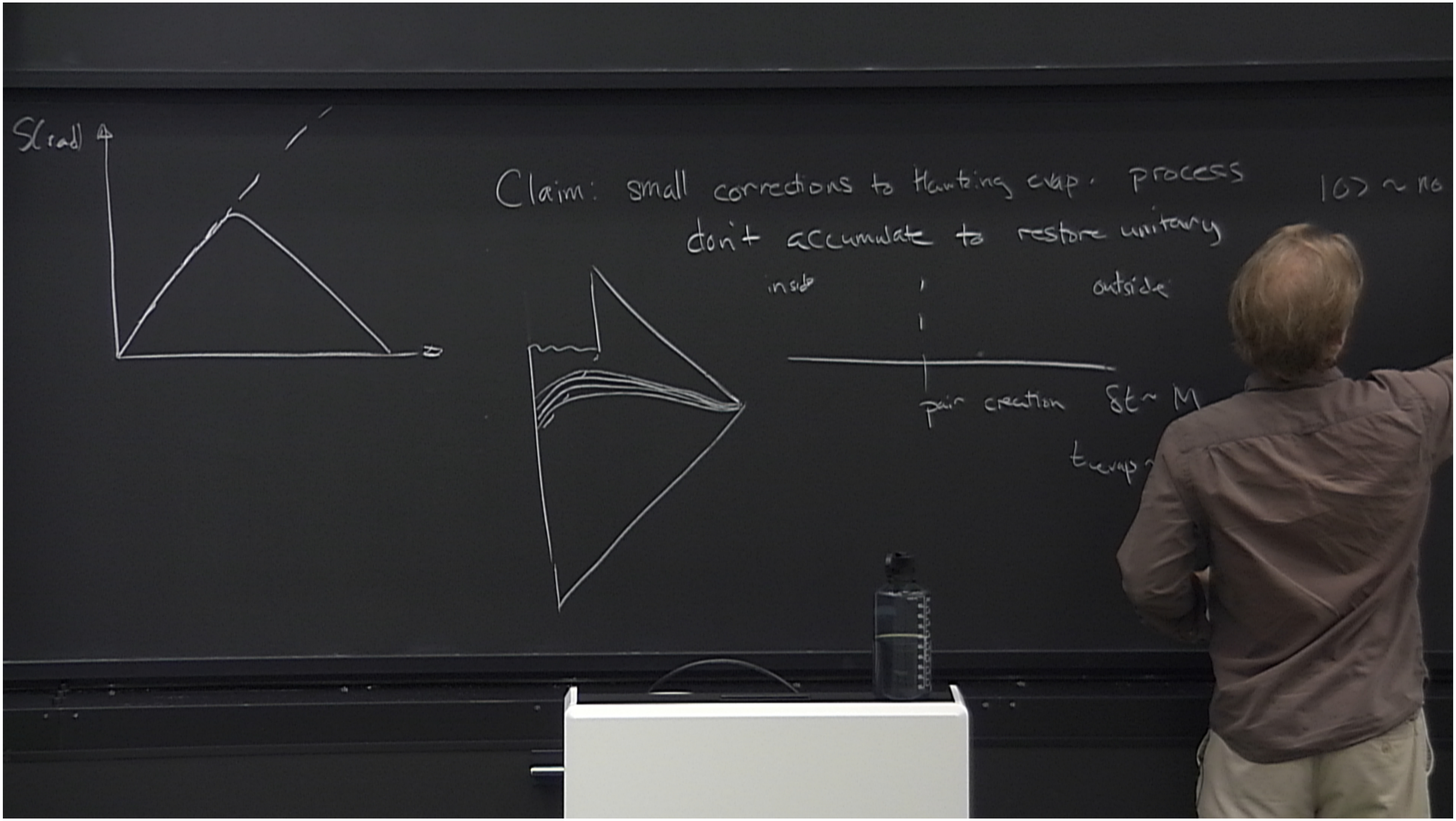
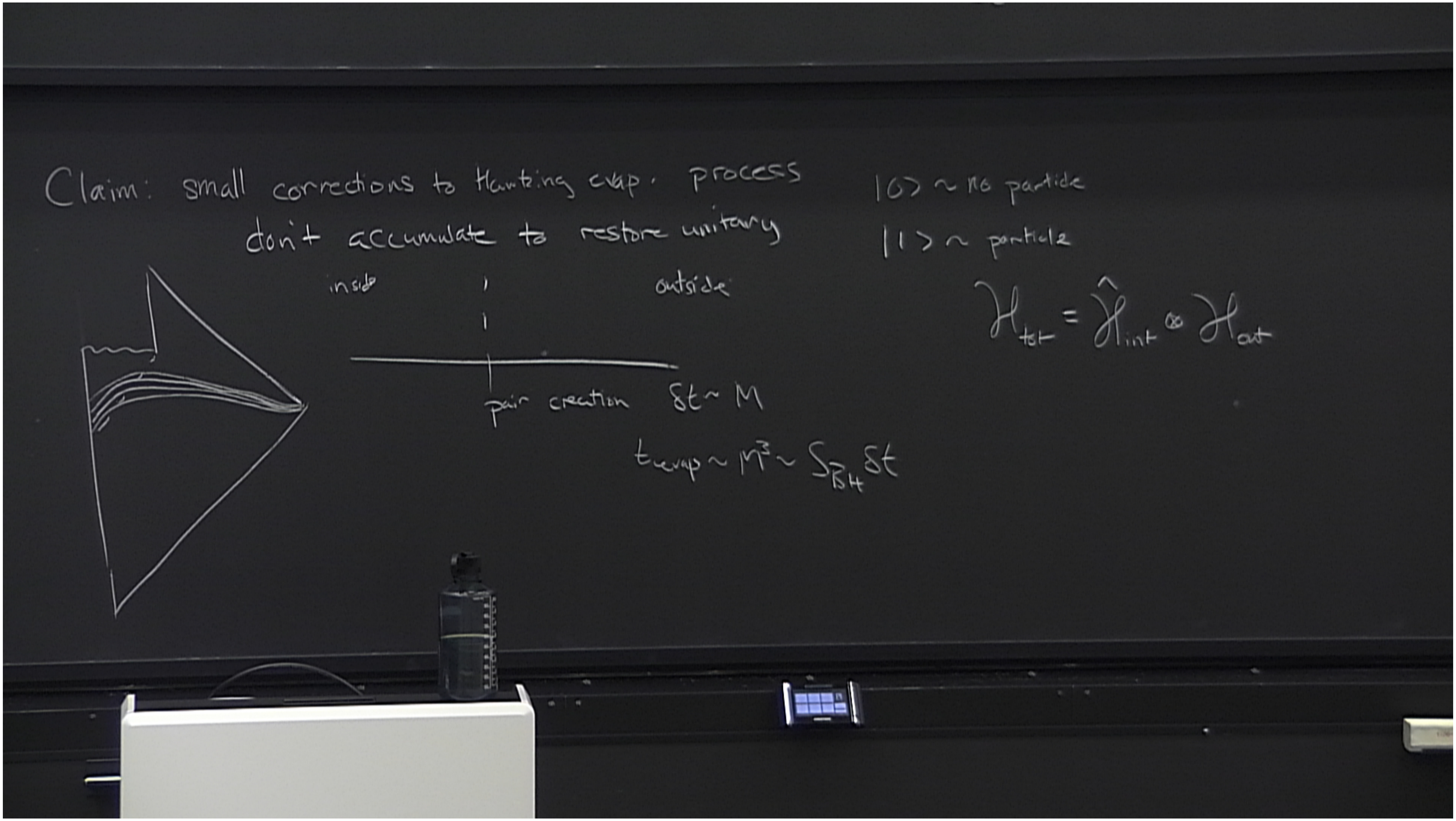
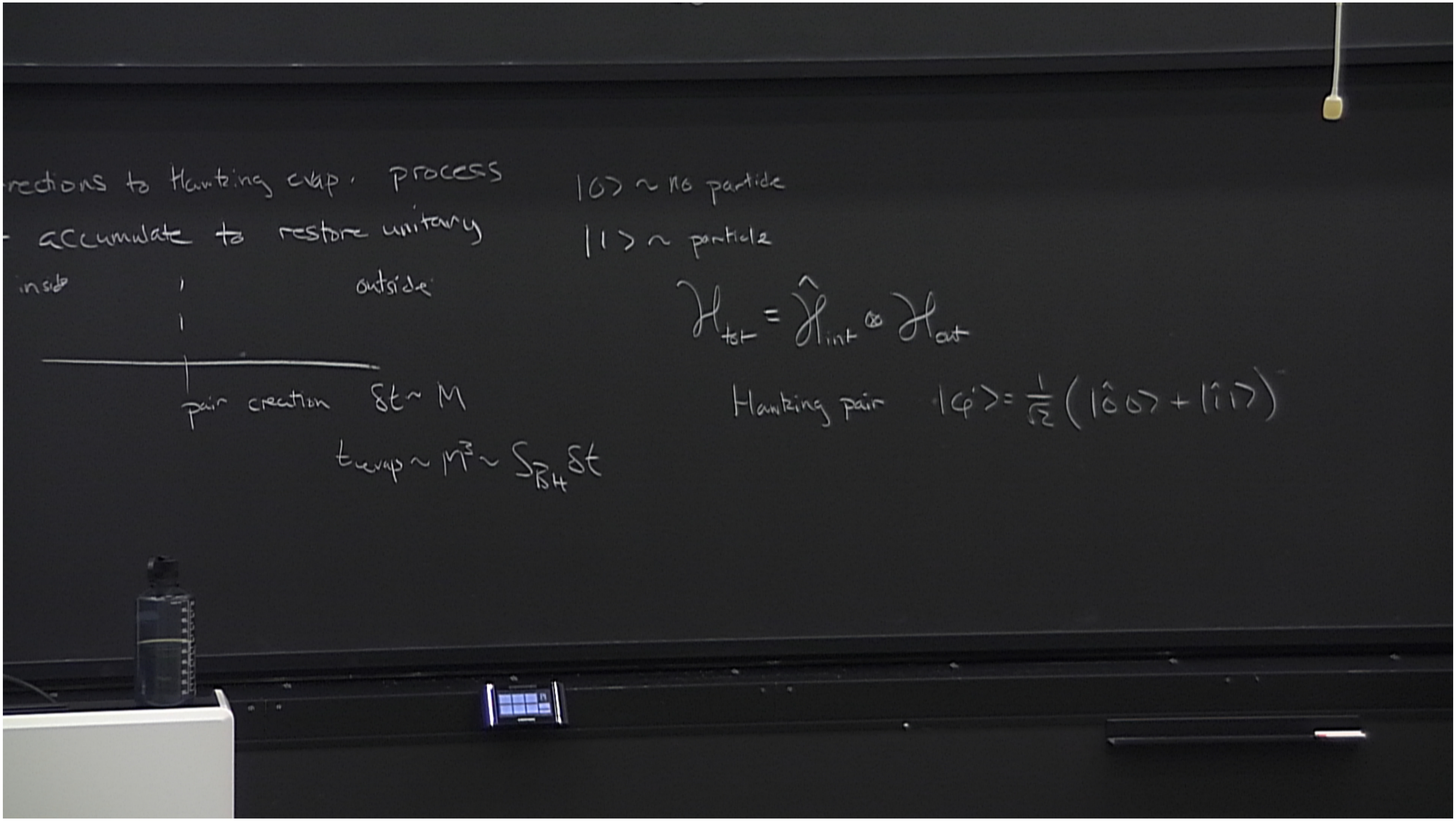

$l_{eff} \sim \left(\frac{M}{M_{pl}}\right)^{\alpha} l_{pl}$
# of particles
$N^{\alpha} \lambda_T$


What keeps microstates from collapsing?
physical mechanism: "fractionation"
F1 string
$n_w$ winding
$n_p$ momentum
$E_{graviton} \sim \frac{\mathbb{Z}}{R}$
multiwound F1 $\sim \frac{\mathbb{Z}}{n_w R}$
"fractional brane" $T_{eff} \sim \frac{T_1}{n_w}$


S(rad)


S(rad)
Claim: small corrections to Hawking evap. process
don't accumulate to restore unitary
inside
outside
pair creation
δt ~ M
|0⟩ ~ no


Claim: small corrections to Hawking evap. process
don't accumulate to restore unitary
inside
outside
pair creation δt ~ M
t_evap ~ M³ ~ S_BH δt
|0> ~ no particle
|1> ~ particle
H_tot = Ĥ_int ⊗ H_out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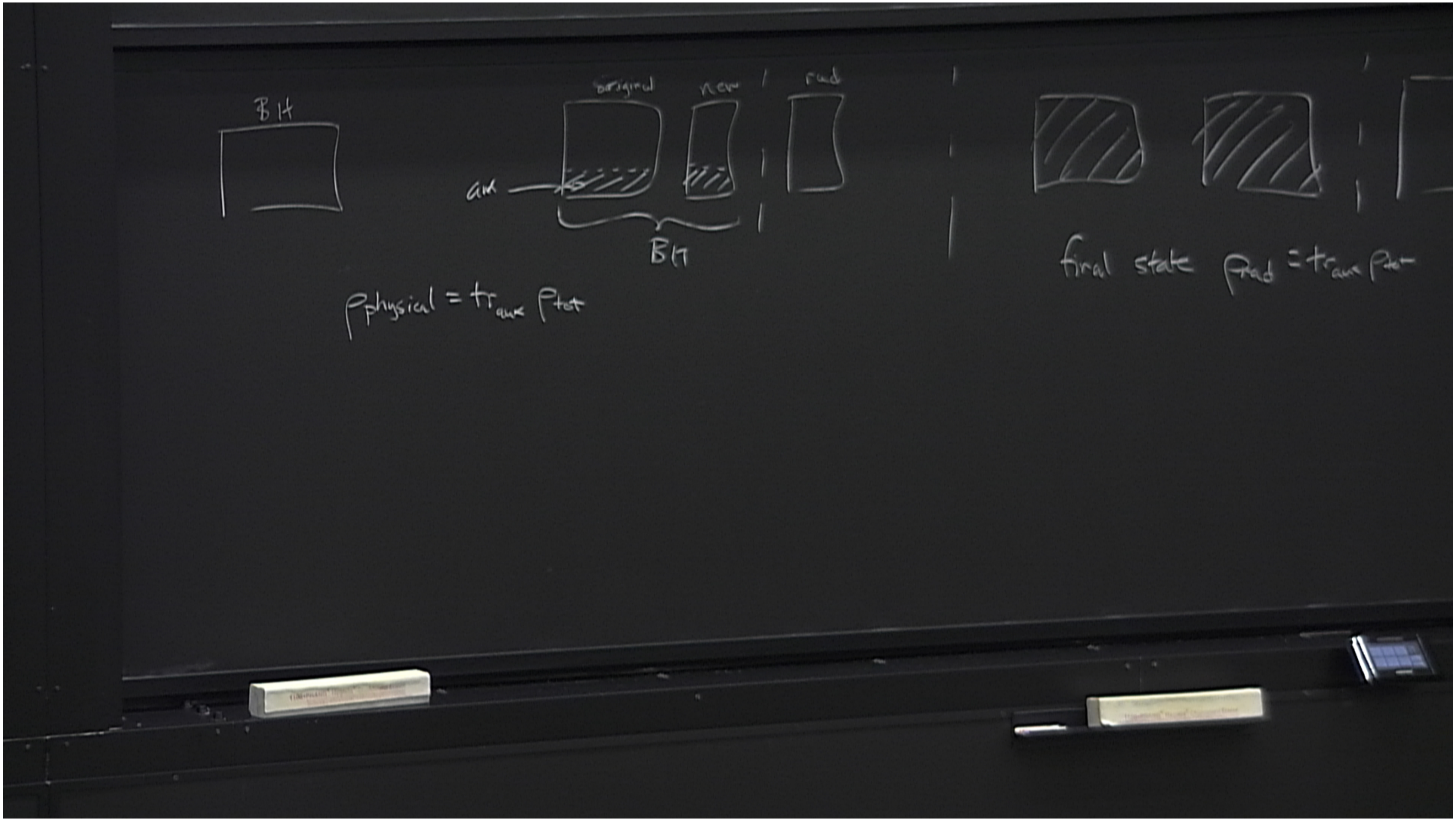
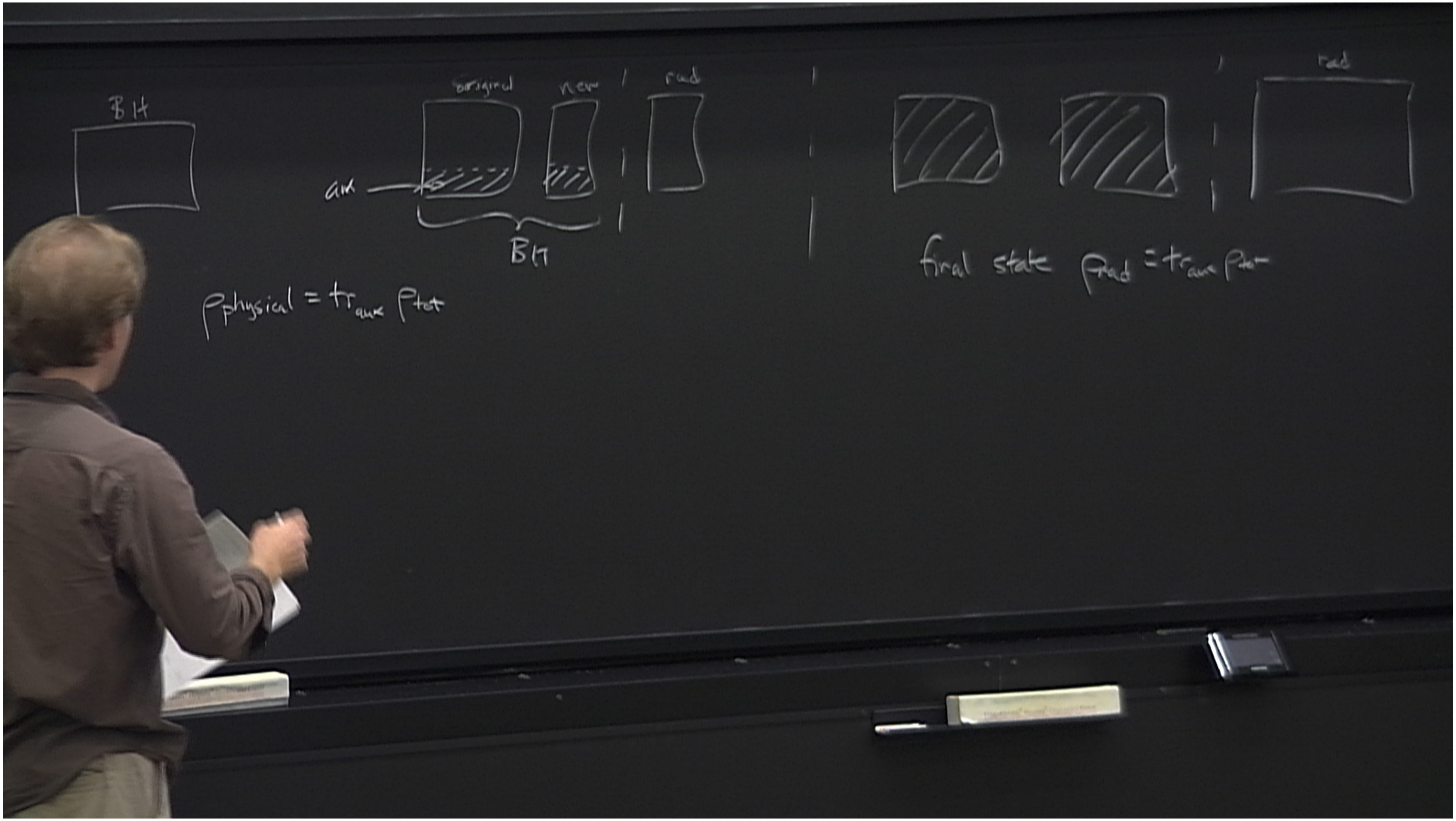
inside
outside
pair creation δt ~ M
t_evap ~ M^3 ~ S_BH δt
|0> ~ no particle
|1> ~ particle
H_tot = Ĥ_int ⊗ H_out
Hawking pair |φ> = 1/√2 (|0̂ 0> + |1̂ 1>)


BH
original
new
rad
aux
BH
ρphysical = tr aux ρtot
final state ρrad = tr aux ρtot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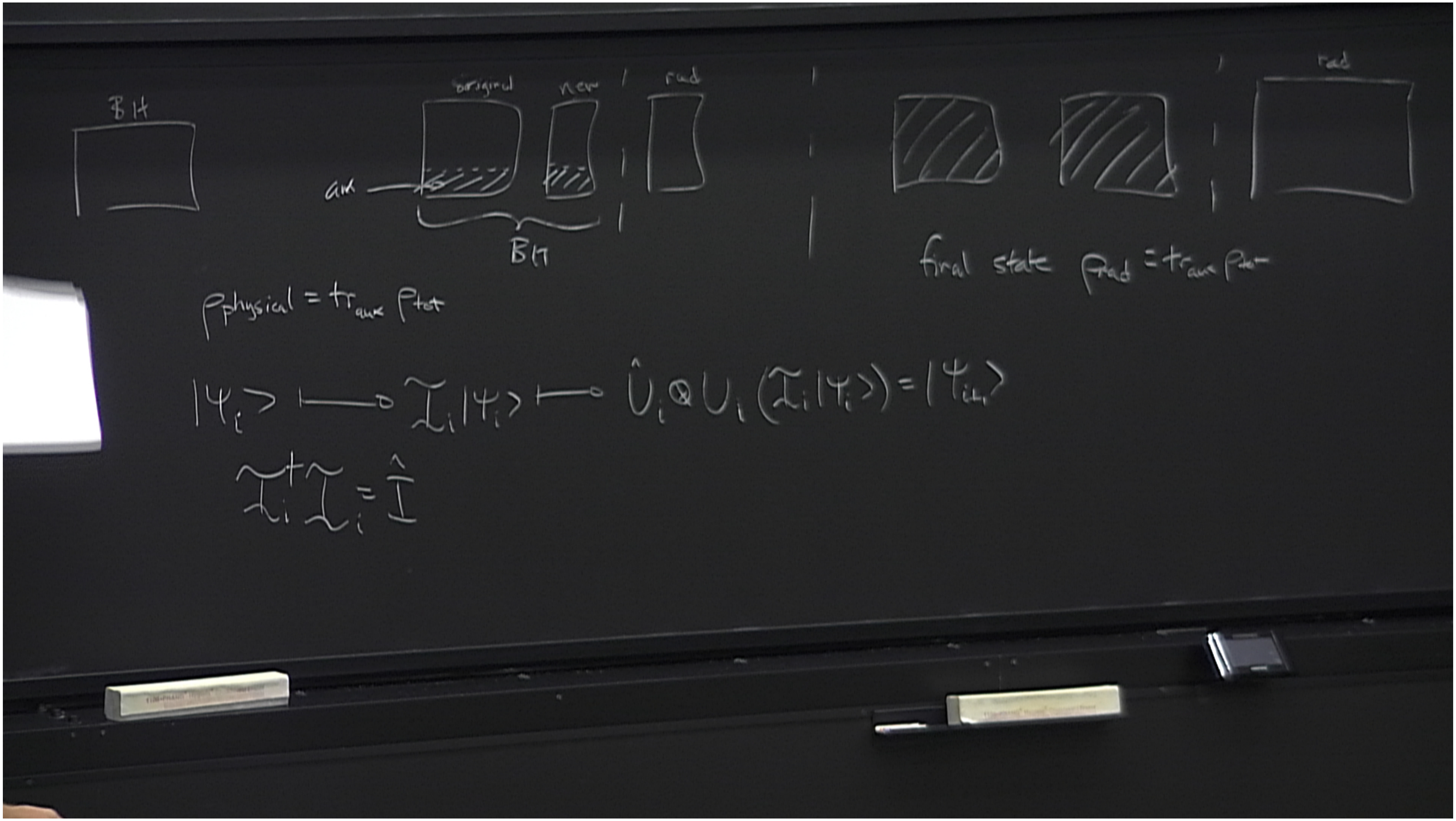
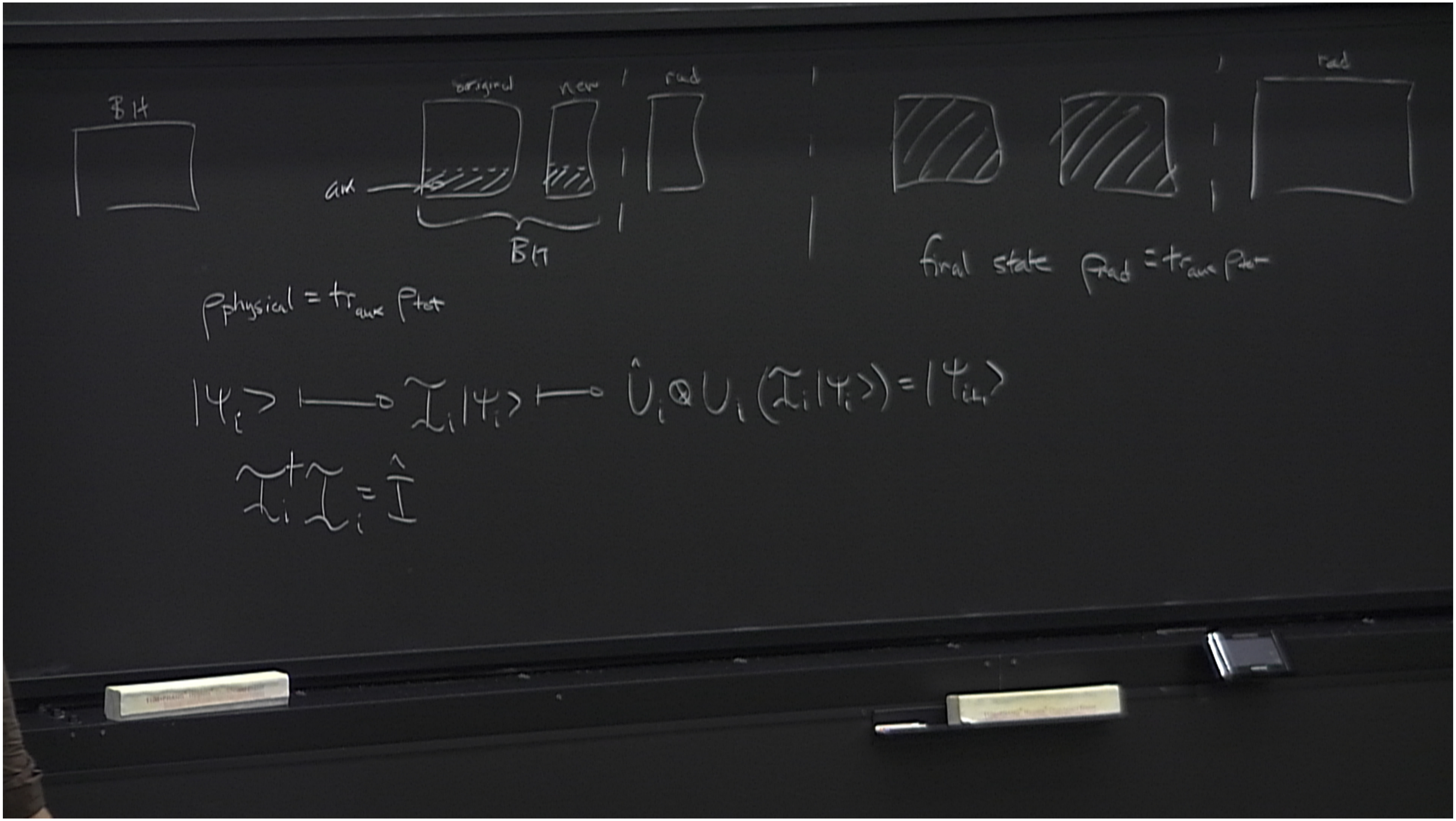

BH
original
new
rad
aux
BH
rad
final state ρrad = traux ρtot
ρphysical = traux ρtot
|ψi⟩ ⟼ Ĩi|ψi⟩ ⟼ Ûi ⊗ Ui (Ĩi|ψi⟩) = |ψi,f⟩
Ĩi† Ĩi = Î


BH
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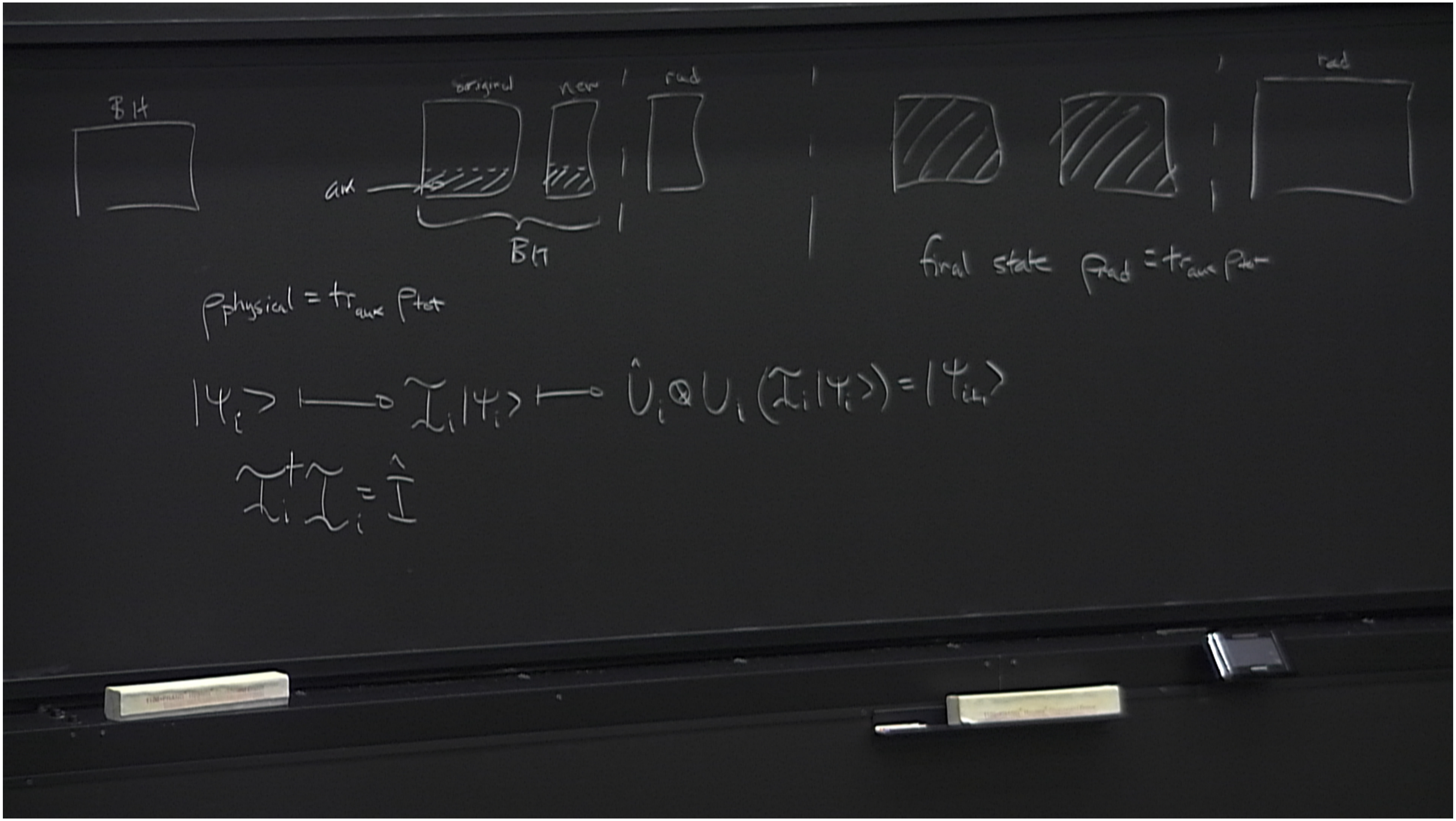
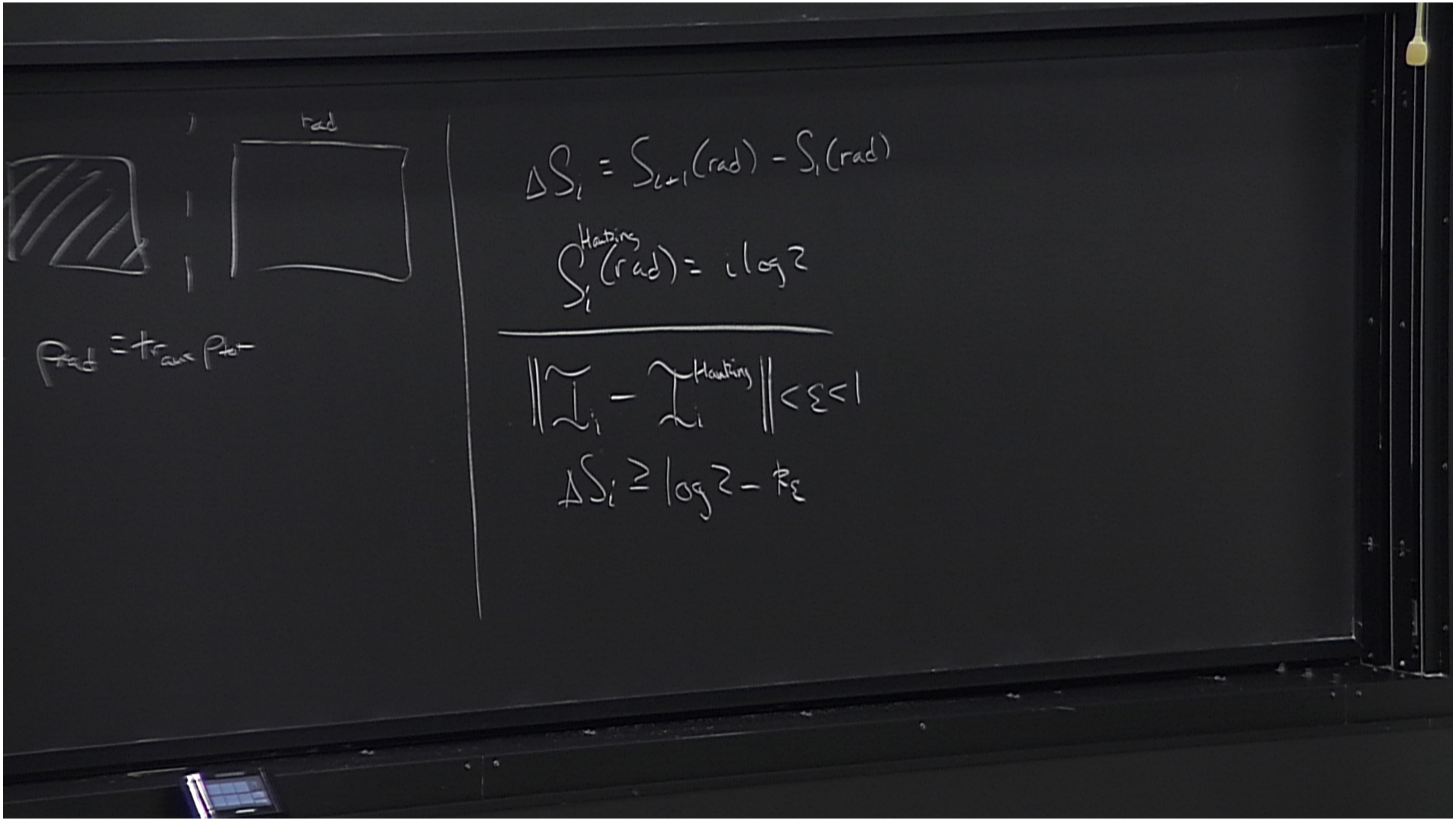
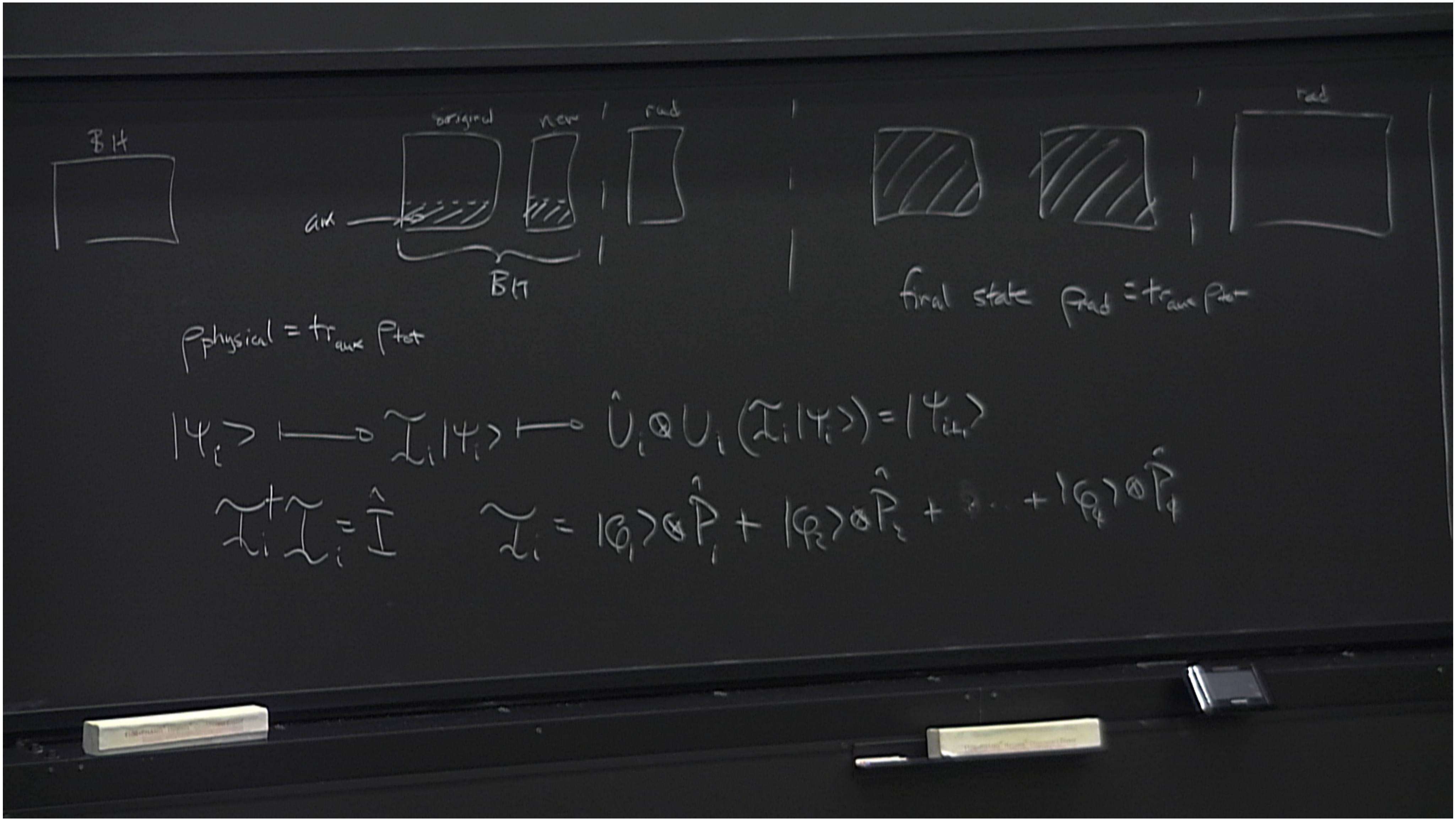
new
rad
aux
BH
rad
final state ρrad = tr aux ρtot
ρphysical = tr aux ρtot
|ψi> ⟼ Ii|ψi> ⟼ Ûi ⊗ Ui (Ii|ψi>) = |ψi+1>
Ii† Ii = Î



BH
original
new
rad
aux
BH
rad
final state $\rho_{rad} = tr_{aux}\, \rho_{tot}$
$\rho_{physical} = tr_{aux}\, \rho_{tot}$
$|\psi_i\rangle \longmapsto \mathcal{I}_i|\psi_i\rangle \longmapsto \hat{U}_i \otimes U_i (\mathcal{I}_i|\psi_i\rangle) = |\psi_{i+1}\rangle$
$\mathcal{I}_i^\dagger \mathcal{I}_i = \hat{I}$


rad
ρrad = tr aux ρtot
ΔSi = Si+1(rad) − Si(rad)
Si Hawking(rad) = i log 2
||Σi − Σi Hawking|| < ε < 1
ΔSi ≥ log 2 − kε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