Title: Special Topics in Physics - Lecture 9A

Date: Mar 12, 2008 07:00 PM

URL: http://pirsa.org/08030020

Abstract: The Problem of Time in Quantum Gravity and Cosmology

Compact (spatially) $M^4 \simeq \Sigma^3 \times R$

$\partial \Sigma^3 = 0$

Compact (spatially) $M^4 = \Sigma^3 \times R$

$\partial \Sigma^3 = 0$

gauge : $\mathrm{Diff}(M)$

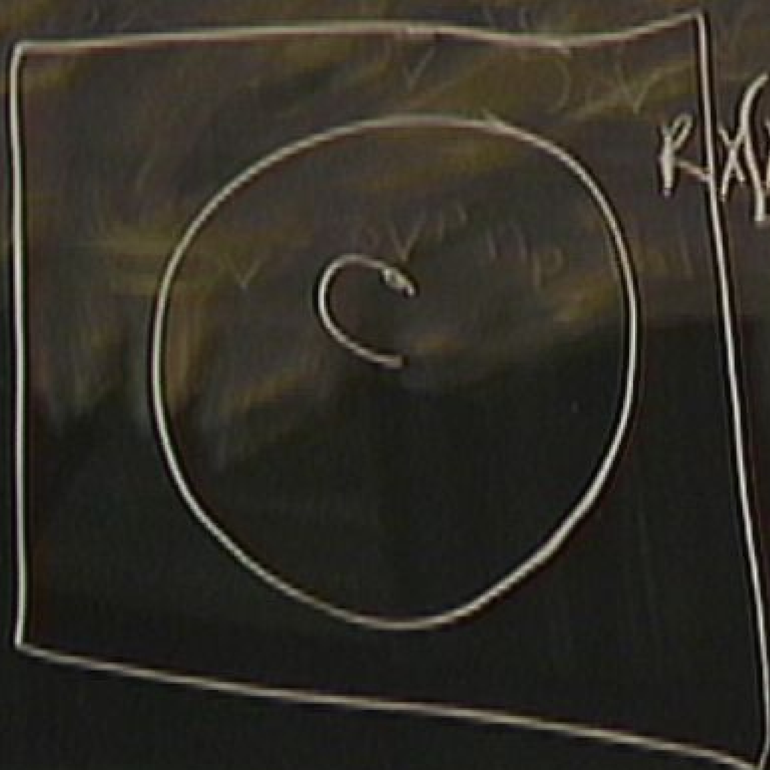
A.F.

$$= \Sigma \times R$$

$$\partial \Sigma^3 = 0$$

$$\Sigma^3 = R^3$$

gauge : $\mathrm{Diff}(\mathcal{M})$



$\Sigma^3 = R^3$

$R \times [R^3 - C]$ choose flat metric

$\eta_{\mu\nu}$ & coordinates

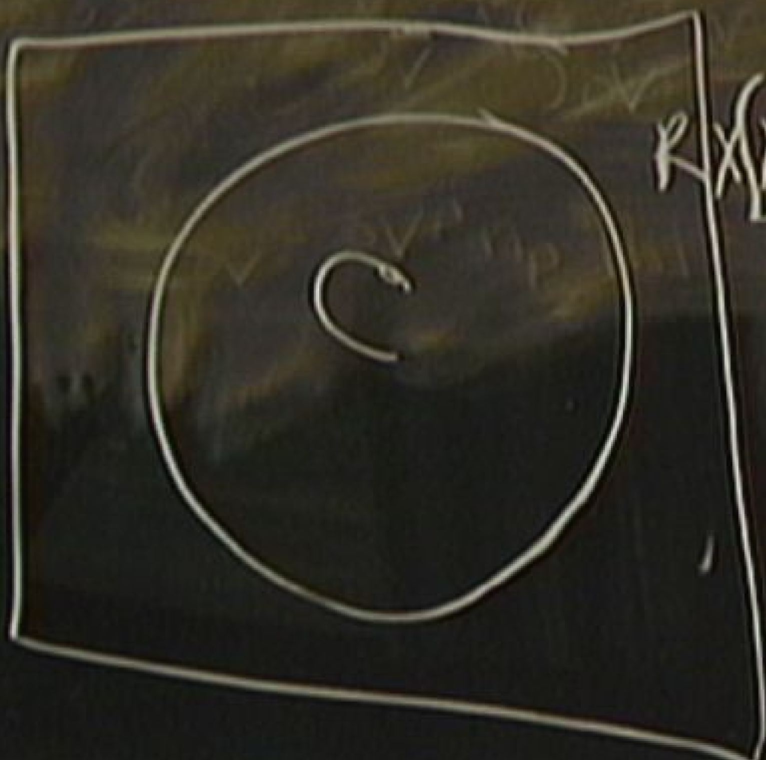
$$ds^2 = dt^2 - dx^2 - dy - dz^2$$

ct (spatially) $M^4 = \Sigma^3 \times R$

$\partial \Sigma^3 = 0$

gauge : $\mathrm{Diff}(M)$

$\Sigma^3 = R^3$



$R \times (R^3 - C)$ } choose flat metric $\eta_{\mu\nu}$ & coordinates

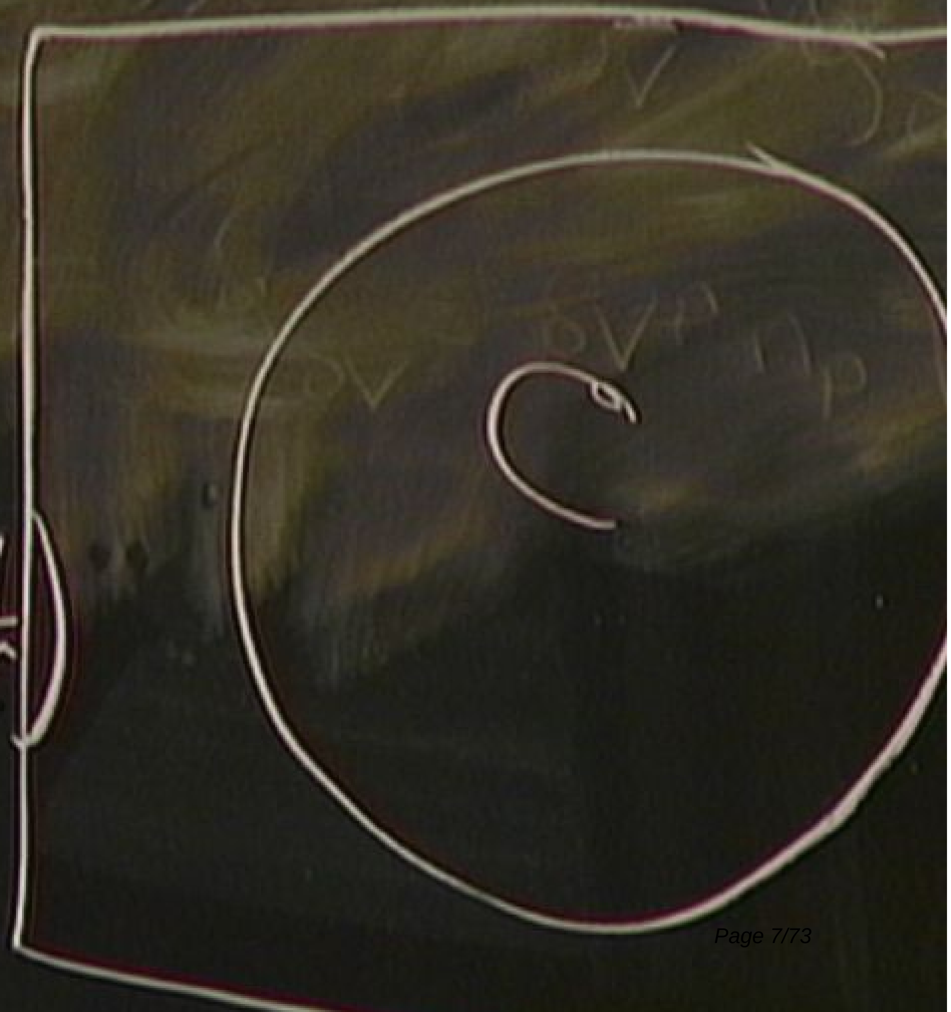
$$ds^2 = dt^2 - dx^2 - dy - dz^2$$

$$dr^2 = dx^2 + dy^2 + dz^2$$

gauge : Diff

$g_{\mu\nu}$ is A.F. if on $R^3 - \mathcal{C}$

$$g_{\mu\nu} = \eta_{\mu\nu} + O\left(\frac{1}{r}\right)$$

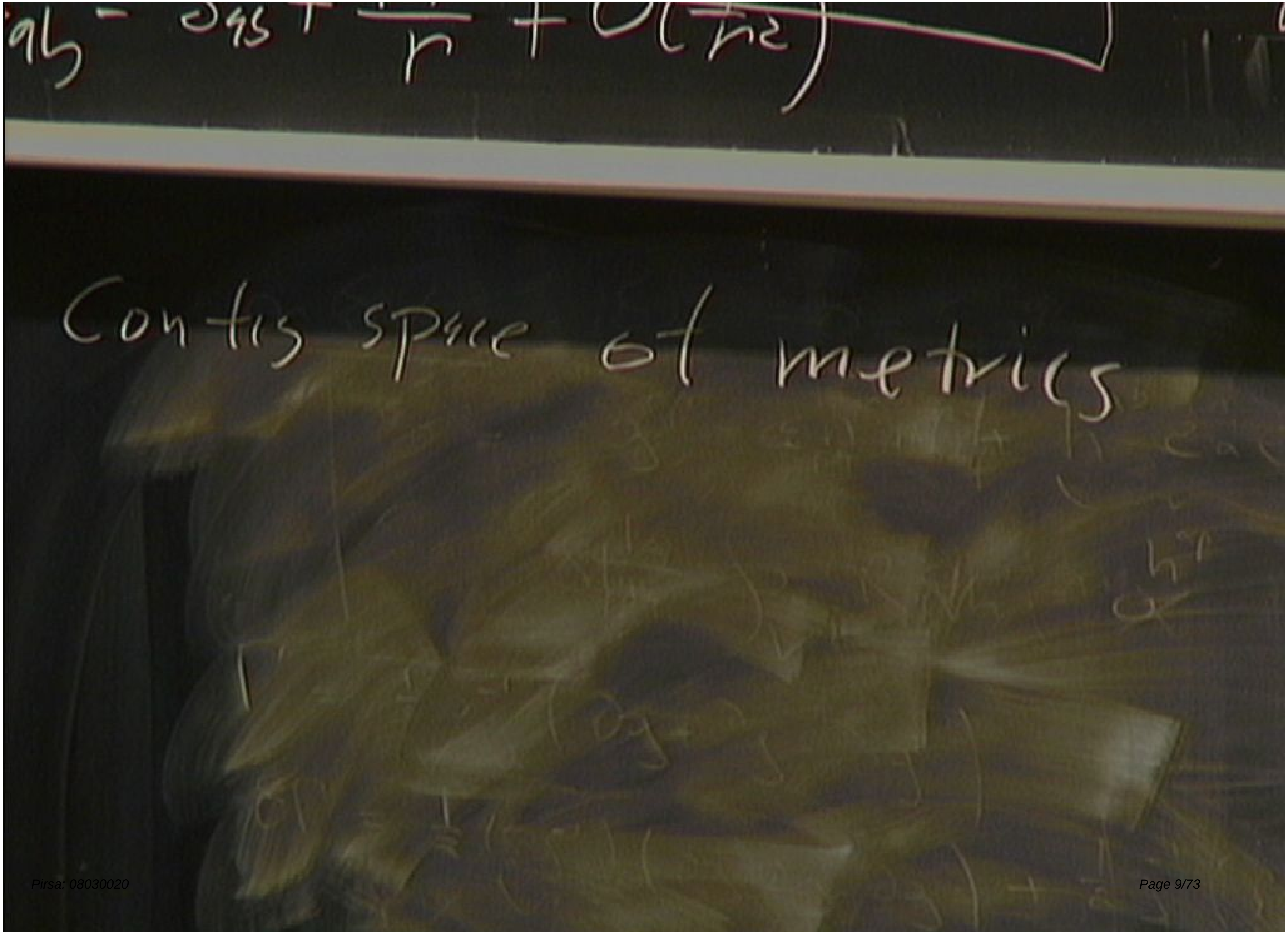


$g_{\mu\nu}$ is A.F. if on $R^3 - \hat{C}$

$$g_{\mu\nu} = \eta_{\mu\nu} + O\left(\frac{1}{r}\right)$$

$$q_{ab} = \delta_{ab} + \frac{M}{r} + O\left(\frac{1}{r^2}\right)$$

$\hat{C}$


Contis space of metrics

Con tis space of metrics

$$|g_{\mu\nu} - \eta_{\mu\nu}| < \frac{c}{r}$$

$$\phi = \delta_{as} + \frac{M}{r} + O\left(\frac{1}{r^2}\right)$$

$$dr^2 = dx^2 + d$$

Contis space of metrics

$$|g_{\mu\nu} - \eta_{\mu\nu}| < \frac{c}{r}$$

gauge group

$\phi \to 1$ as $r \to \infty$

gauge group = restricted diffeos

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Cont's space of metrics

$$|g_{\mu\nu} - \eta_{\mu\nu}| < \frac{c}{r}$$

gauge group = restricted diffeos

$\phi \to 1$ as $r \to \infty$

M is invariant under restricted diffeos

Observable

metrics

$$|g_{\mu\nu} - \eta_{\mu\nu}| < \frac{c}{r}$$ gauge group = restricted

$\phi \to 1$ as $r \to \infty$

M is invariant under restricted diffeos

Observable

$\to$ P_a momentum, J_{ab} – γ-momentum, multiple moments

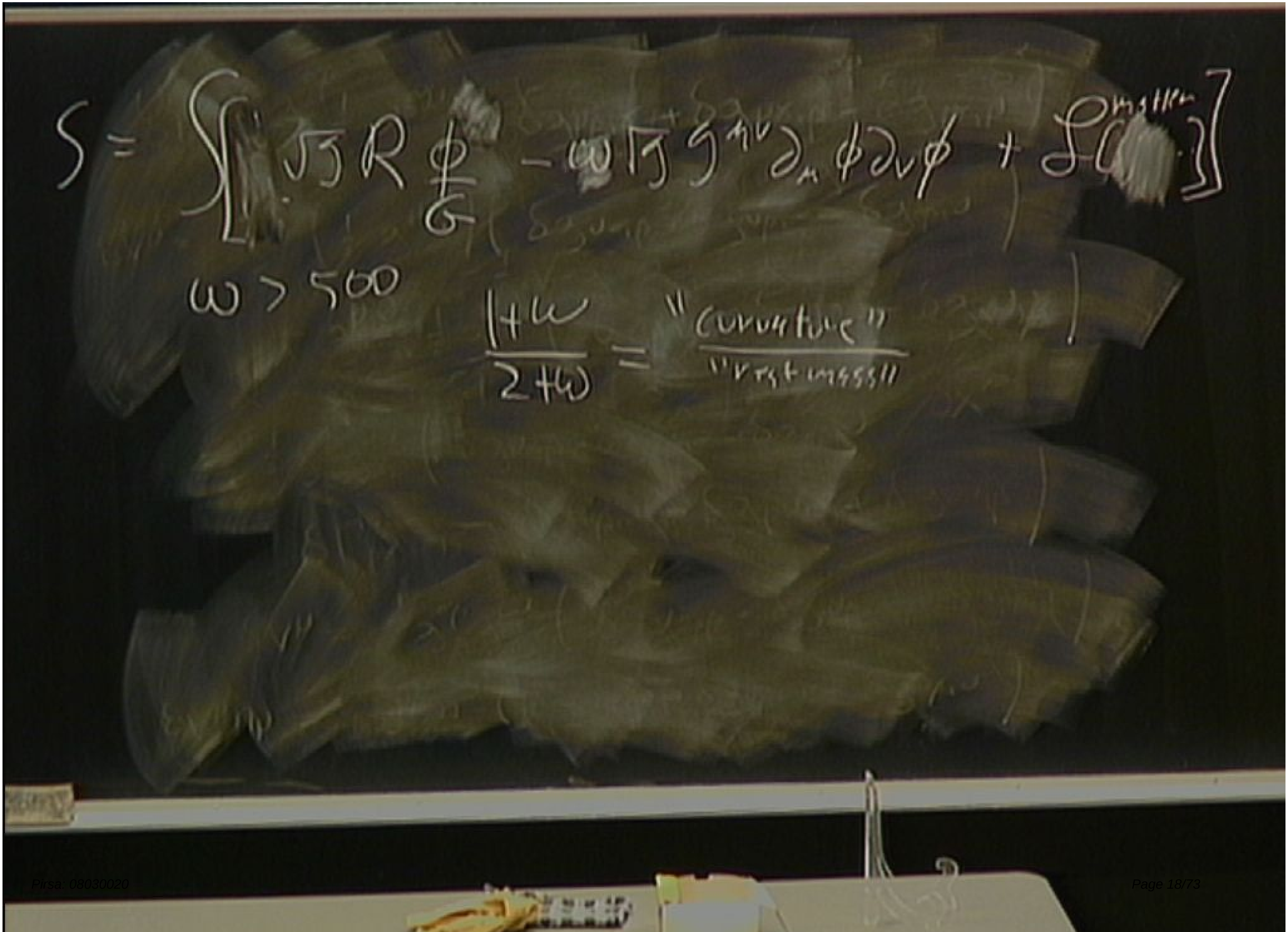
$$S = \int \left[\frac{1}{G} \sqrt{g} R \phi - \eta \sqrt{g} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi + \mathcal{L}^{\text{matter}} \right]$$

$$S = \int_{\omega} \left[\sqrt{g} R \phi - \omega \sqrt{g} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi + \mathcal{L}^{matter}[\phi, \ldots] \right]$$

$$S = \int \left[\sqrt{g}\, R\, \frac{\phi}{G} - \omega \sqrt{g}\, g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi + \mathcal{L}^{matter}(\phi, \ldots) \right]$$

ω

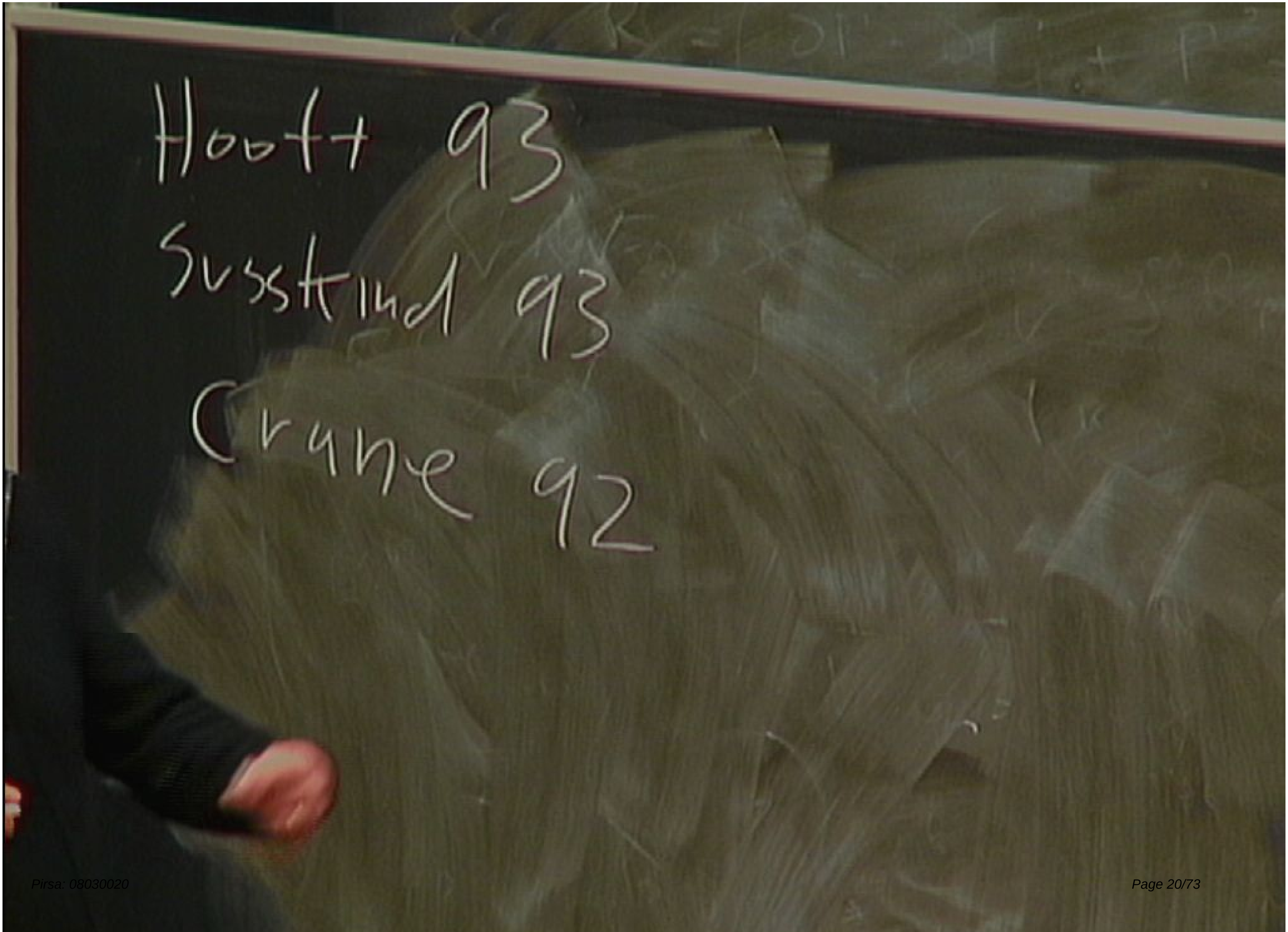
$$\frac{1+\omega}{2+\omega}$$


$S = \int \left[\sqrt{g} R \frac{\phi}{G} - \omega \sqrt{g} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi + \mathcal{L}^{matter} \right]$
$\omega > 500$
$\frac{1+\omega}{2+\omega} = \frac{\text{"curvature"}}{\text{"restmass"}}$

$$S = \int \left[\sqrt{g} R \frac{\phi}{G} - \omega \sqrt{g} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi + \mathcal{L}^{\text{matter}}(\ldots) \right]$$

$$\omega > 40{,}000$$

$$\frac{1+\omega}{2+\omega} = \frac{\text{"curvature"}}{\text{"restmass"}}$$


Hooft 93
Susskind 93
Crane 92

Hooft 93

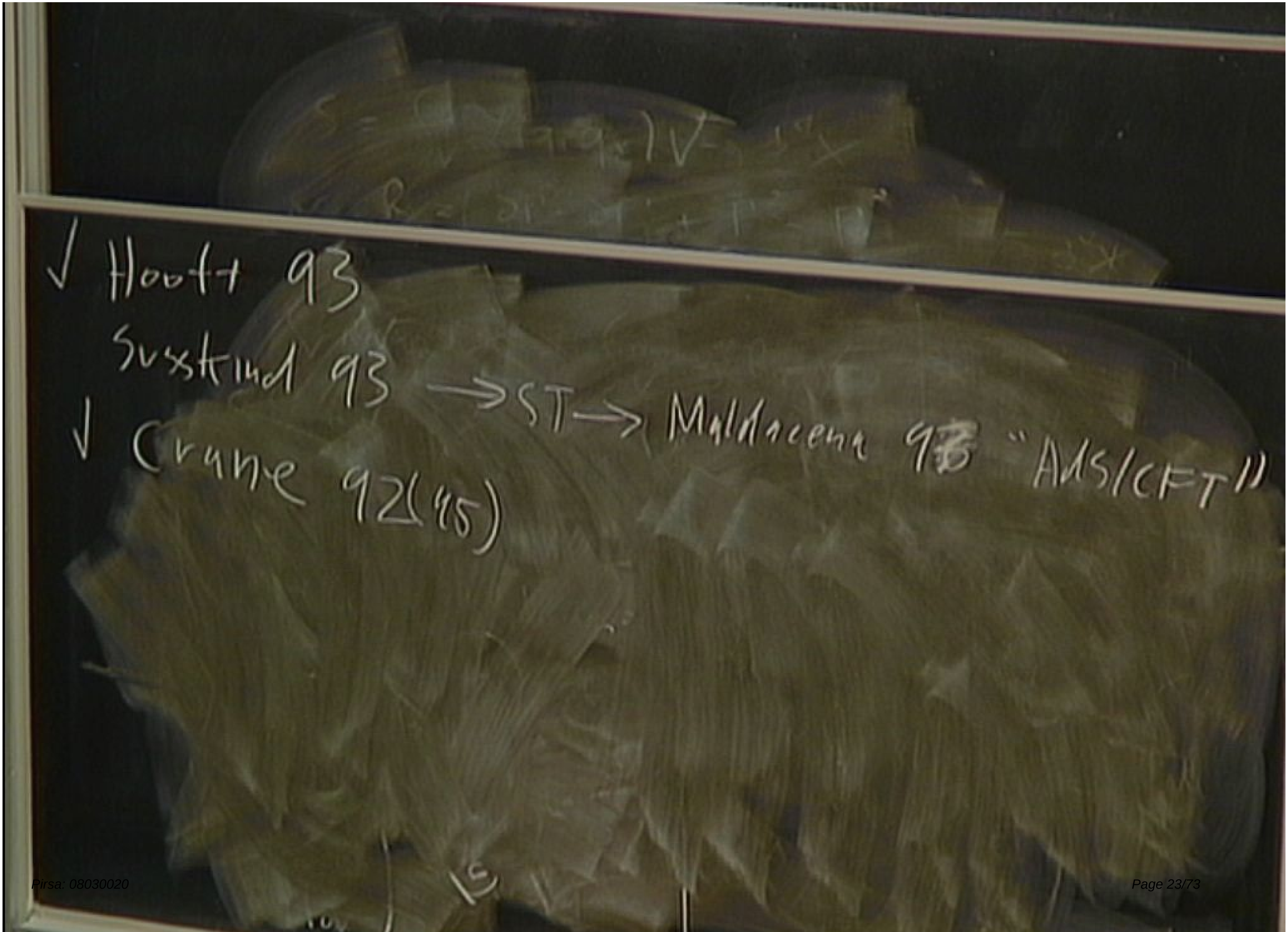
Susskind 93

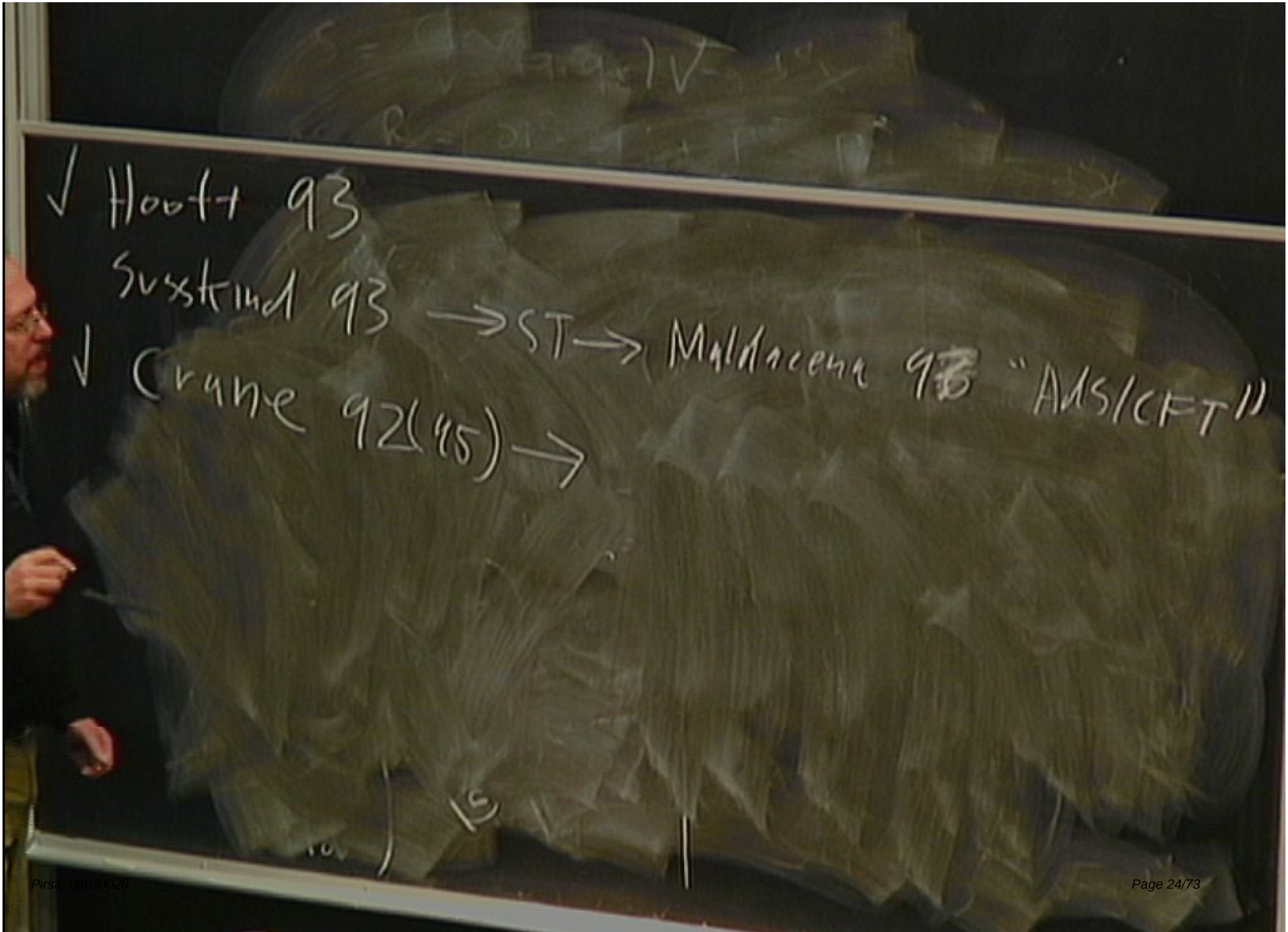
Crane 92

✓ Hooft 93

Susskind 93

✓ Crane 92(95)


√ Hooft 93
Susskind 93 → ST → Maldacena 98 "AdS/CFT"
√ Crane 92(95)


√ Hooft 93
Susskind 93 → ST → Maldacena 98 "AdS/CFT"
√ Crane 92(95) →

√ Hooft 93

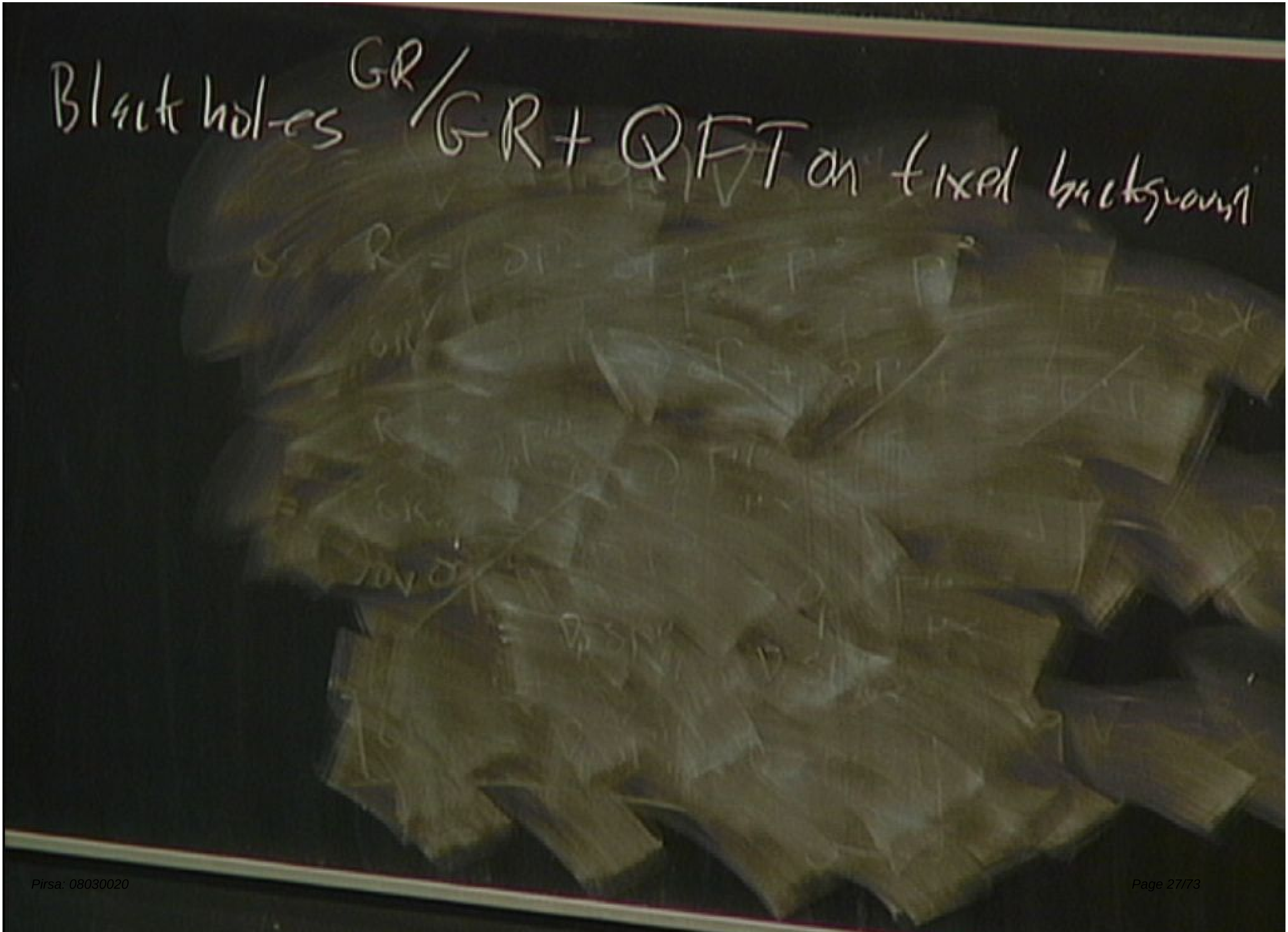
Susskind 93 $\longrightarrow$ ST $\longrightarrow$ Maldacena 97 "AdS/CFT"

√ Crane 92(95) $\longrightarrow$ Isolated horizon picture in LQG

✓ Hooft 93 $\longrightarrow$? "hidden variable"

Susskind 93 $\longrightarrow$ ST $\longrightarrow$ Maldacena 97 "AdS/CFT"

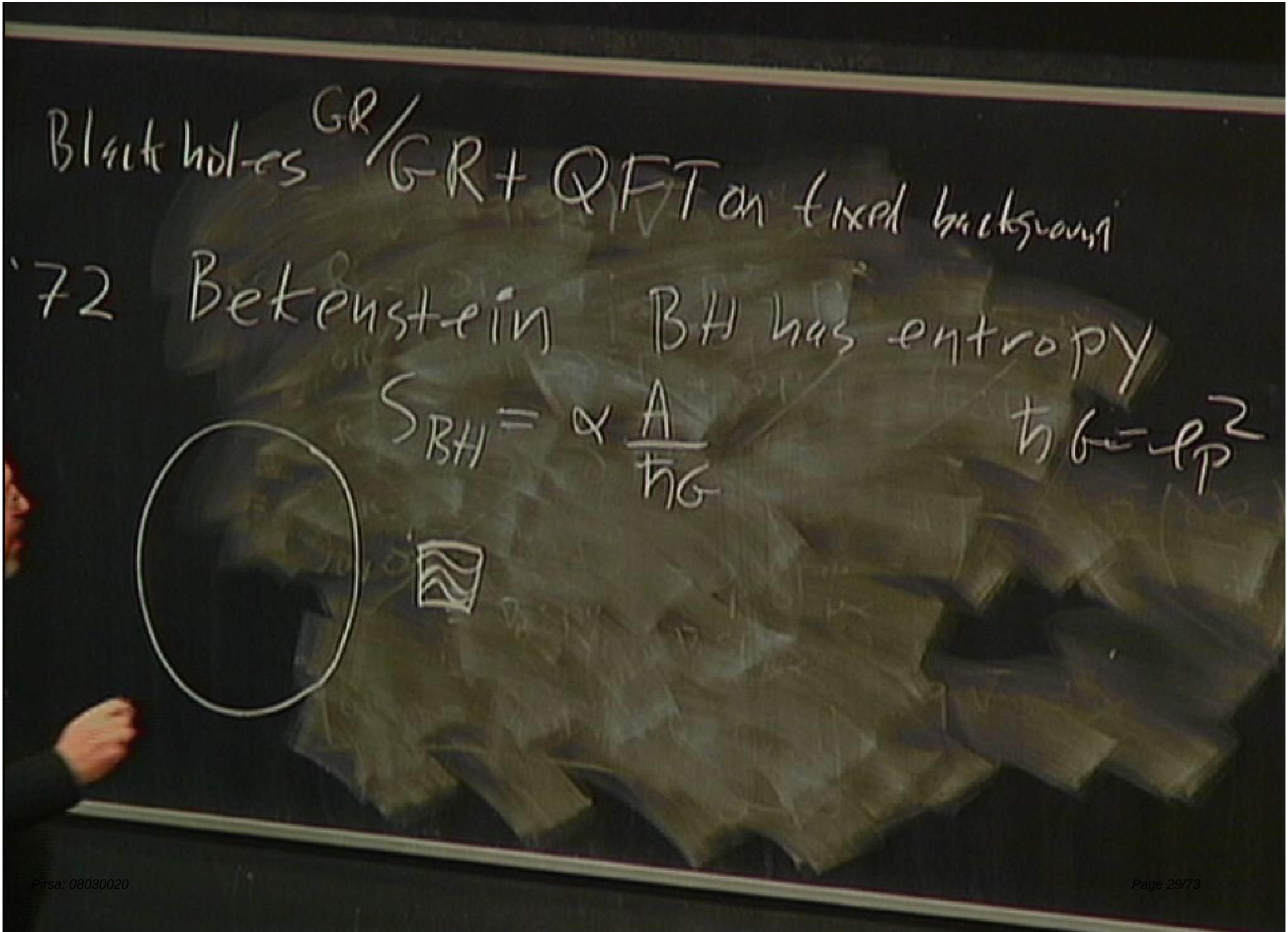
✓ Crane 92(95) $\longrightarrow$ Isolated horizon picture in LQG


Black holes GR/GR + QFT on fixed background

Black holes $^{GR}/$ GR + QFT on fixed background

'72 Bekenstein BH has entropy

$$S_{BH} = \alpha \frac{A}{\hbar G} \qquad \hbar G = \ell_P^2$$


Black holes GR / GR + QFT on fixed background
'72 Bekenstein BH has entropy
$S_{BH} = \alpha \frac{A}{\hbar G}$
$\hbar G = \ell_P^2$

Black holes GR / GR + QFT on fixed background

'72 Bekenstein BH has entropy

$$S_{BH} = \alpha \frac{A}{\hbar G} \qquad \hbar G = l_P^2$$

$$S^{Box} = VT^3$$

$$R = V^{1/3} << R_{Sch}$$

$$\Delta S^{outside} = -VT^3$$

$$M^{Box} \sim VT^4$$

$M^{Box} \sim VT^4$ $\quad M_{BH} \gg M^{Box}$

$\Delta M_{BH} \sim VT^4$

$$M^{Box} \sim VT^4 \qquad M_{BH} \gg M^{Box}$$

$$\Delta M_{BH} \sim VT^4$$

$$A \sim R_{Sc}^2 = M^2$$

$$M^{Box} \sim VT^4 \qquad M_{BH} \gg M^{Box}$$

$$\Delta M_{BH} \sim VT^4$$

$$A \sim R_{Sc}^2 = M^2 \qquad \Delta A \sim M_{BH} \Delta H > 0$$

$$M^{Box} \sim V T^4 \qquad M_{BH} \gg M^{Box}$$

$$\Delta M_{BH} \sim V T^4$$

$$A \sim R_{Sc}^2 = M^2 \qquad \Delta A \sim M_{BH} \Delta H > 0$$

$$\lambda \sim \frac{\hbar}{T} < R$$

$M^{Box} \sim VT^4$ $\qquad M_{BH} \gg M^{Box}$

$\Delta M_{BH} \sim VT^4$

$A \sim R_{SC}^2 = M^2$ $\qquad \Delta A \sim M_{BH} \Delta H > 0$

$\lambda \sim \frac{\hbar}{T} < R$ $\qquad \Delta S_{BH} = \frac{a \Delta A}{\hbar G} \gg S^{Box}$

$S^{Gen} = S^{outside} + S^{BH}$ $\qquad \Delta S^{gen} \geq 0$

$M^{Box} \sim VT^4$ $\qquad M_{BH} \gg M^{Box}$

$\Delta M_{BH} \sim VT^4$

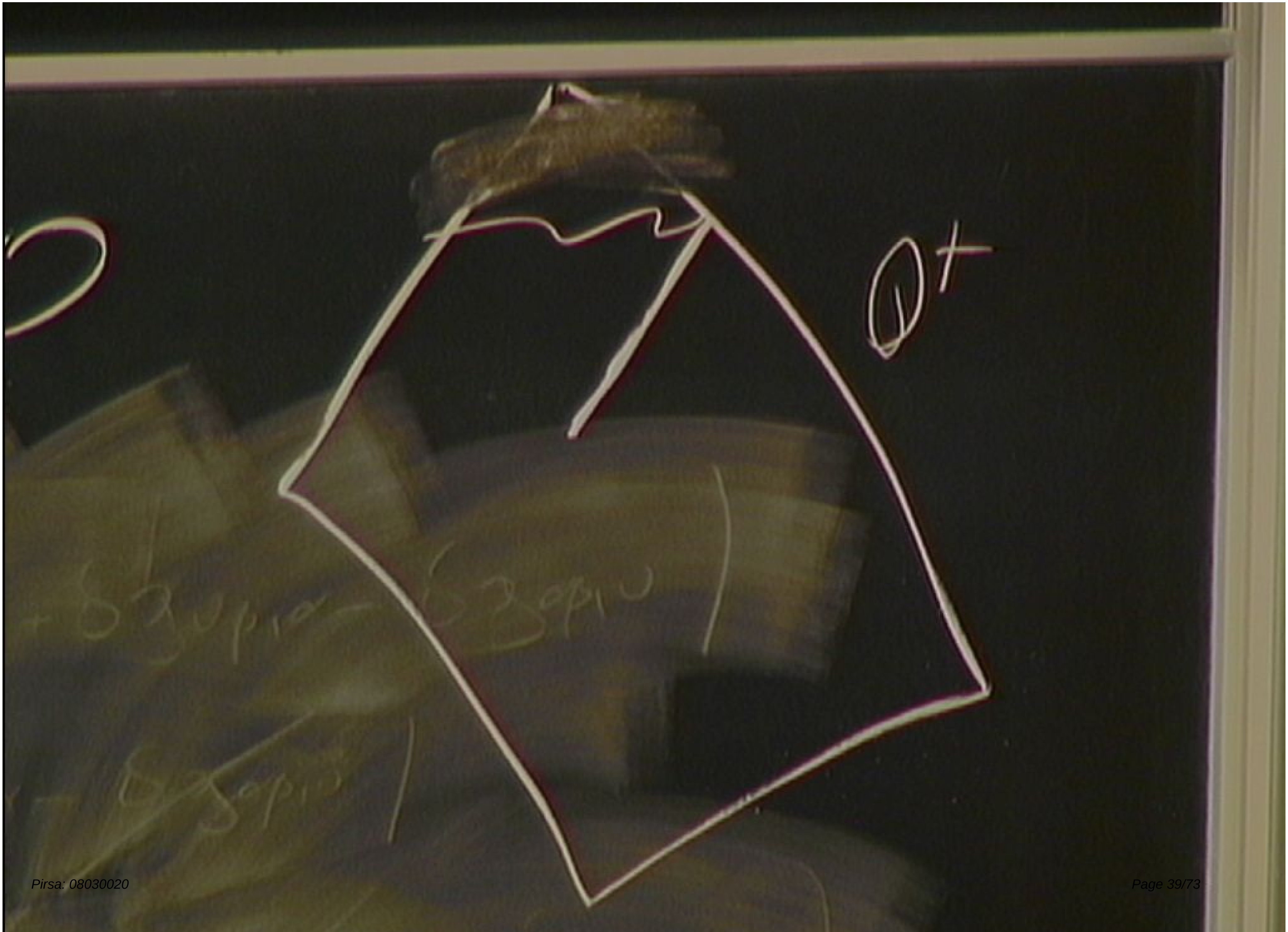
$A \sim R_{SC}^2 = M^2$ $\qquad \Delta A \sim M_{BH} \Delta M > 0$

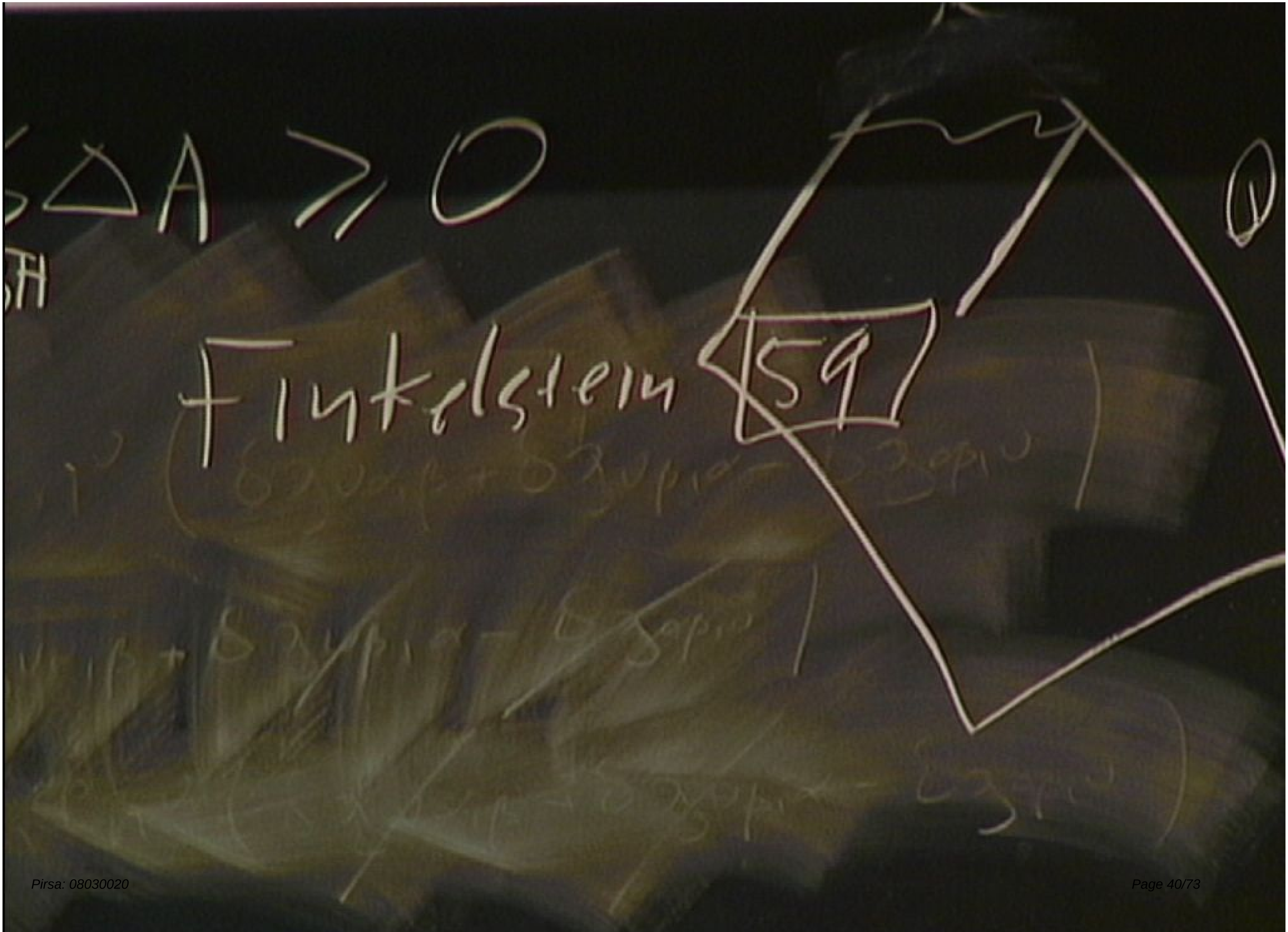
$\lambda \sim \frac{\hbar}{T} < R$ $\qquad \boxed{\Delta S_{BH} = \frac{a \Delta A}{\hbar G} \gg S^{Box}}$

$S^{Gen} = S^{outside} + S^{BH}$ $\qquad \Delta S^{gen} \geq 0$

Hawking (Classical GR)

$$\sum_{BH} \Delta A \geq 0$$


Q+


Finkelstein [59]

Hawking (Classical GR)

$$\sum_{BH} \delta A \geq 0$$

1st law of BH mechanics

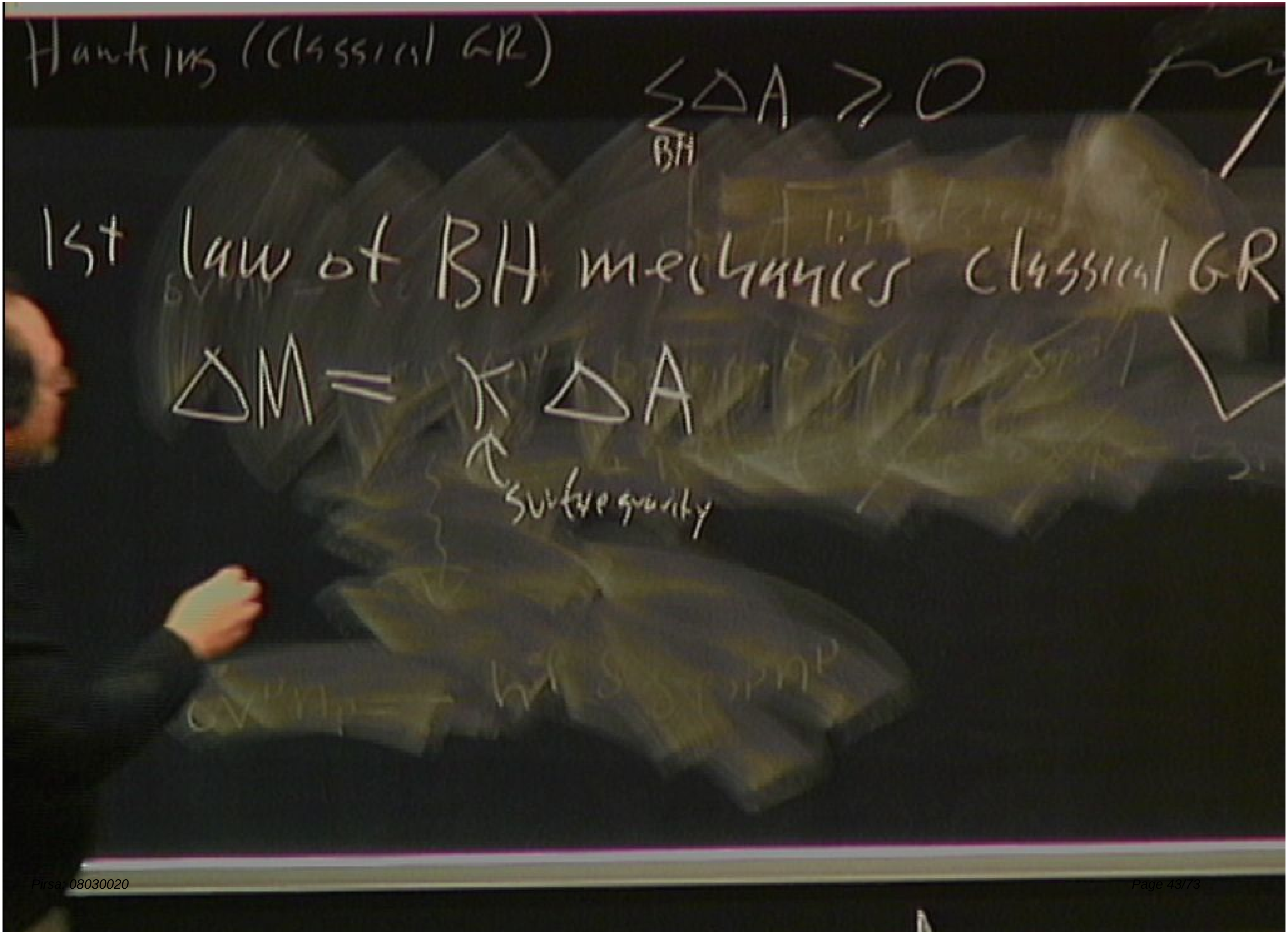
Hawking (classical GR)

$$\sum_{BH} \Delta A \geq 0$$

1st law of BH mechanics

$$\Delta M = \kappa \Delta A$$

surface gravity


Hawking (classical GR)
$\sum_{BH} \Delta A \geq 0$
1st law of BH mechanics classical GR
$\Delta M = \kappa \Delta A$
surface gravity

Hawking (classical GR)

$$\sum_{BH} \Delta A \geq 0$$

1st law of BH mechanics classical GR

$$\Delta M = \kappa \Delta A + \Omega \Delta J$$

surface gravity

Hawking (classical GR)

$$\sum_{BH} \Delta A \geq 0$$

1st law of BH mechanics classical GR

$$\Delta M = \kappa \, \Delta A$$

surface gravity

$$\Delta E = T \Delta S$$

Hawking (Classical GR)

$$\sum_{BH} \Delta A \geq 0$$

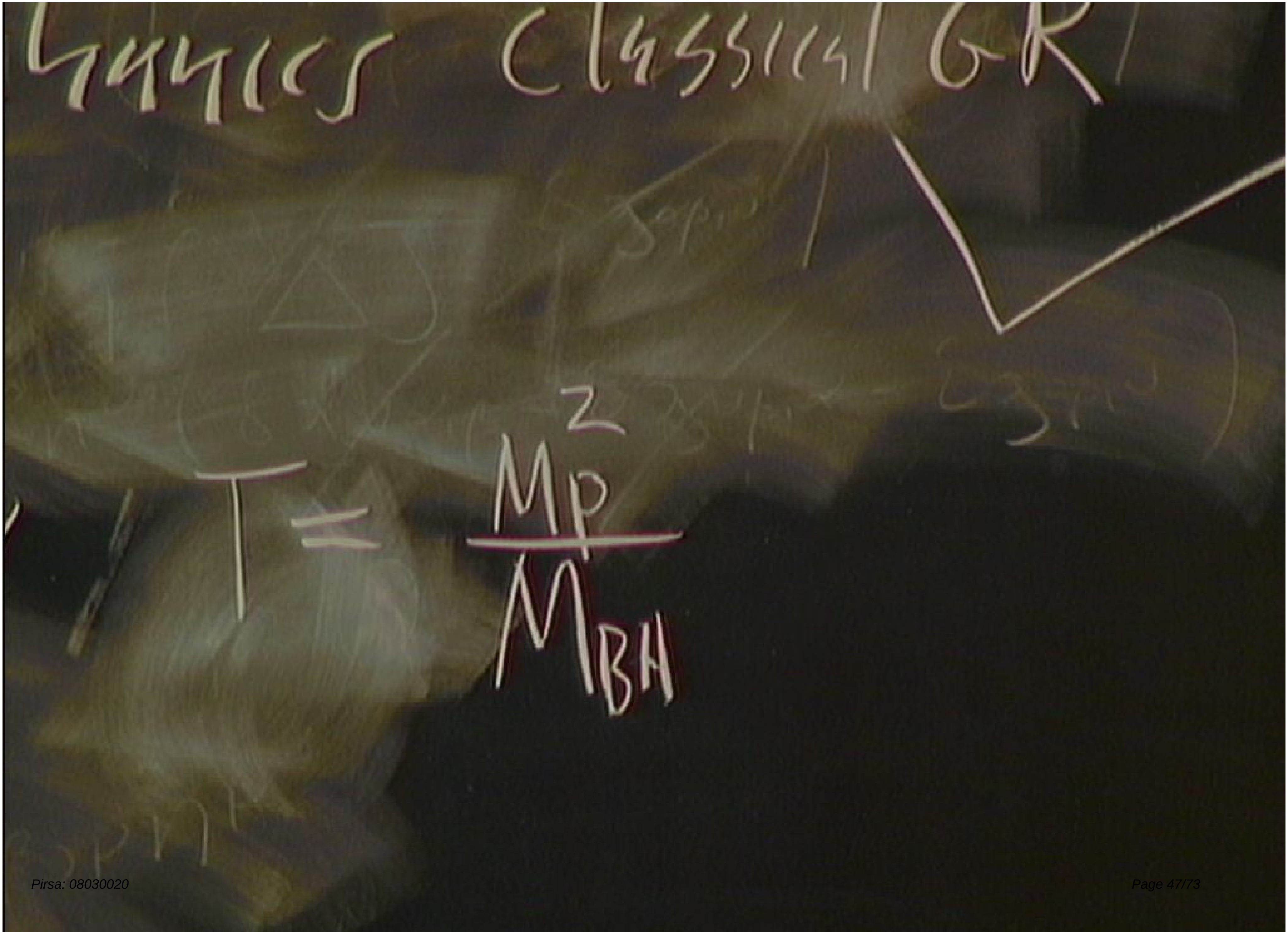
1st law of BH mechanics classical GR

$$\Delta M = \kappa \Delta A$$

surface gravity

$$T = 0$$

$$\Delta E = T \Delta S$$


classical GR
$T = \frac{M_P^2}{M_{BH}}$

Classical GR

$$T = \frac{M_p^2}{M_{BH}} = 1K$$

Hawking (classical GR)

$$\boxed{\sum_{BH} \Delta A \geq 0}$$

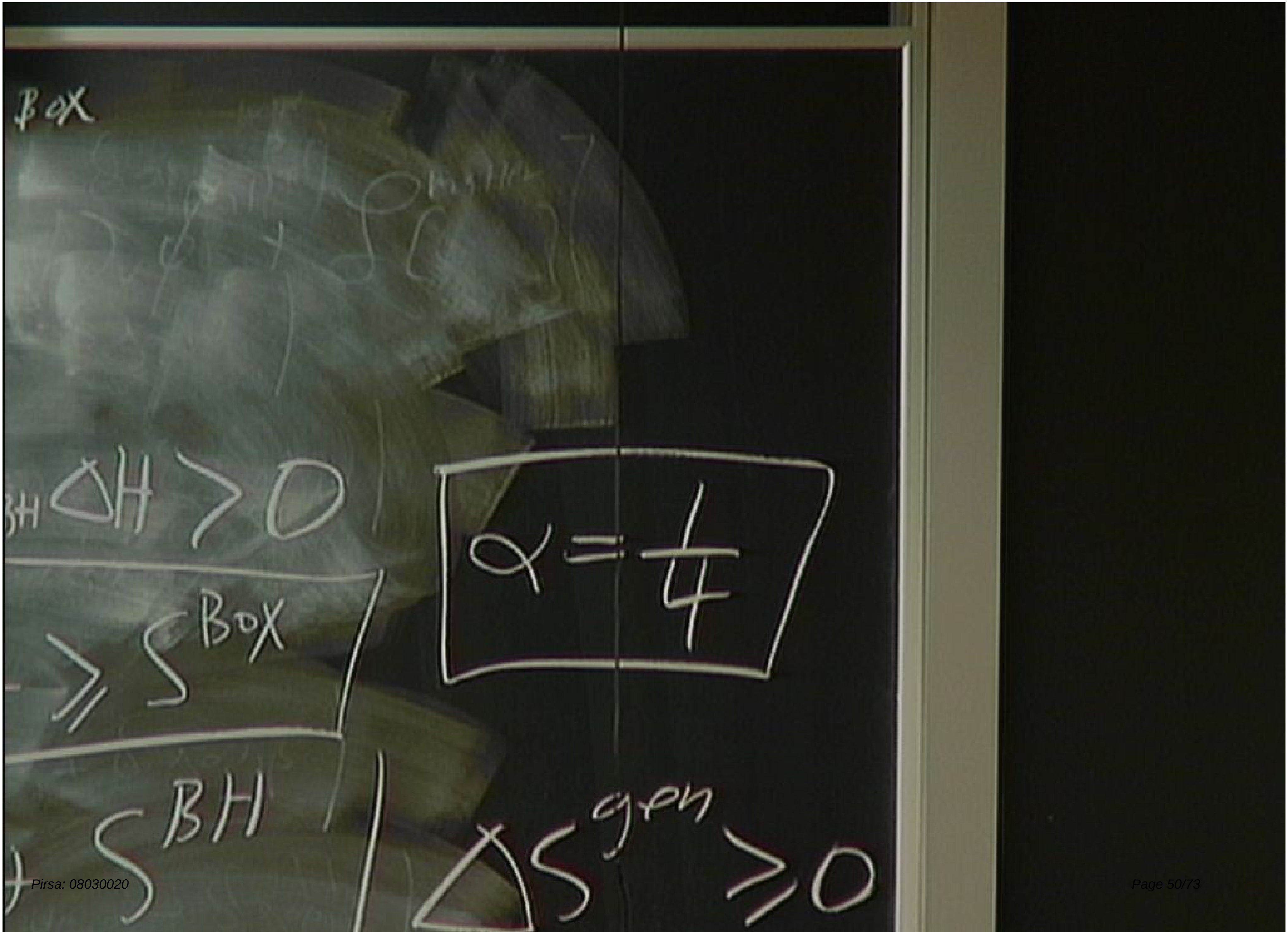
1st law of BH mechanics classical GR

$$\boxed{\Delta M = \kappa \, \Delta A}$$

surface gravity

$$T = \frac{M_P^2}{M_{BH}} = (\;)\kappa$$

$$\Delta E = T \Delta S$$


Box
ΔH > 0
S^Box
α = 1/4
S^BH
ΔS^gen > 0

Hawking (classical GR)

$$\boxed{\sum_{BH} \Delta A \geq 0}$$

1st law of BH mechanics classical

$$\boxed{\Delta M = \kappa \Delta A}$$

surface gravity

$$T = \frac{M_P^2}{M_{BH}} = ($$

$$\Delta E = T \Delta S$$

$$g_{\mu\nu} = \eta_{\mu\nu} + O\left(\frac{1}{r}\right)$$

r ≈ consts

$$g = S_{ss} + \frac{M}{r} + O\left(\frac{1}{r^2}\right)$$

$$ds^2 = dt^2 - dx^2 - dy^2 - dz^2$$

$$dr^2 = dx^2 + dy^2 + dz^2$$

$$S^{BH} = \frac{A}{4G\hbar}$$

strong

$$e^{S_{BH}} =$$ "# of dofs in the BH"

"dimension of $\mathcal{H}$ of BH"

$S = S_{\text{as}} + \frac{M}{r} + O\left(\frac{1}{r^2}\right)$ $\quad ds^2 = dx^2 + dx^2 + d\ldots$

$S^{BH} = \frac{A}{4G\hbar}$ strongly $e^{S_{BH}} =$ "# of dof in the BH"

"dimension of $\mathcal{H}$ of BH"

OR

$S_{BH} =$ Information

$$\ldots = S_{95} + \frac{M}{r} + O\left(\frac{1}{r^2}\right) \qquad dr^2 = dx^2 + dy^2 + dz^2$$

$$S^{BH} = \frac{A}{4G\hbar}$$

strong

$e^{S_{BH}}$ = "# of dof in the BH"

"dimension of $\mathcal{H}$ of BH"

OR

S_{BH} = Information measurable just over the horizon

$$\ldots = S_{45} + \frac{M}{r} + O\left(\frac{1}{r^2}\right) \qquad d\Gamma^2 = dx^2 + dy^2 + dz^2$$

$$S^{BH} = \frac{A}{4G\hbar}$$

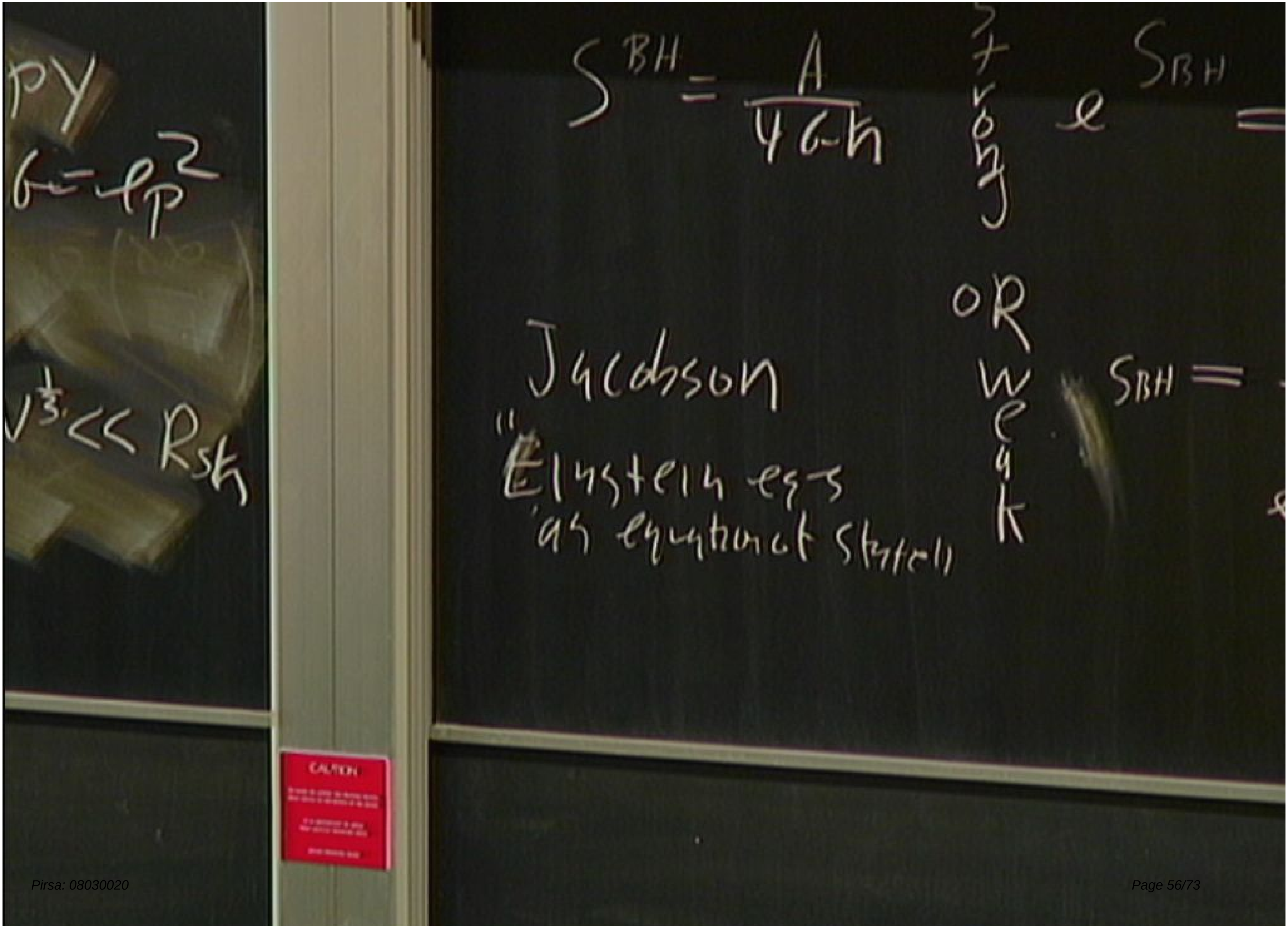
strong $\quad e^{S_{BH}}$ = "# of dof in the BH"

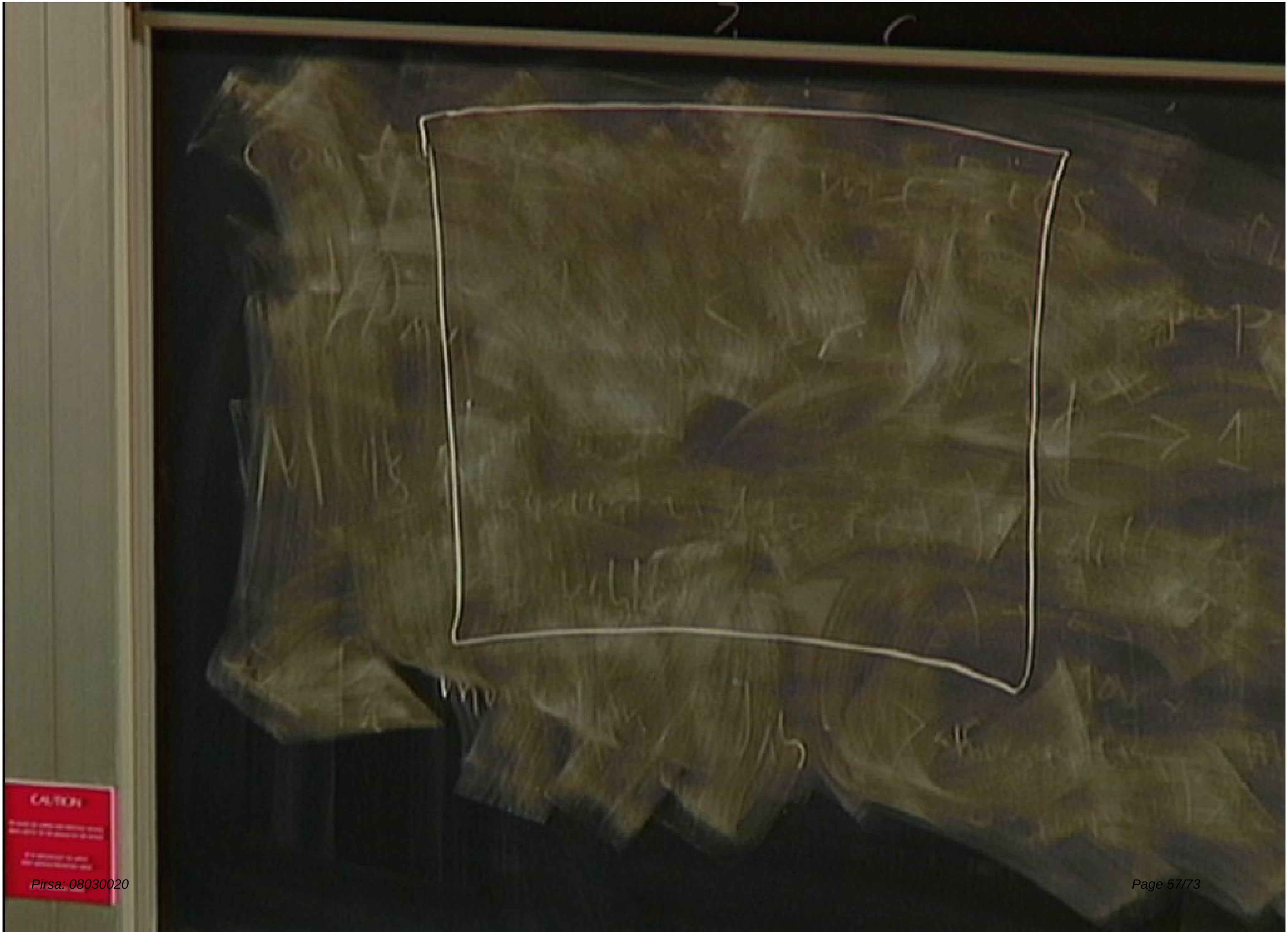
"dimension of $\mathcal{H}$ of BH"

OR

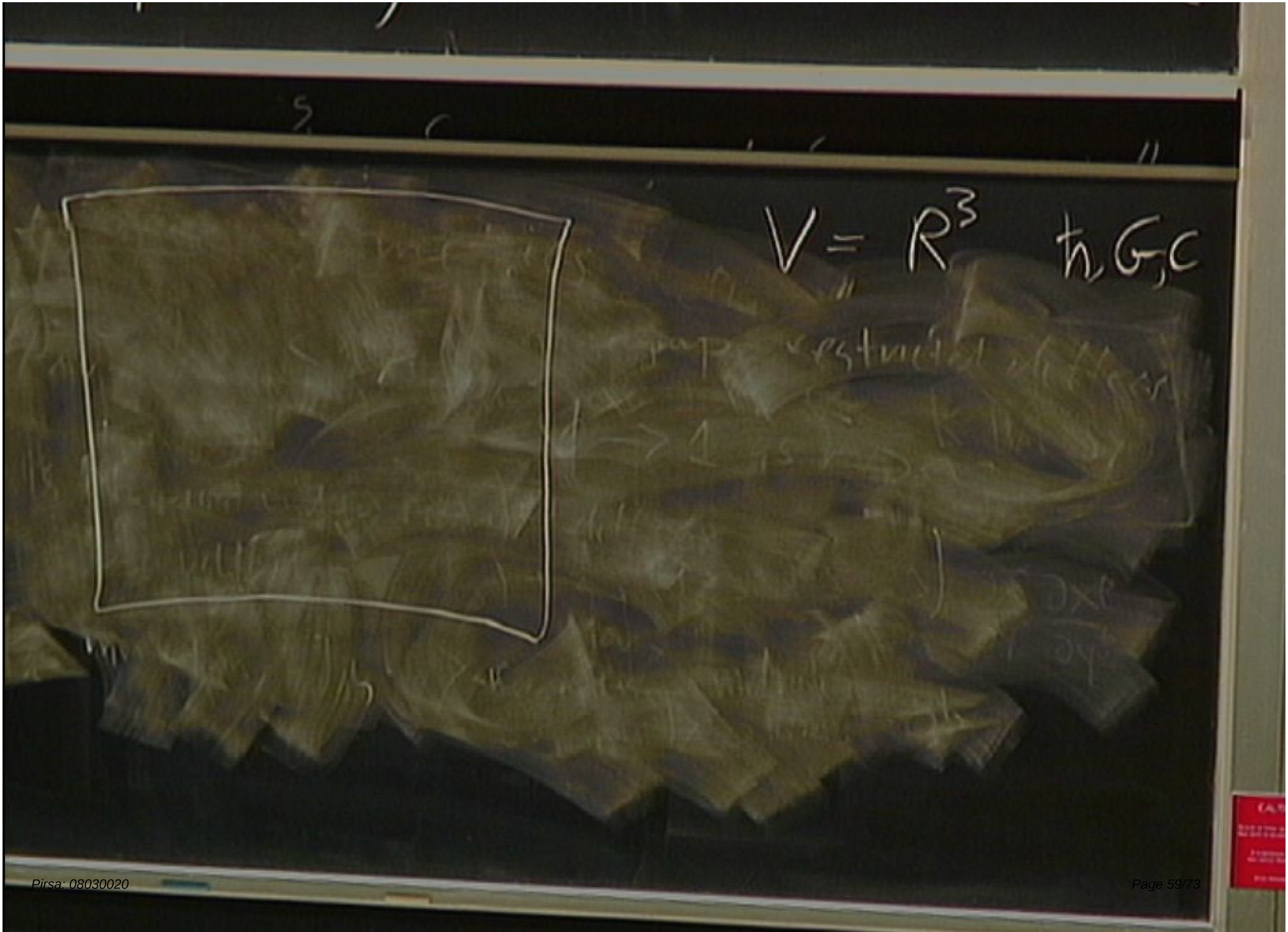
weak $\quad S_{BH}$ = Information measurable just over the horizon

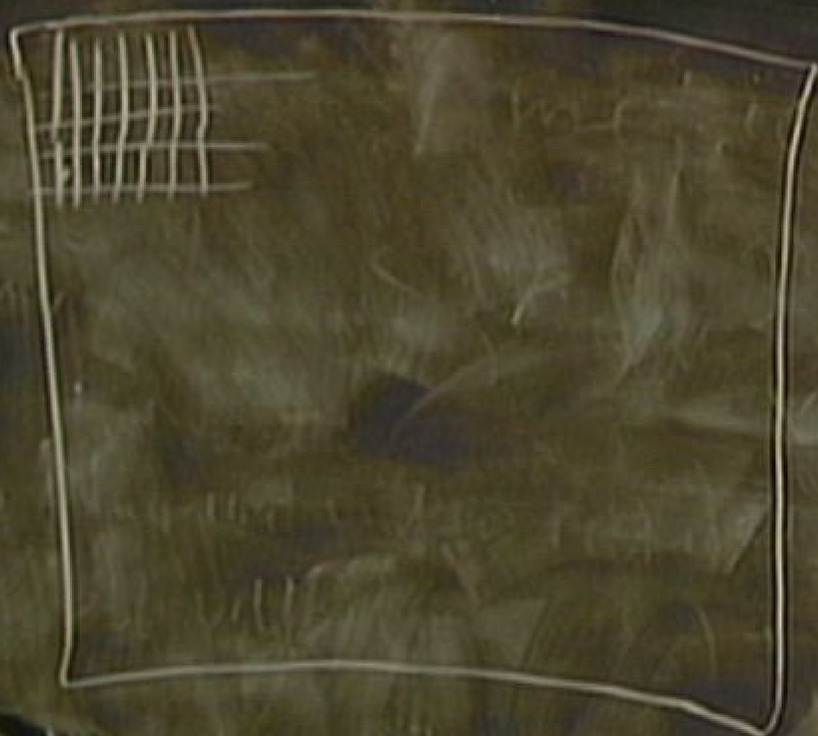
$e^{S_{BH}}$ = ~~#~~ of orthogonal states needed to describe measurements made at horizon


py
G = lp^2
V^1/3 << Rsch
S^BH = A/4Għ
strong
e^SBH =
OR
Jacobson
weak
SBH =
"Einstein eqs
as equation of state"
CAUTION



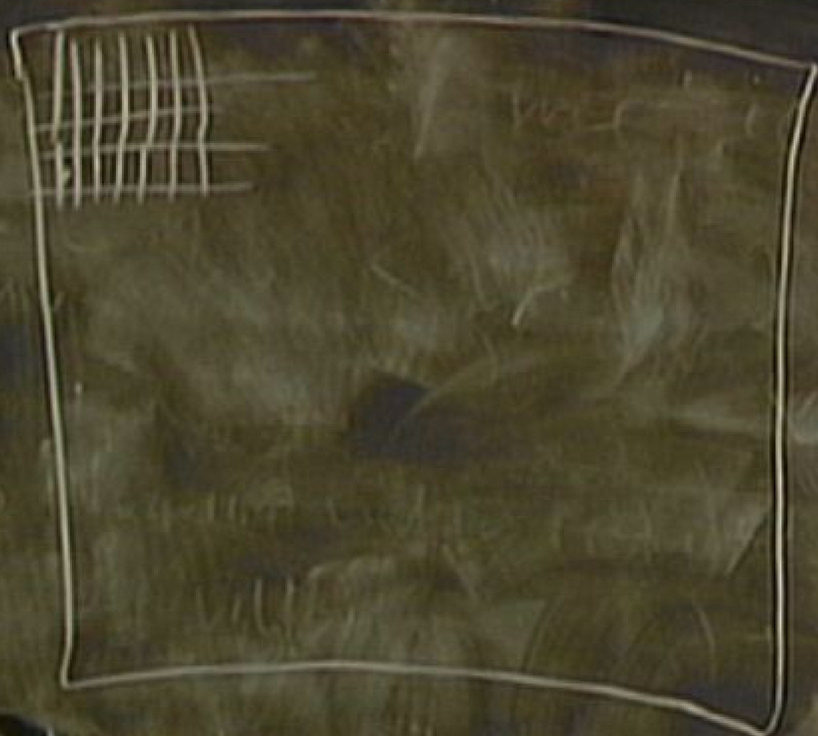
$$V = R^3$$


$V = R^3$ $\hbar, G, c$



$V = R^3 \qquad \hbar, G, c$

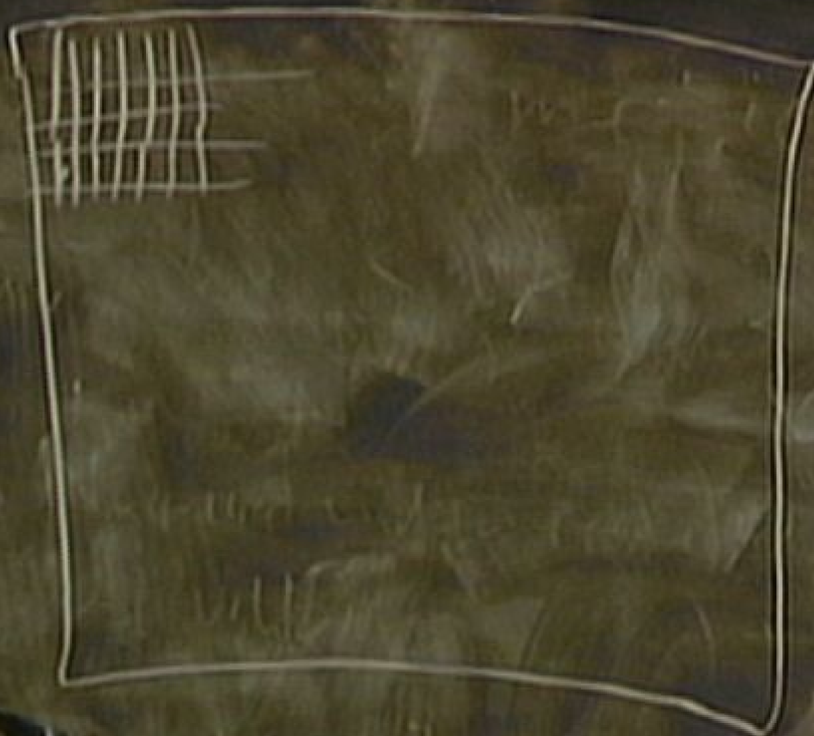
$N \sim \left(\frac{R}{l_{Pl}}\right)^3$



$V = R^3 \qquad \hbar, G, c$

$N \sim \left(\frac{R}{l_{Pl}}\right)^3$

E^{Box}



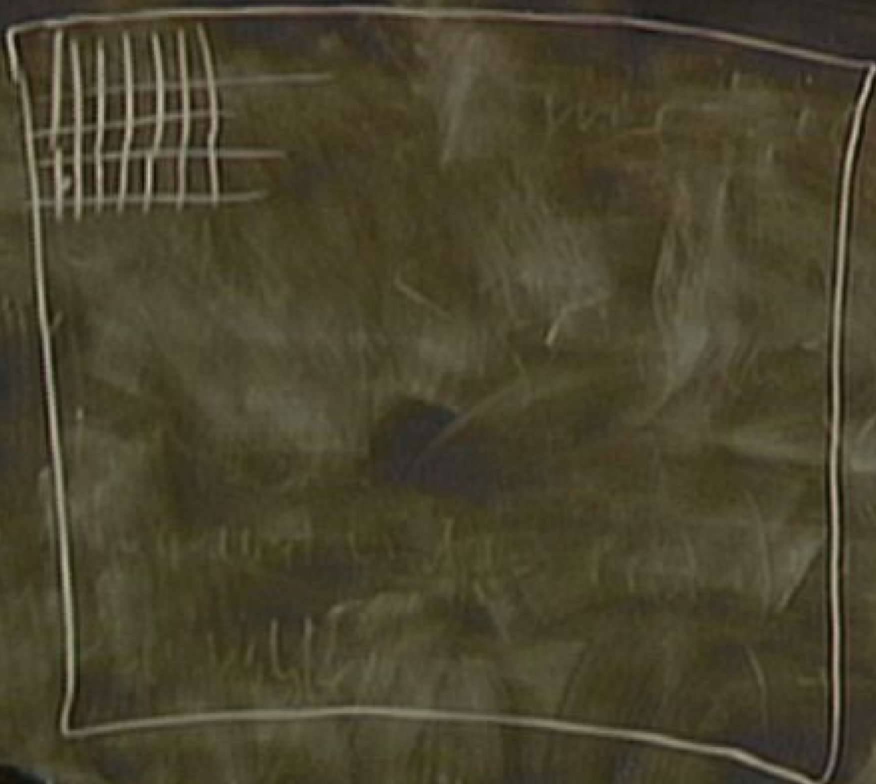
$V = R^3$ $\hbar, G, c$

$N \sim \left(\frac{R}{l_{Pl}}\right)^3$

E^{Box}

Hoop conjecture

$GM > R \Rightarrow$ horizon



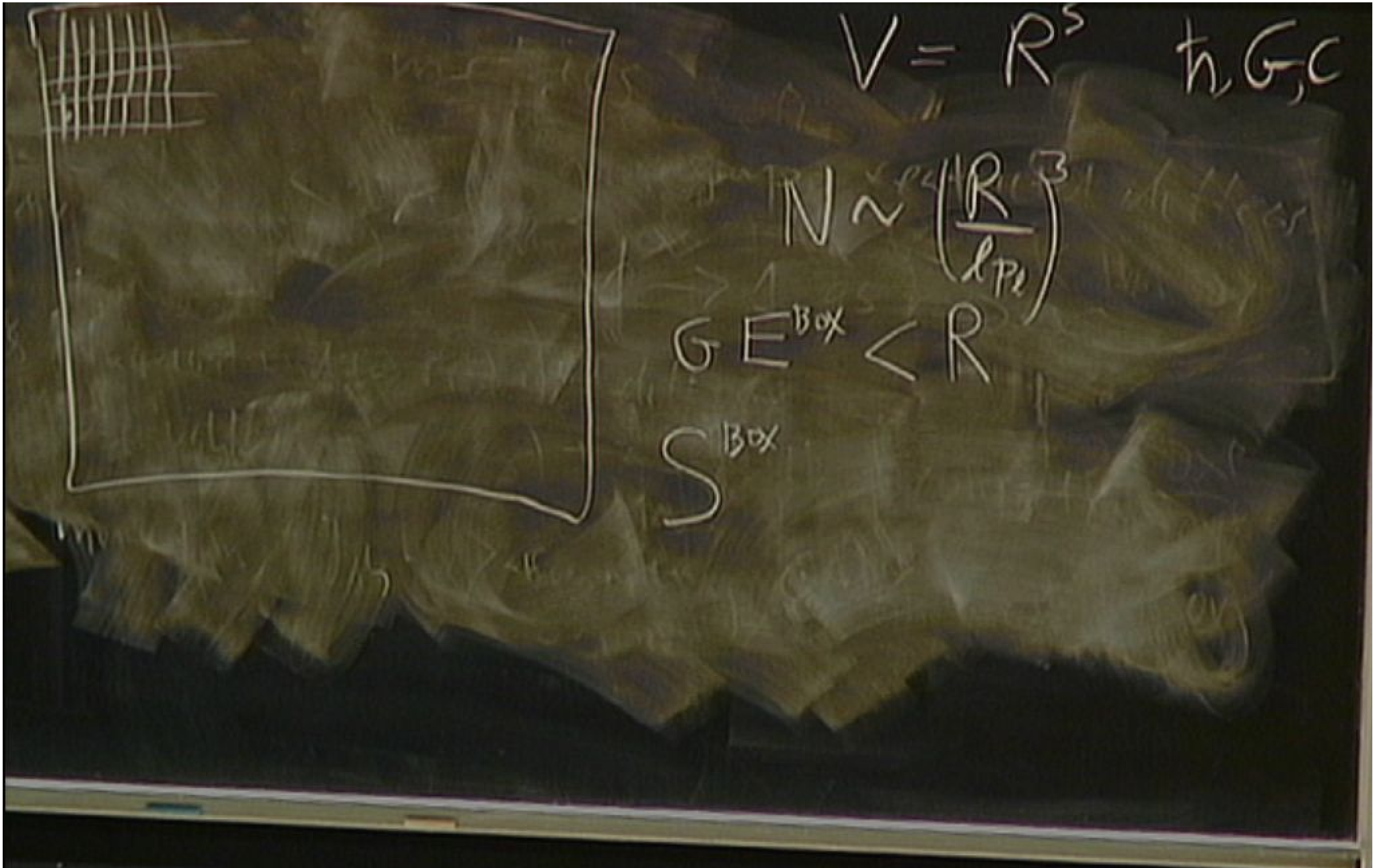
$V = R^3 \quad \hbar, G, c$

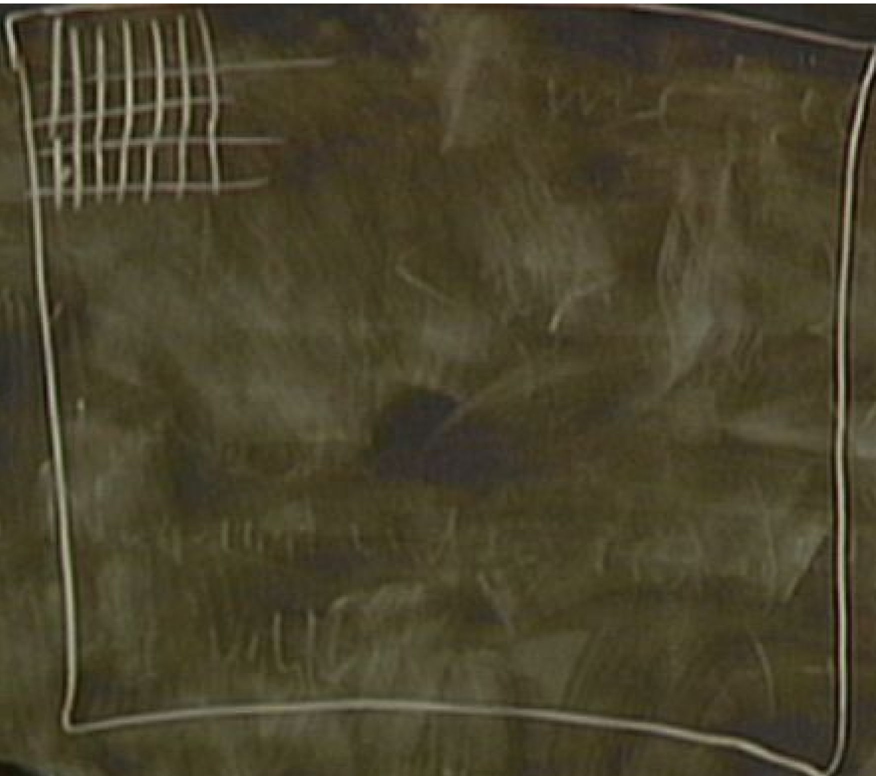
$N \sim \left(\frac{R}{l_{Pl}}\right)^3$

$G E^{Box} < R$

Hoop conjecture

$GM > R \Rightarrow$ horizon


$V = R^3$
$\hbar, G, c$
$N \sim \left(\frac{R}{\ell_{Pl}}\right)^3$
$GE^{Box} < R$
S^{Box}

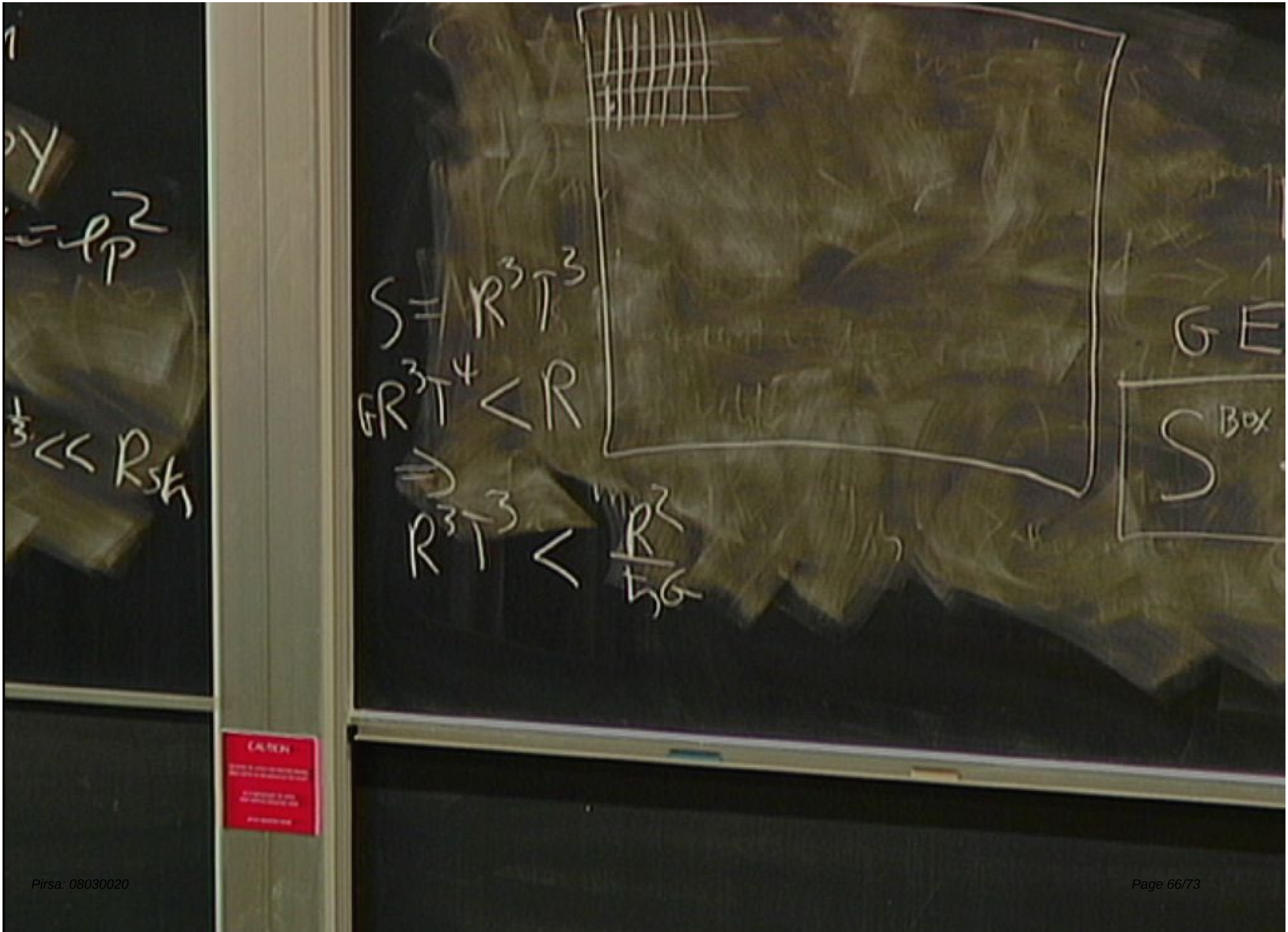


$$V = R^3 \qquad \hbar, G, c$$

$$N \sim \left(\frac{R}{l_{Pl}}\right)^3$$

$$GE^{Box} < R$$

$$\boxed{S^{Box} < \frac{R^2}{\hbar G}}$$

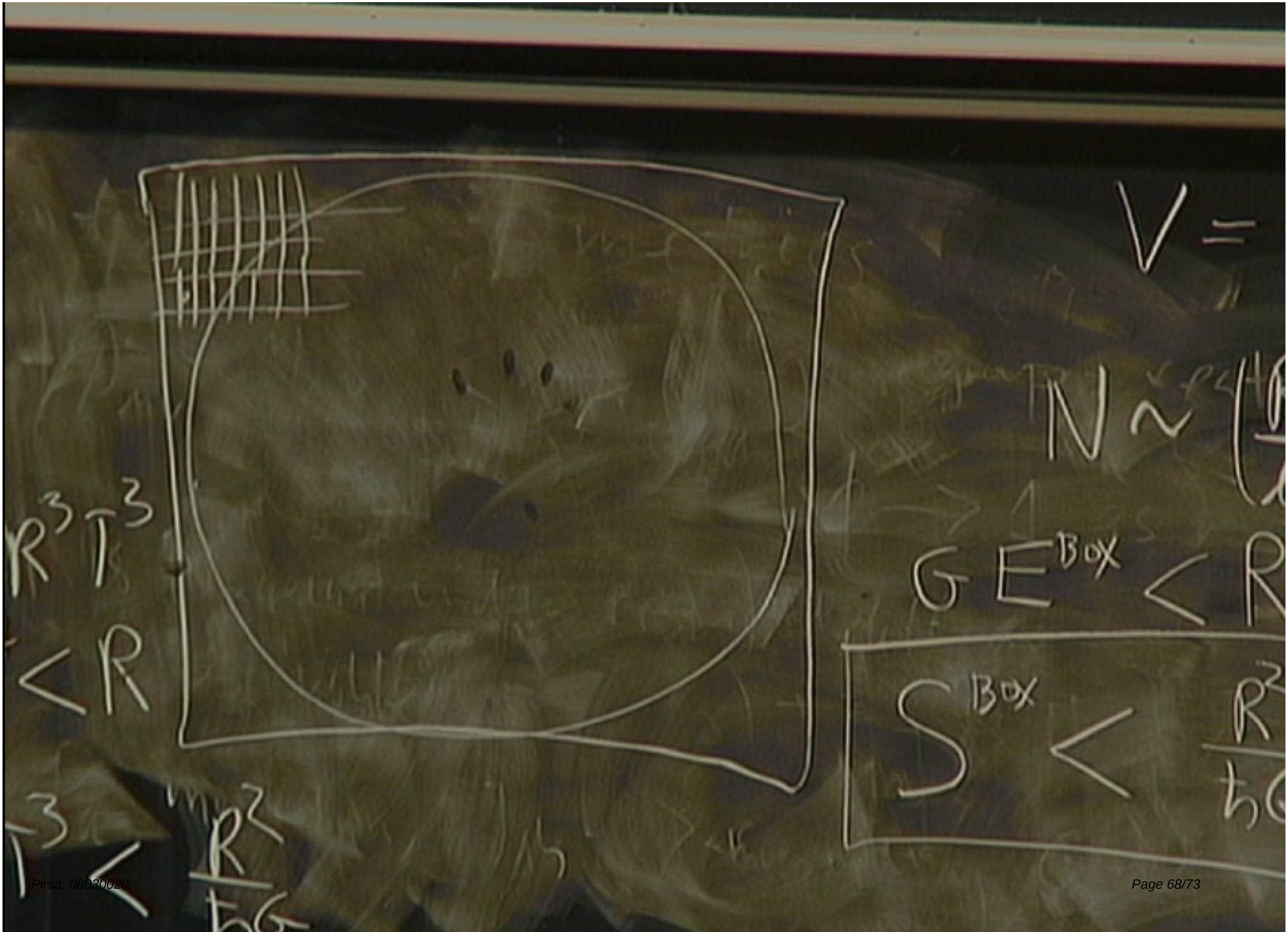

S = R³T³
GR³T⁴ < R
R³T³ < R²/l_pG
GE
S^BOX
<< R_sch
CAUTION

$$S = R^3 T^3$$

$$R^3 T^4 < R$$

$$\Rightarrow$$

$$R^3 T^3 < \frac{R^2}{G}$$

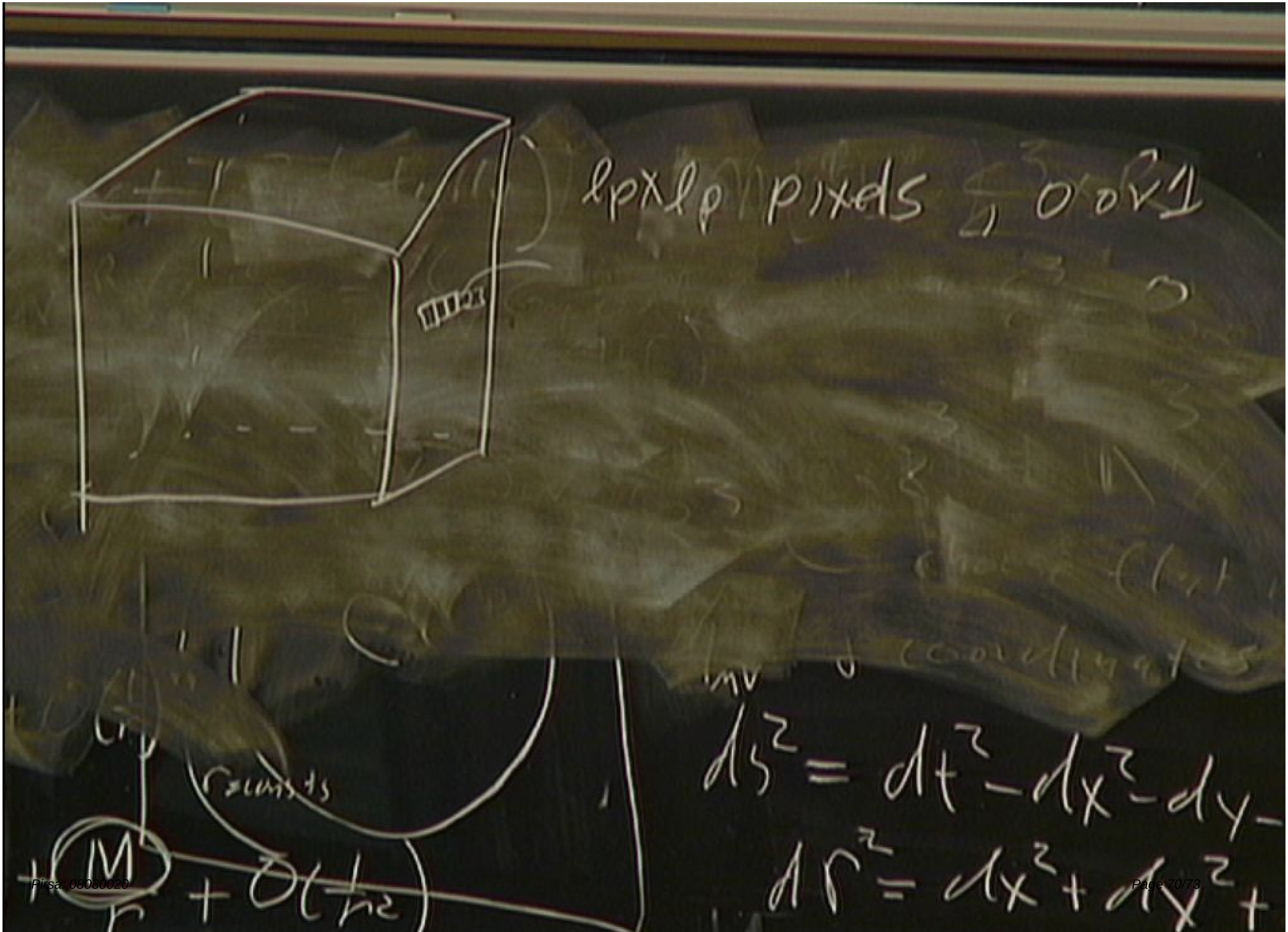

V =
N ~ (
R3T3
< R
G EBox < R
SBox < R2 / ħG
T3 < R2 / ħG

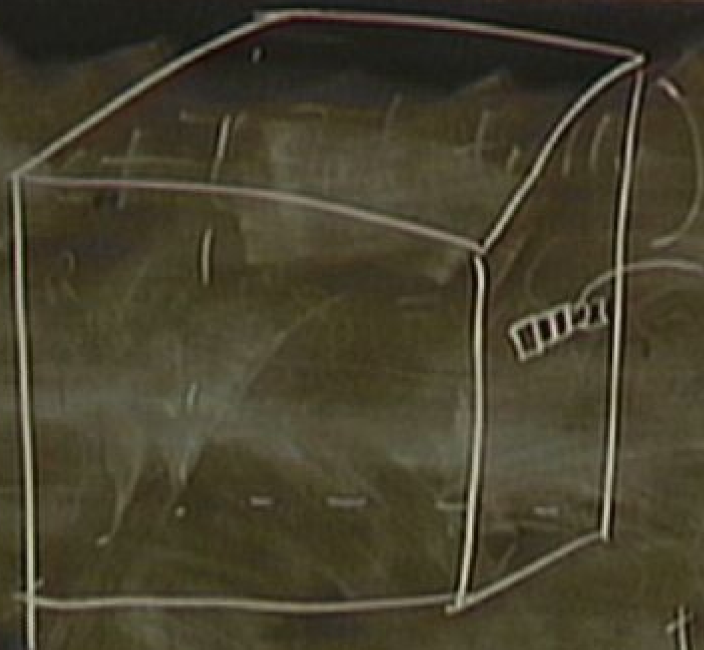
$$\left(\ell_{Pl}\right)$$

$$GE^{Box} < R$$

$$\boxed{S^{Box} < \frac{R^2}{\hbar G}}$$

under no circumstances are more than $\frac{R^2}{\hbar G}$ bits of info needed to describe the physical state in the box


lp×lp pixels 0 or 1
r=consts
ds² = dt² − dx² − dy −
dr² = dx² + dy² +
M
+ O(1/r²)

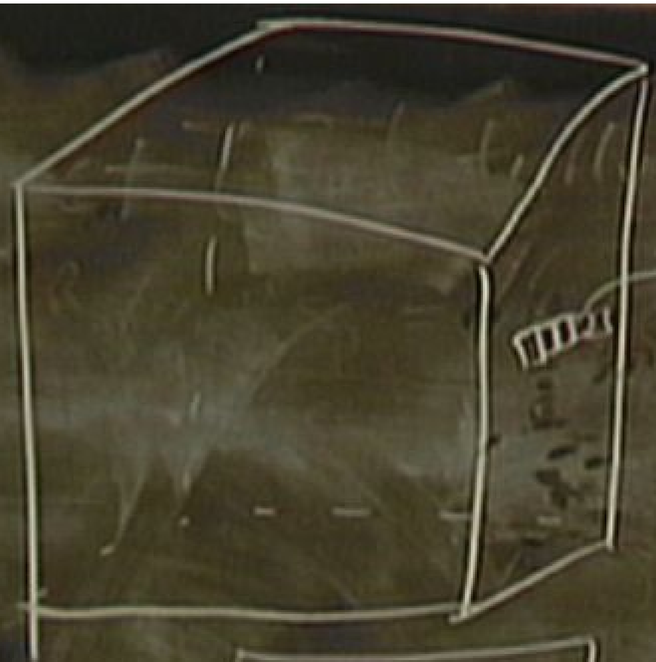


$l_p \times l_p$ pixels $\in$ 0 or 1

Hypothesizes! There exists a highly compact description of the phys state of the interior coded as pixels on the surface

$l_p \times l_p$ pixels $\in$ 0 or 1

Hypothesizes! There ex
highly compact descrip
the Phys state of the int
Coded as pixels on the



$l_p \times l_p$ pixels ; 0 or 1

Hypothesizes: There exists a highly compact description of the phys state of the interior coded as pixels on the surface

0 0 0 0