Title: Strings and Cosmology

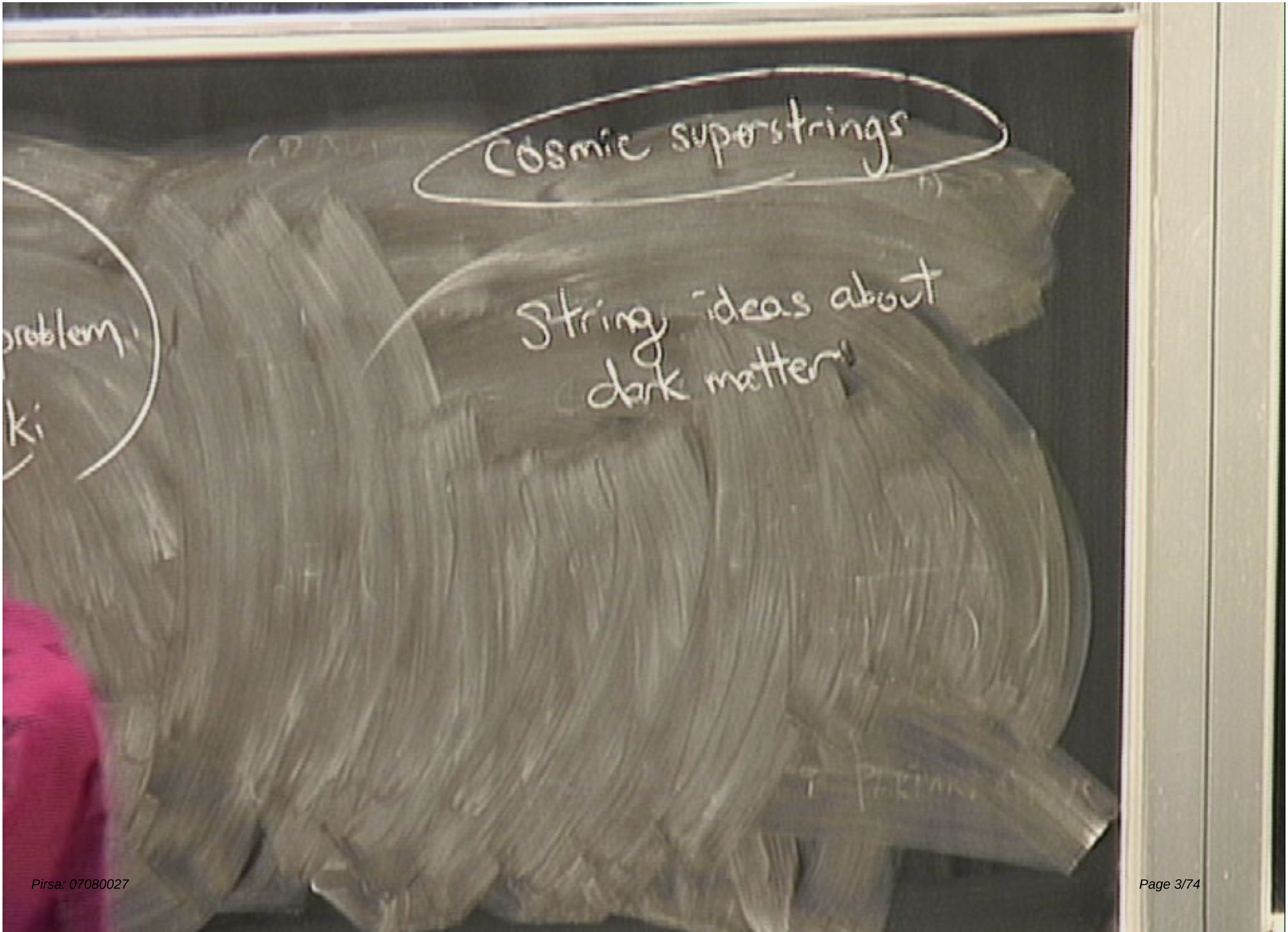
Date: Aug 14, 2007 02:00 PM

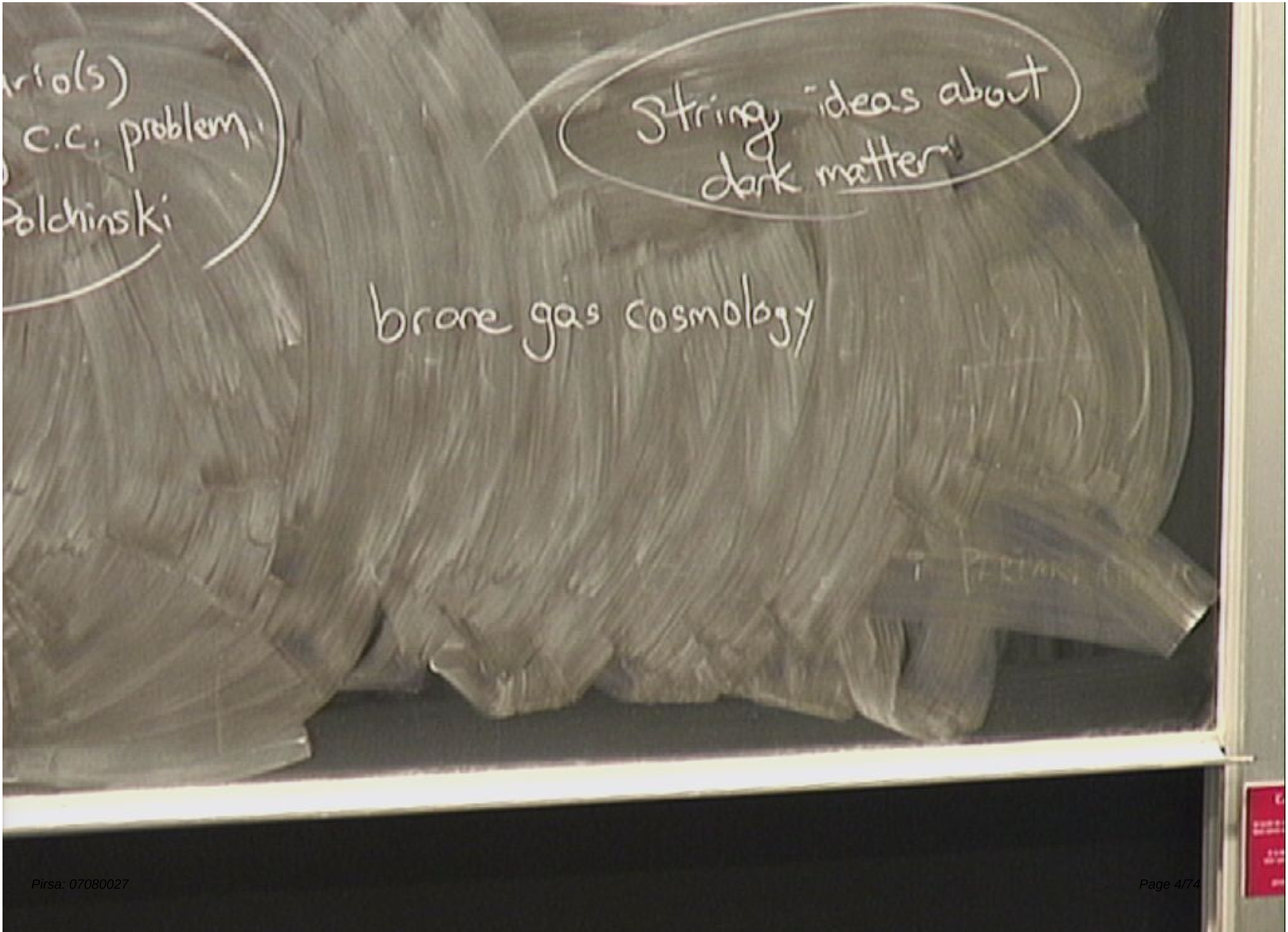
URL: http://pirsa.org/07080027

Abstract:

S.T. scenario(s)
for solving C.C. problem.

Bousso-Polchinski


Cosmic superstrings
String ideas about
dark matter!


c.c. problem
Polchinski
String ideas about
dark matter
brane gas cosmology

...rio(s)
c.c. problem:
Polchinski

String ideas about
dark matter!

brane gas cosmology

non-inflationary early universe theories

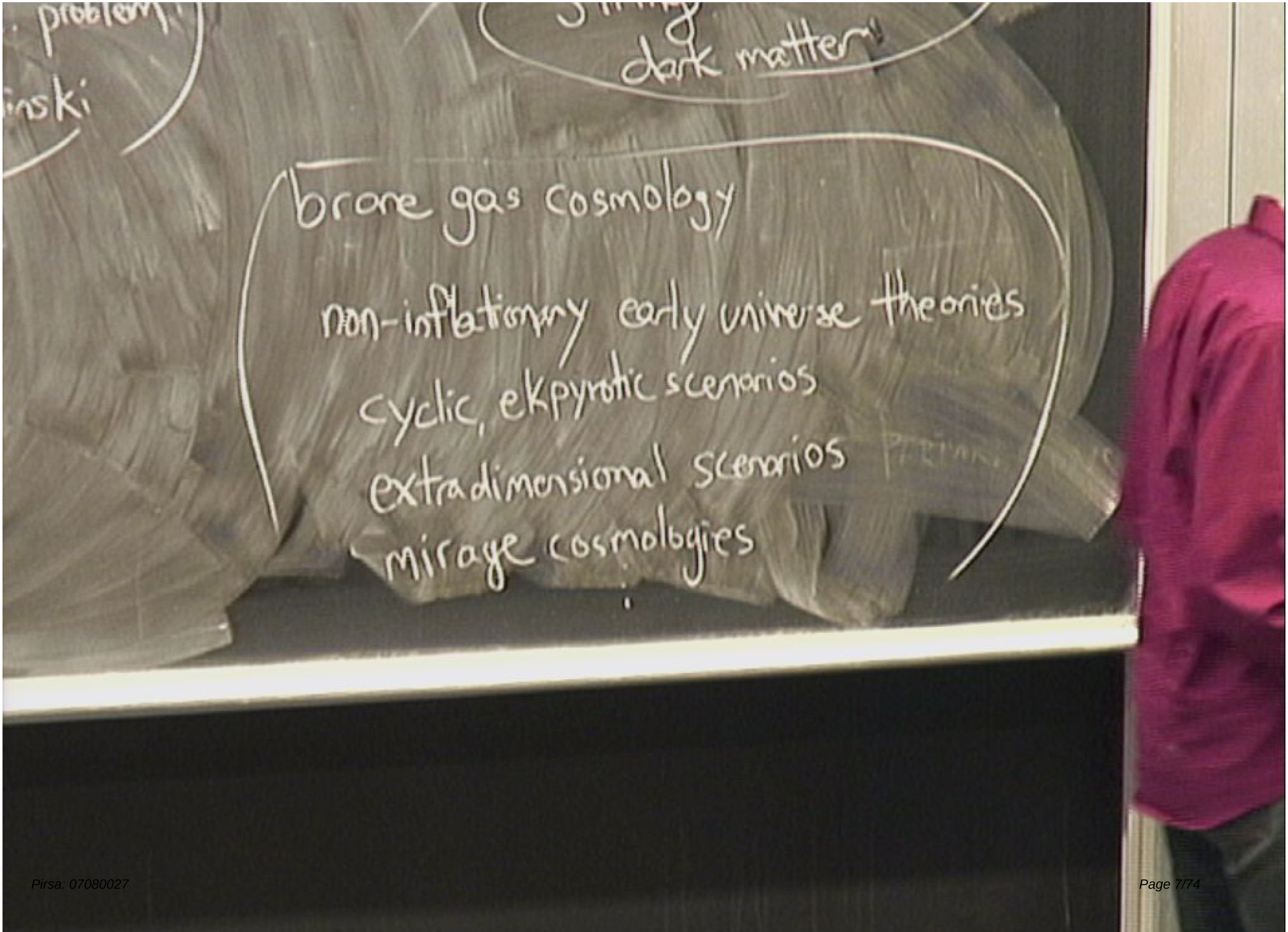
rio(s)
c.c. problem:
Polchinski

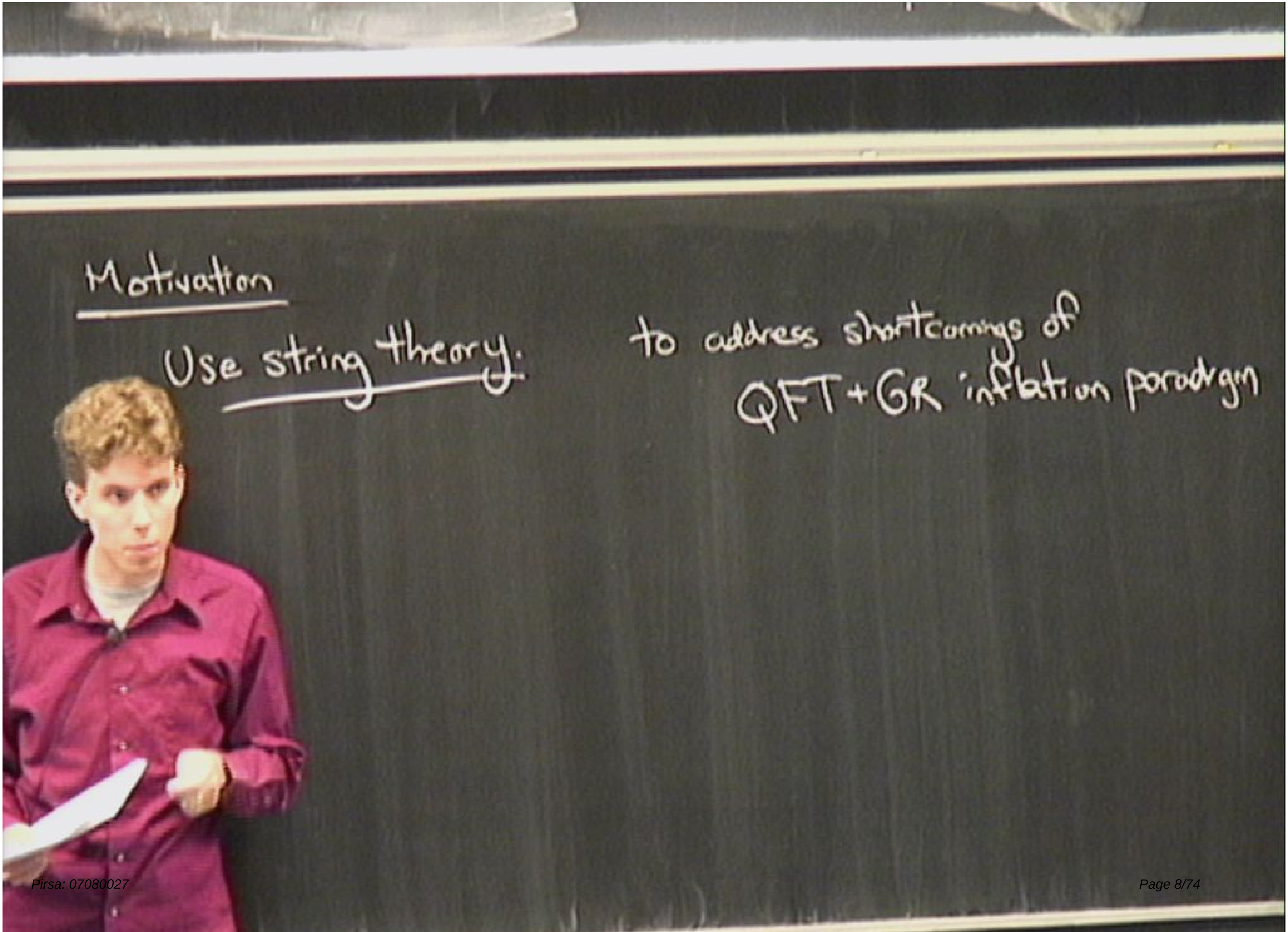
String ideas about dark matter:

brane gas cosmology

non-inflationary early universe theories

cyclic, ekpyrotic scenarios


dark matter!
brane gas cosmology
non-inflationary early universe theories
cyclic, ekpyrotic scenarios
extradimensional scenarios
mirage cosmologies


Motivation
Use string theory.
to address shortcomings of
QFT + GR inflation paradigm

QFT + GR inflation paradigm

(1) is ST consistent w/observation?

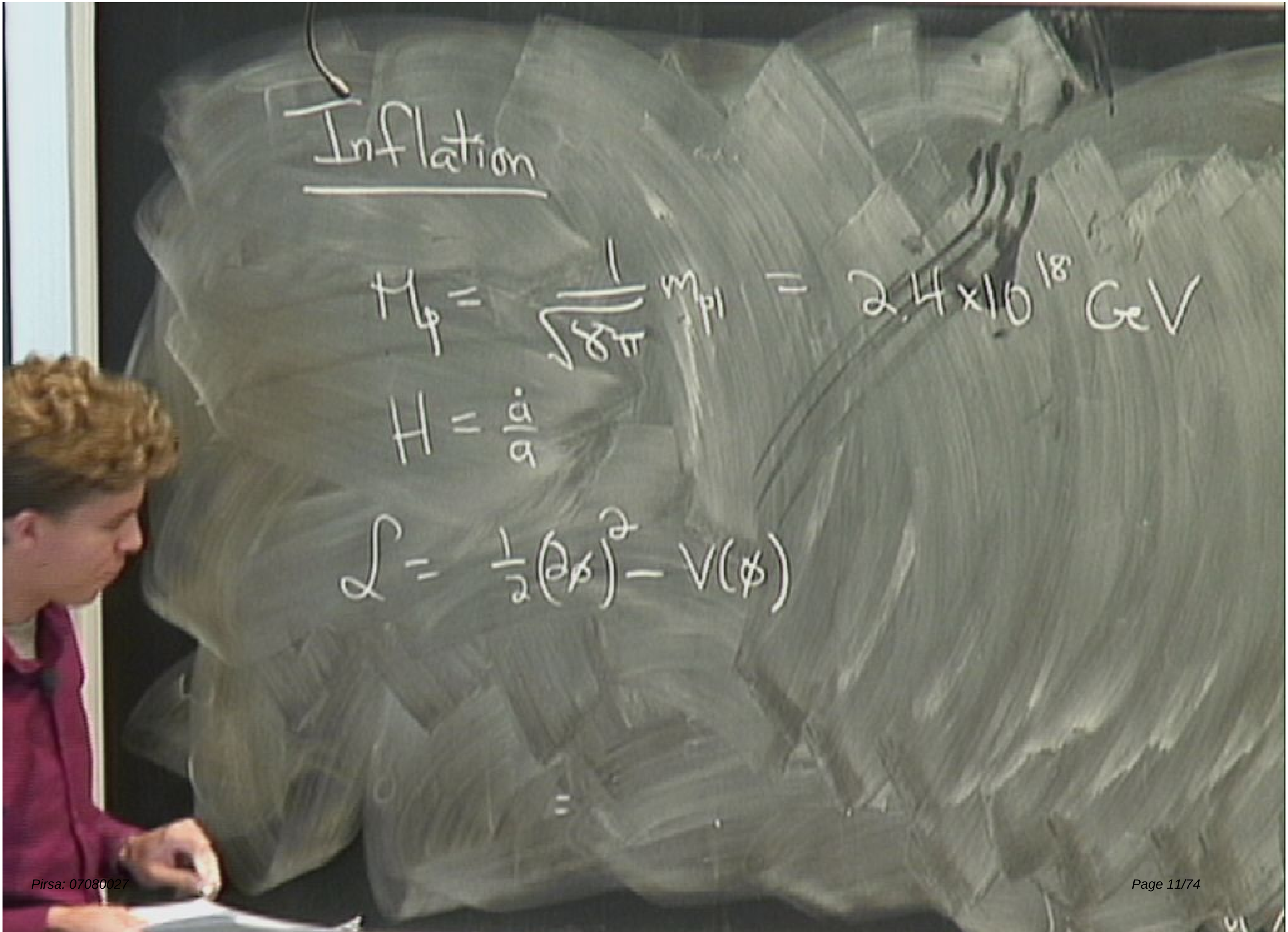
(2) to restrict attention to subsectors of ST

(3) to give evidence for/against ST.

↳ inflation in St

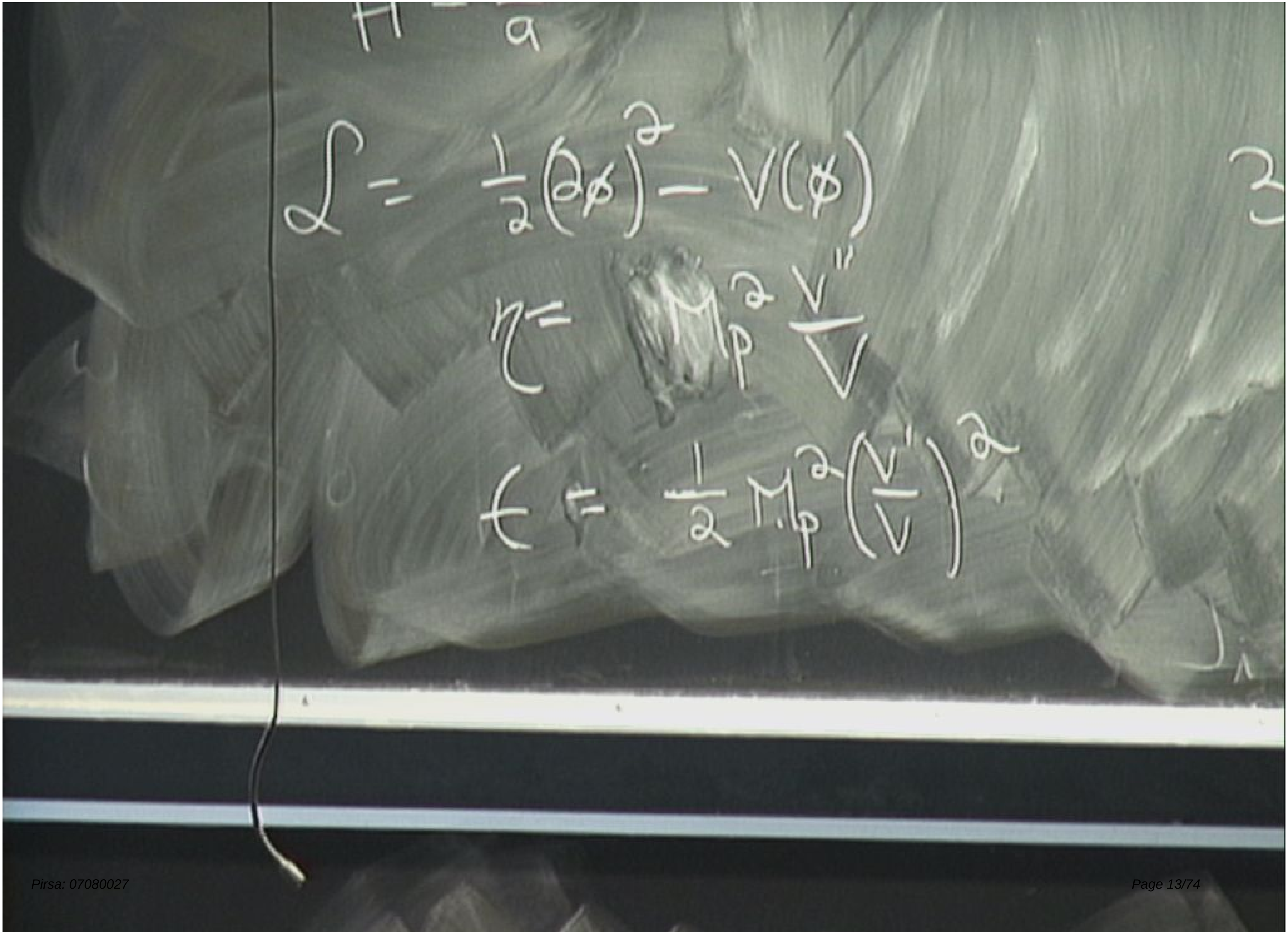
How can we achieve inflation in S.T.?

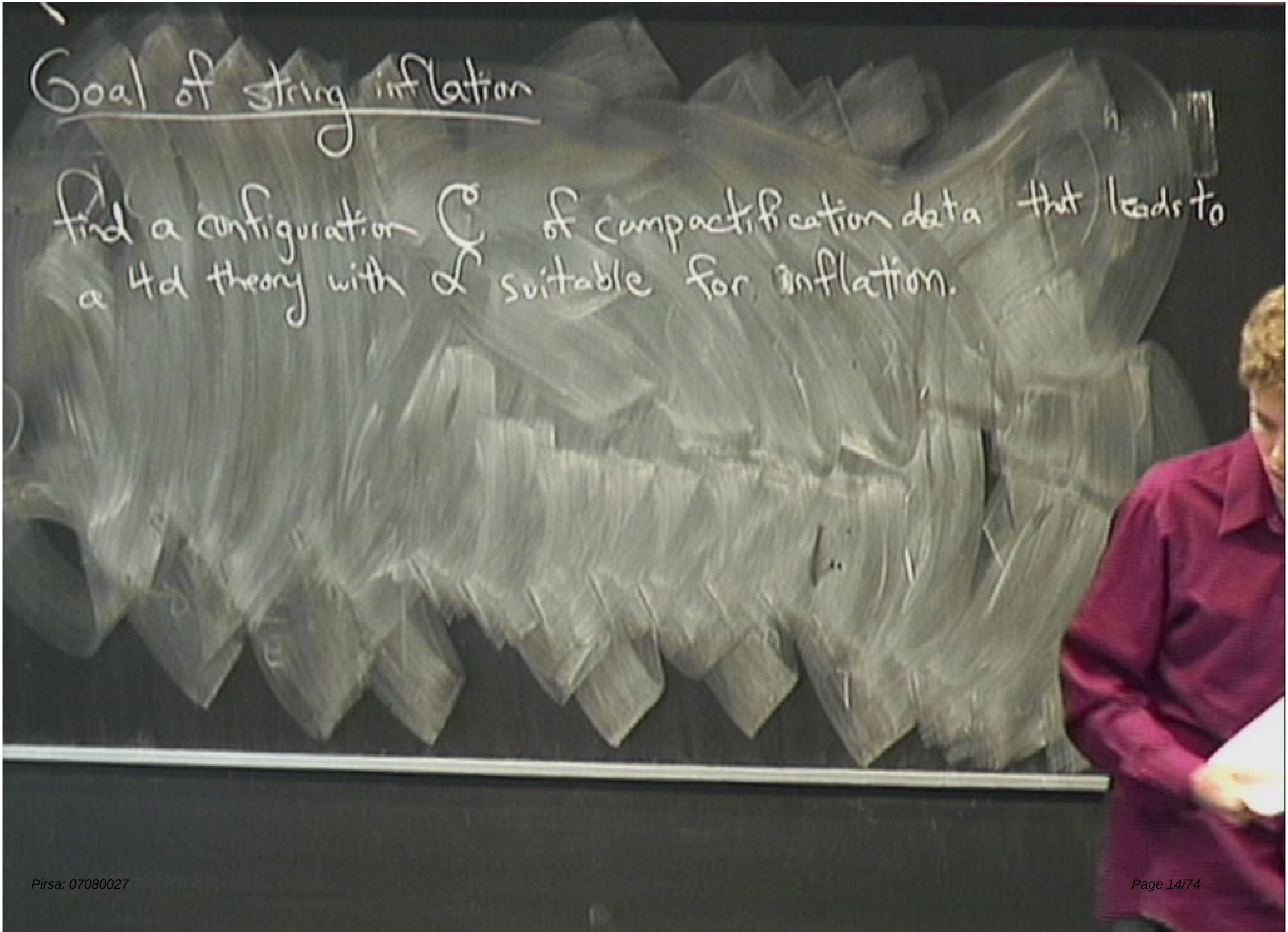
what are the special challenges?


Inflation
$M_p = \frac{1}{\sqrt{8\pi}} m_{pl} = 2.4 \times 10^{18}$ GeV
$H = \frac{\dot{a}}{a}$
$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - V(\phi)$

2.4×10^{18} GeV

$$3H^2M_p^2 = V(\phi) \quad \text{in slow roll}$$


$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - V(\phi)$
$\eta = M_p^2 \frac{V''}{V}$
$\epsilon = \frac{1}{2} M_p^2 \left(\frac{V'}{V}\right)^2$


Goal of string inflation
find a configuration $\mathcal{C}$ of compactification data that leads to a 4d theory with $\mathcal{L}$ suitable for inflation.

C^{σ} should be consistent.

eg. · no anomalies
· no tadpoles

typically choose C^0 to preserve SUSY

Typically ...

$\mathcal{C}$ should be computable

$\frac{\alpha'}{R^2} \ll 1$ large volume

$g_s \ll 1$ weak coupling

$\mathcal{C}$ should be explicit.

$\mathcal{C}$ should be explicit.

$\mathcal{L}$ should not have unstabilized moduli (

weak coupling

$g_s \ll 1$

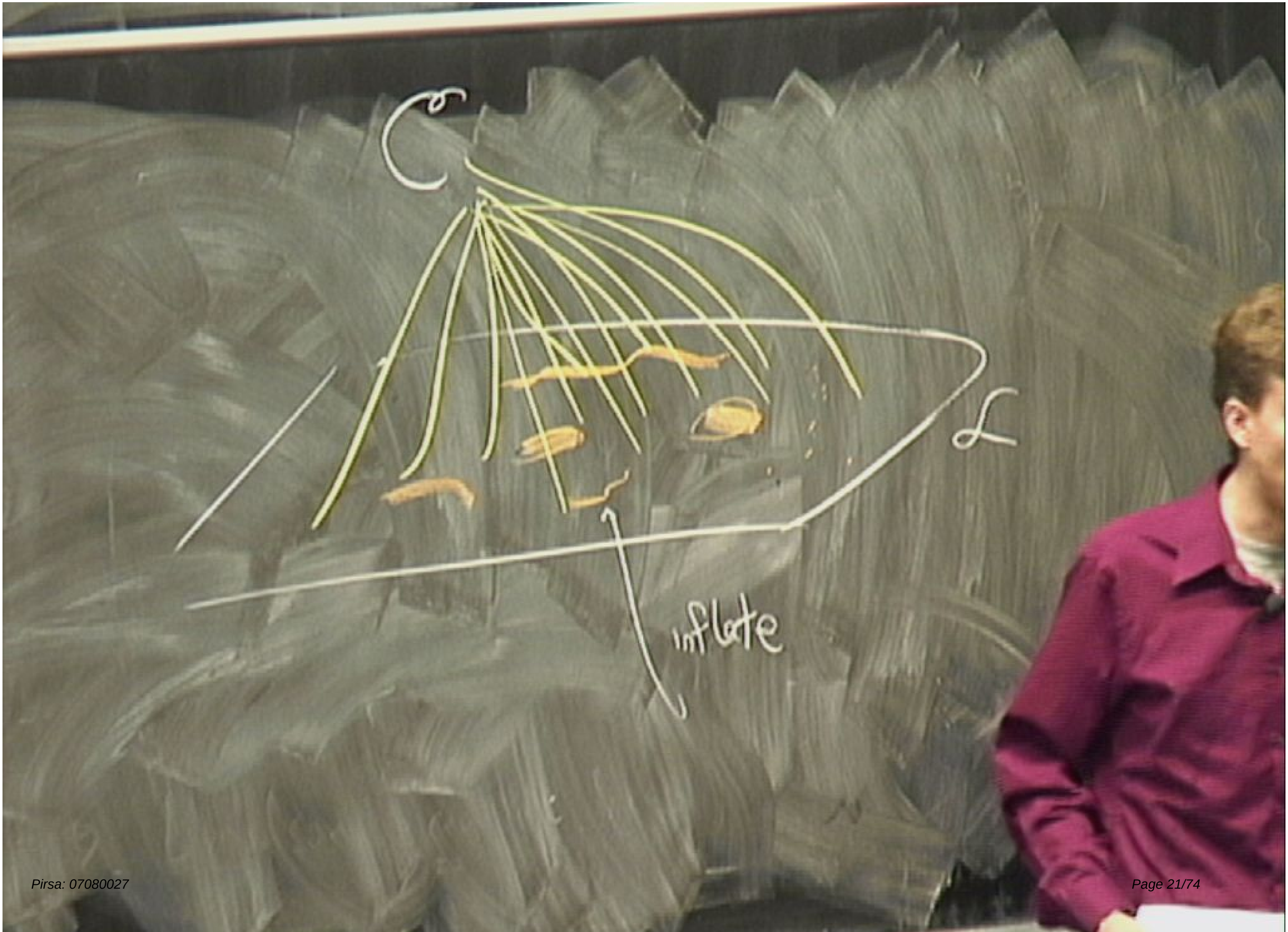
moduli: (light, gravitationally-coupled scalars)

Not yet:

$\mathcal{L}$ has distinctive signatures

$\mathcal{L}$ is natural

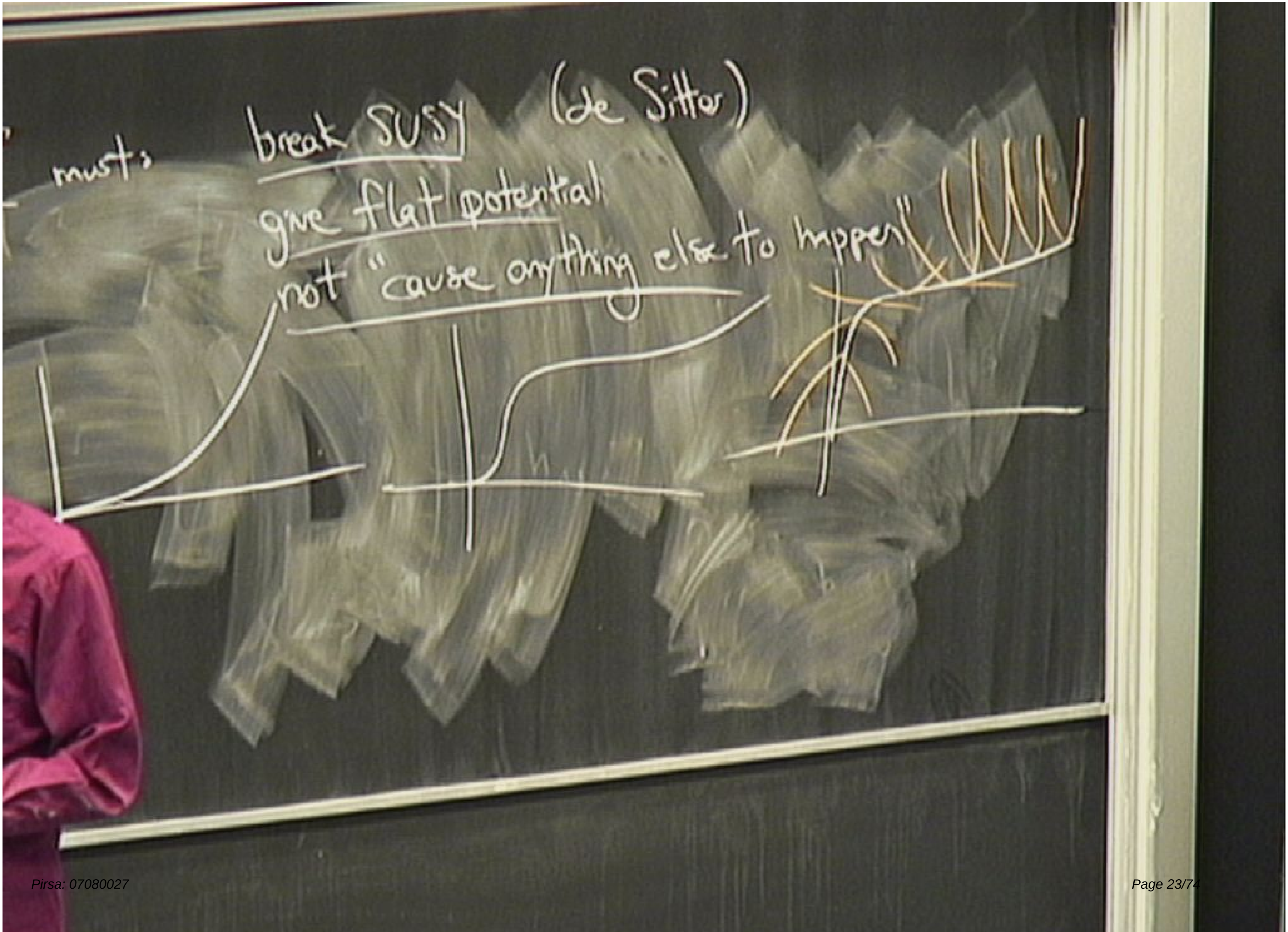
$\mathcal{L}$ could not arise in EFT


$\mathcal{C}$
$\mathcal{L}$
inflate

C^{o} must: break SUSY (de Sitter)

give flat potential

not "cause anything else to happen"


must:
break SUSY (de Sitter)
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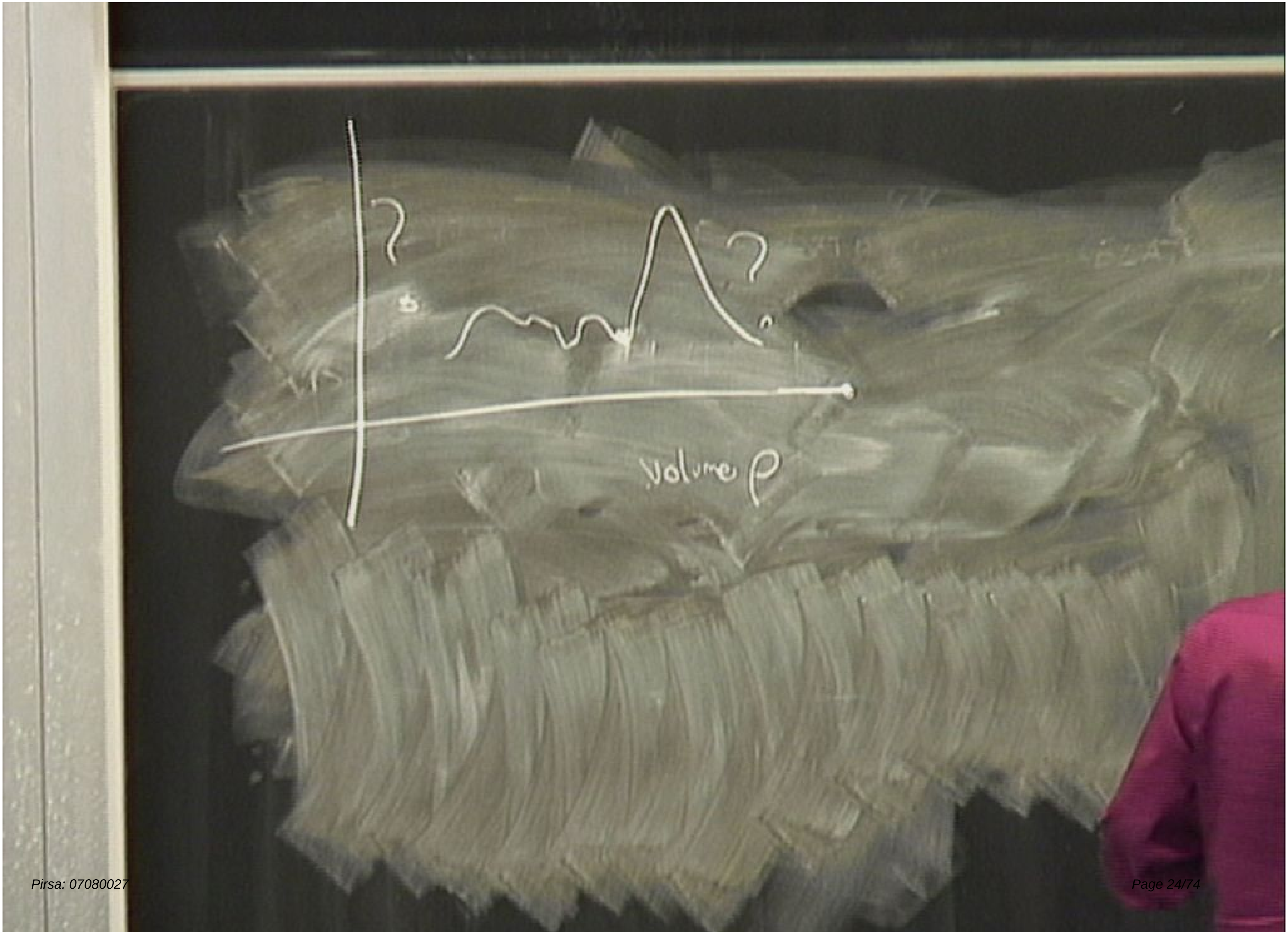
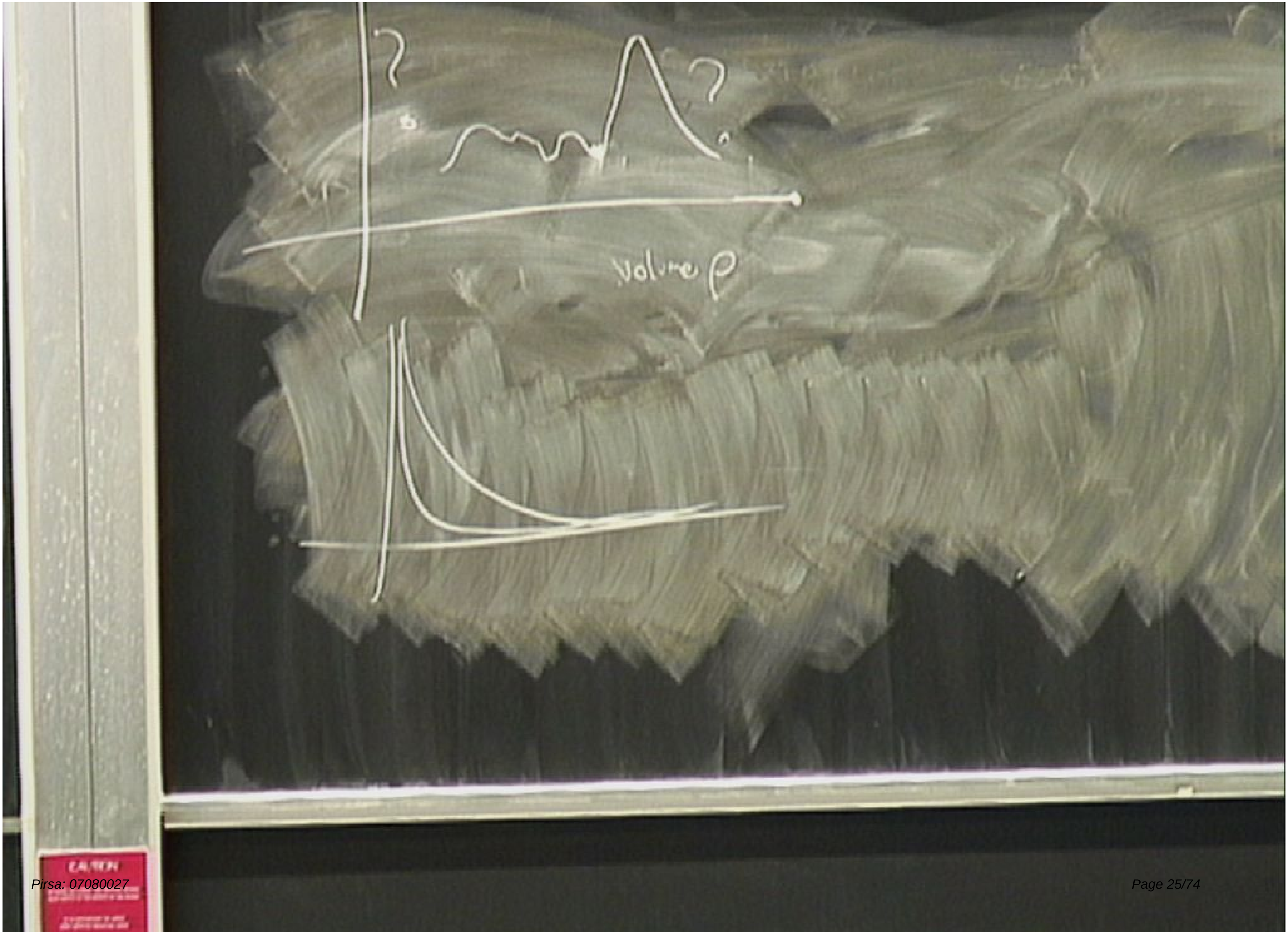

?
?
volume ρ


?
?
Volume ρ

1. SUSY compactification on CY

2. SUSY stabilization

3. controllable ~~SUSY~~

D3. embedded $\Sigma_4 \to M_{10}$

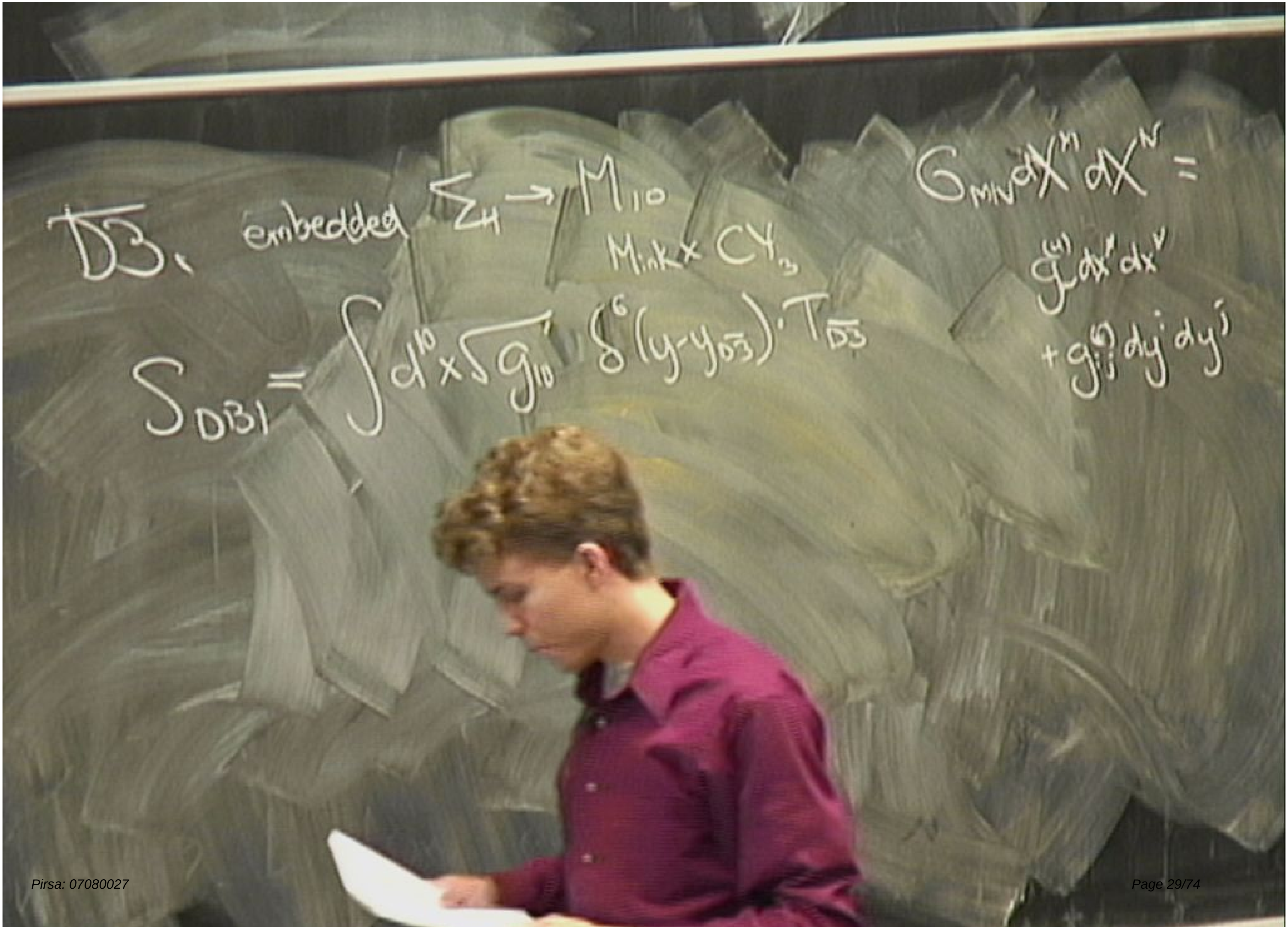
$\mathrm{Mink} \times CY_3$

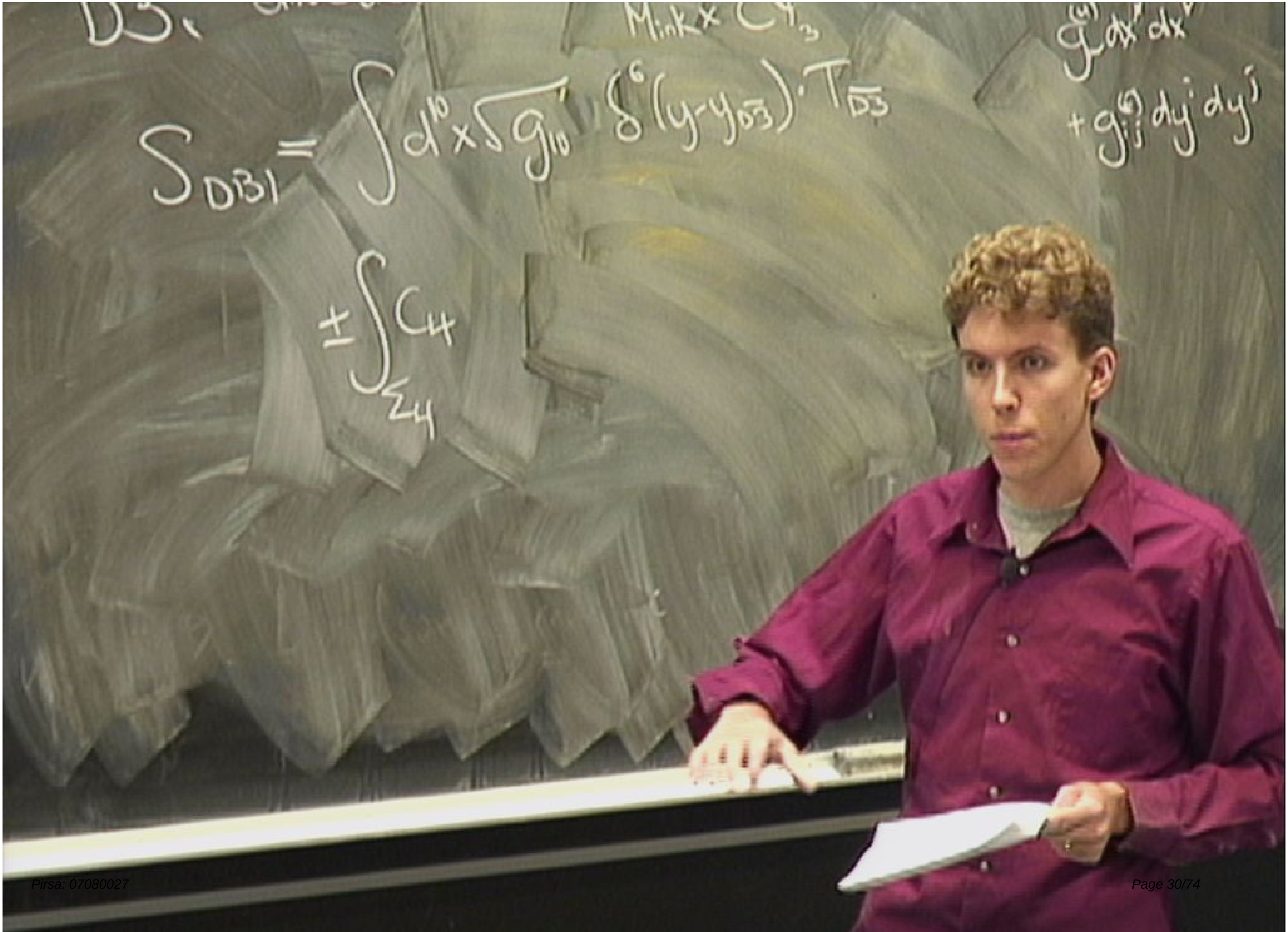
$\overline{D3}$. embedded $\Sigma_4 \to M_{10}$

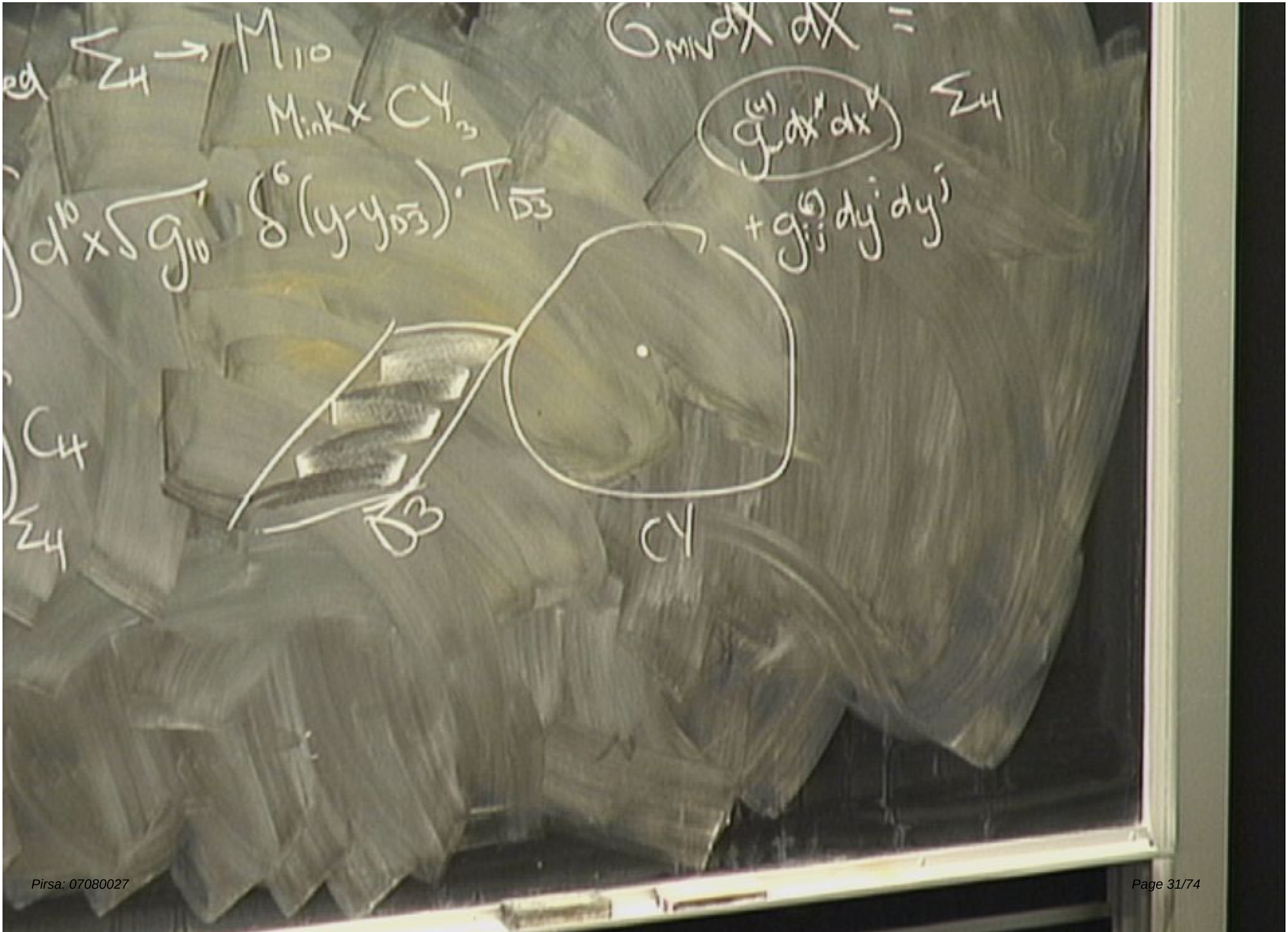
$\mathrm{Mink} \times CY_3$

$$S_{DBI} = \int d^{10}x \sqrt{g_{10}}\; \delta^6(y - y_{\overline{D3}}) \cdot T_{\overline{D3}}$$

$$G_{MN}\, dX^M dX^N = g_{\mu\nu}\, dx^\mu dx^\nu + g_{ij}\, dy^i dy^j$$


D3, embedded Σ4 → M10
Mink × CY3
S_DBI = ∫ d^10x √g10 δ^6(y−y_D3) · T_D3
G_MN dX^M dX^N =
g^(4)_μν dx^μ dx^ν
+ g^(6)_ij dy^i dy^j


D3,
Mink × CY3
S DBI = ∫ d10x √g10 δ6(y-yD3) · TD3
+ gij(6) dyi dyj
± ∫Σ4 C4


eq $\Sigma_4 \to M_{10}$
Mink × CY_3
$G_{MN} dX dX =$
$g^{(4)}_{\mu\nu} dx^\mu dx^\nu$
Σ_4
$+ g^{(6)}_{ij} dy^i dy^j$
$\int d^{10}x \sqrt{g_{10}}\ \delta^6(y - y_{\overline{D3}}) \cdot T_{\overline{D3}}$
C_4
Σ_4
D3
CY

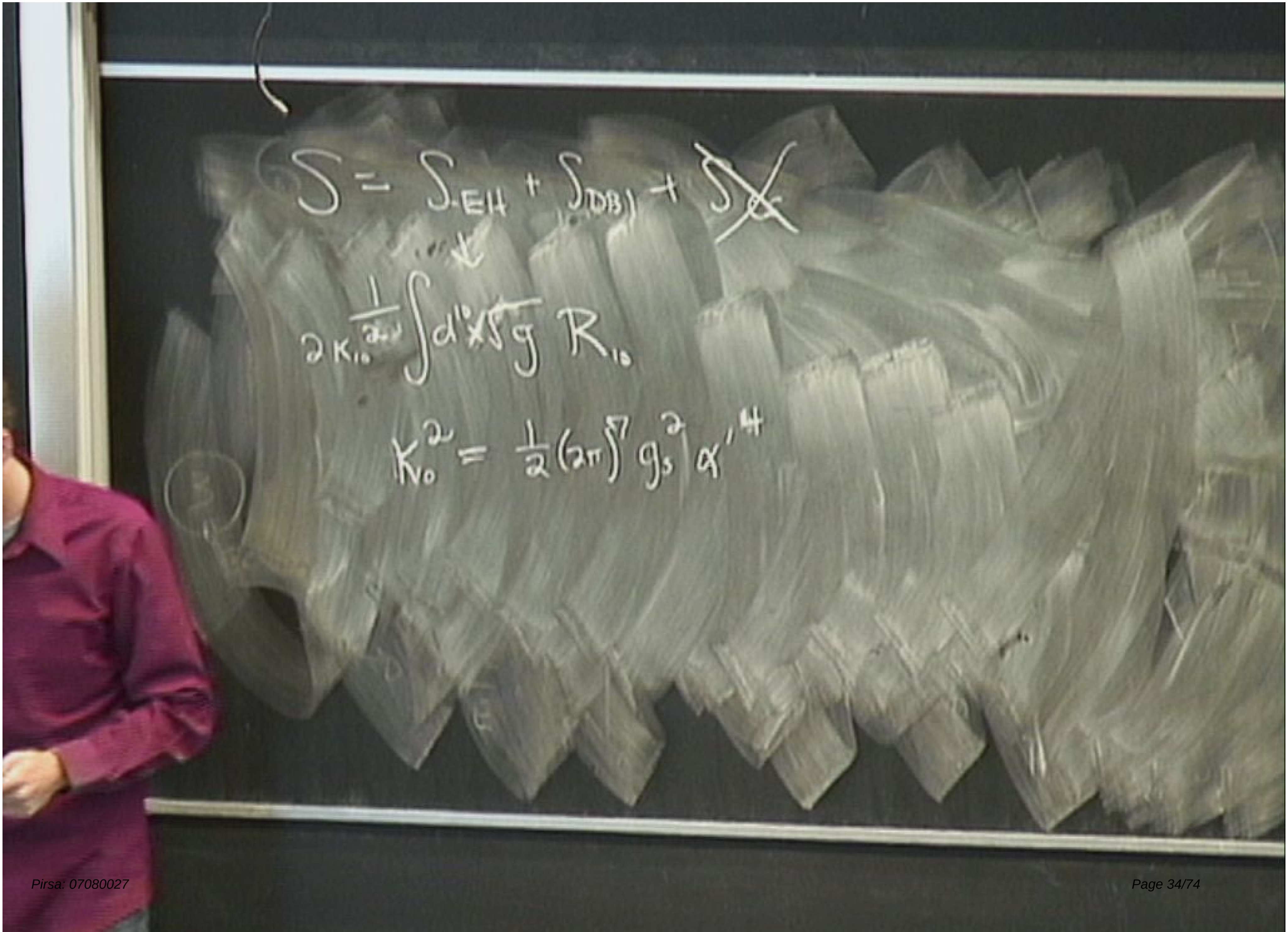
$$\pm \int_{\Sigma_4} C_4$$

$$S_{DBI} = T_{D3} \int_{\Sigma_4} d^4\xi \sqrt{g_{induced}}$$

Σ_4 $D3$ CY

$$S_{DBI} = T_{\overline{D3}} \int_{\Sigma_4} d^4\xi \sqrt{g_{induced}}$$

$$T_{\overline{D3}} = \frac{1}{(2\pi)^3} \frac{1}{g_s} \frac{1}{\alpha'^2}$$


$S = S_{EH} + S_{DBI} + \cancel{S_X}$
$\frac{1}{2\kappa_{10}^2}\int d^{10}x\sqrt{-g}\,R_{10}$
$\kappa_{10}^2 = \frac{1}{2}(2\pi)^7 g_s^2 \alpha'^4$

$$S = S_{EH} + S_{DBI} + \cancel{S_{X}}$$

$$\downarrow$$

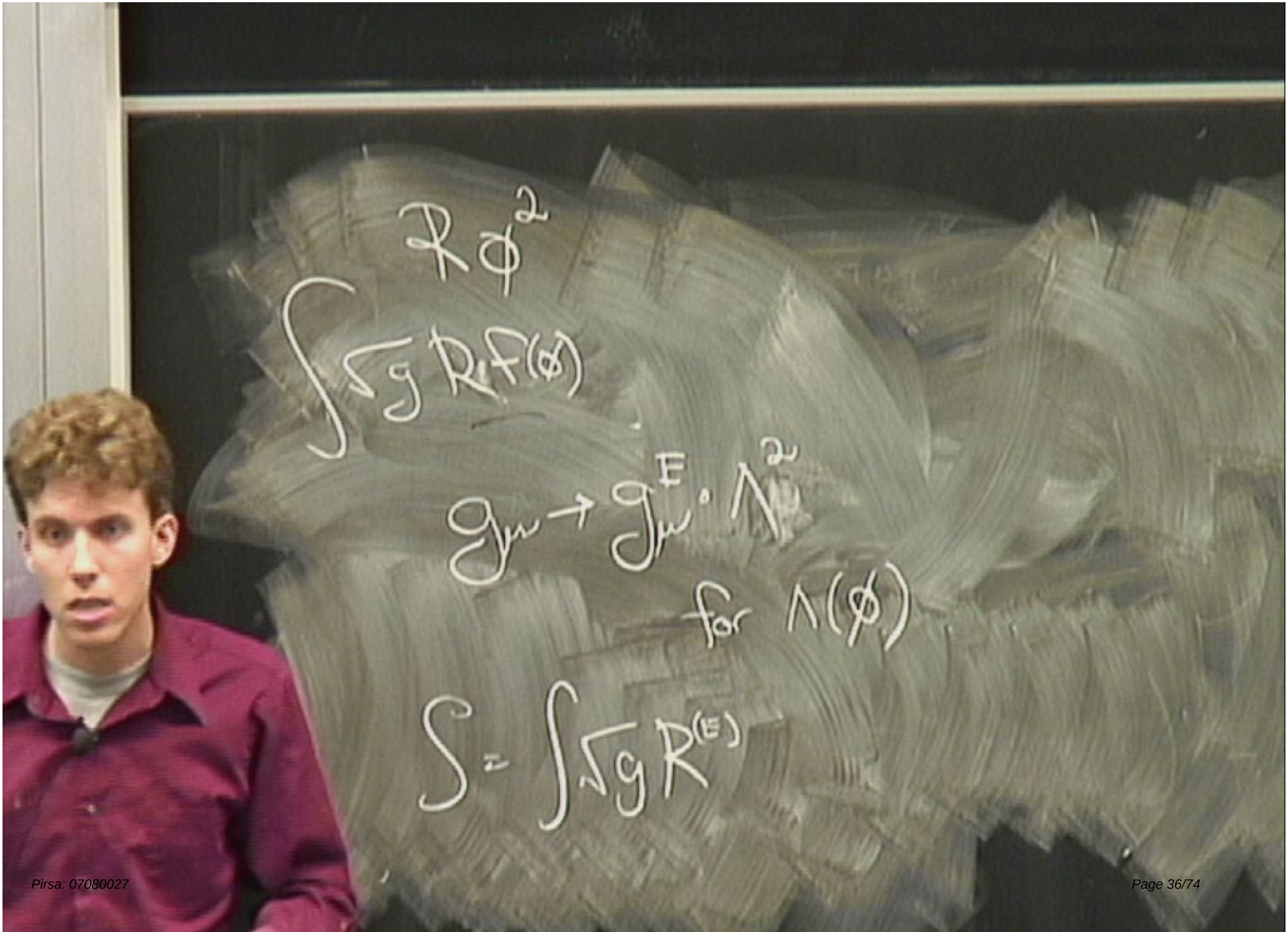
$$\frac{1}{2\kappa_{10}^2}\int d^{10}x\sqrt{g}\,R_{10}$$

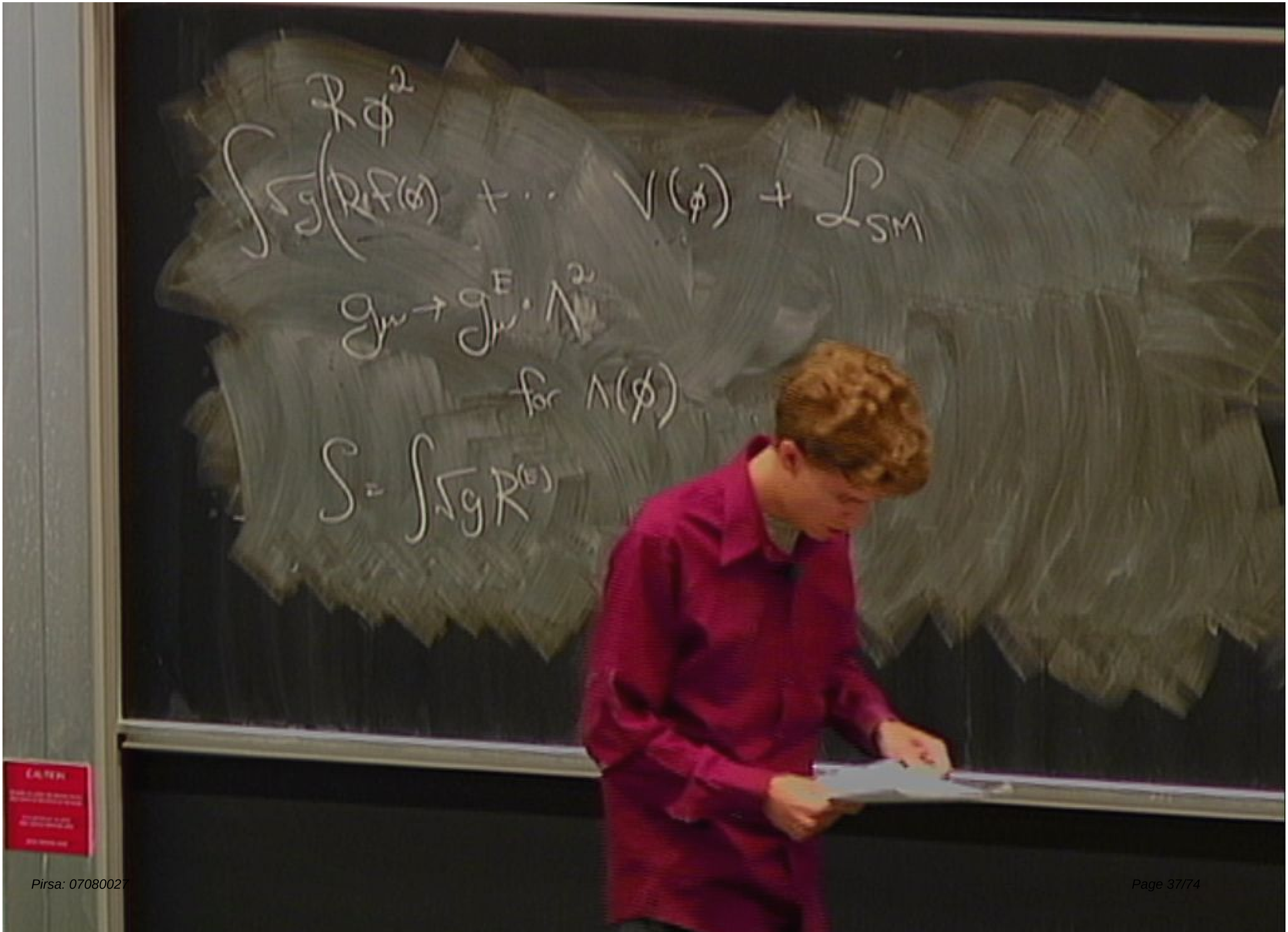
$$\left[\kappa_{10}^2 = \frac{1}{2}(2\pi)^7 g_s^2 \alpha'^4\right]$$

$$R_{10} \to R_4 + \ldots$$

$$= \frac{1}{2\kappa_{10}^2}\int d^4x\sqrt{g_4}\,\underbrace{\int d^6y\sqrt{g_6}}_{V_{CY}}\,R_4$$

$$= \frac{1}{2\kappa_{10}^2}\int d^4x\sqrt{g}\,R_4\cdot V_{CY}$$


$R\phi^2$
$\int \sqrt{g}\, R\, f(\phi)$
$g_{\mu\nu} \to g^{E}_{\mu\nu} \cdot \Lambda^2$
for $\Lambda(\phi)$
$S = \int \sqrt{g}\, R^{(E)}$


$R\phi^2$
$\int\sqrt{g}\left(R f(\phi) + \dots V(\phi) + \mathcal{L}_{SM}\right.$
$g_{\mu\nu} \to g^E_{\mu\nu} \cdot \Lambda^2$
for $\Lambda(\phi)$
$S = \int\sqrt{g}\,R^{(E)}$

Exercise 1 find $\Lambda(V_{CY})$ such that one ends up in 4d Einstein frame.

Exercise 1

- find $\Lambda(V_{CY})$ such that one ends up in 4d Einstein frame.
- show that $S_{DBI}(\overline{D3})$ in Einstein frame

$$= \frac{1}{(2\pi)^3} \frac{1}{g_s} \frac{1}{\alpha'^2} \int d^4x \sqrt{g^E} \left(\frac{\alpha'^2}{V_{CY}}\right)^2$$

4d Einstein frame

• show that $S_{DBI}(\overline{D3})$ in Einstein frame

$$\frac{1}{(2\pi)^3}\frac{1}{g_s}\frac{1}{\alpha'^2}\int d^4x\sqrt{g^E}\left(\frac{\alpha'^3}{V_{CY}}\right)^2$$

$$S_{D3+\overline{D3}} = \frac{2T_{D3}}{V_{CY}^2}\left(1+\text{interaction}\right)$$

Show that $S_{D3}(\overline{D3})$

$$\frac{1}{(2\pi)^3}\frac{1}{g_s}\frac{1}{\alpha'^2}\int d^4x\sqrt{g^E}\left(\frac{\alpha'^3}{V_{CY}}\right)^2$$

$$S_{D3+\overline{D3}} = \frac{2T_{D3}}{V_{CY}^2}\left(1+\text{interaction}\right)$$

- find the kinetic term for R with $R^6 = V_{CY}$

$$\frac{1}{2\kappa_{10}^2}\int d^4x\sqrt{g_4}\int d^6y\sqrt{g_6}\,R_4$$

$$\underbrace{\int d^6y\sqrt{g_6}}_{V_{CY}}$$

$$= \frac{1}{2\kappa_{10}^2}\int d^4x\sqrt{g}\,R_4\,V_{CY}$$

$$R_4(g),\; R_4^E(g^E = g\Lambda^2)$$

Moduli problem:

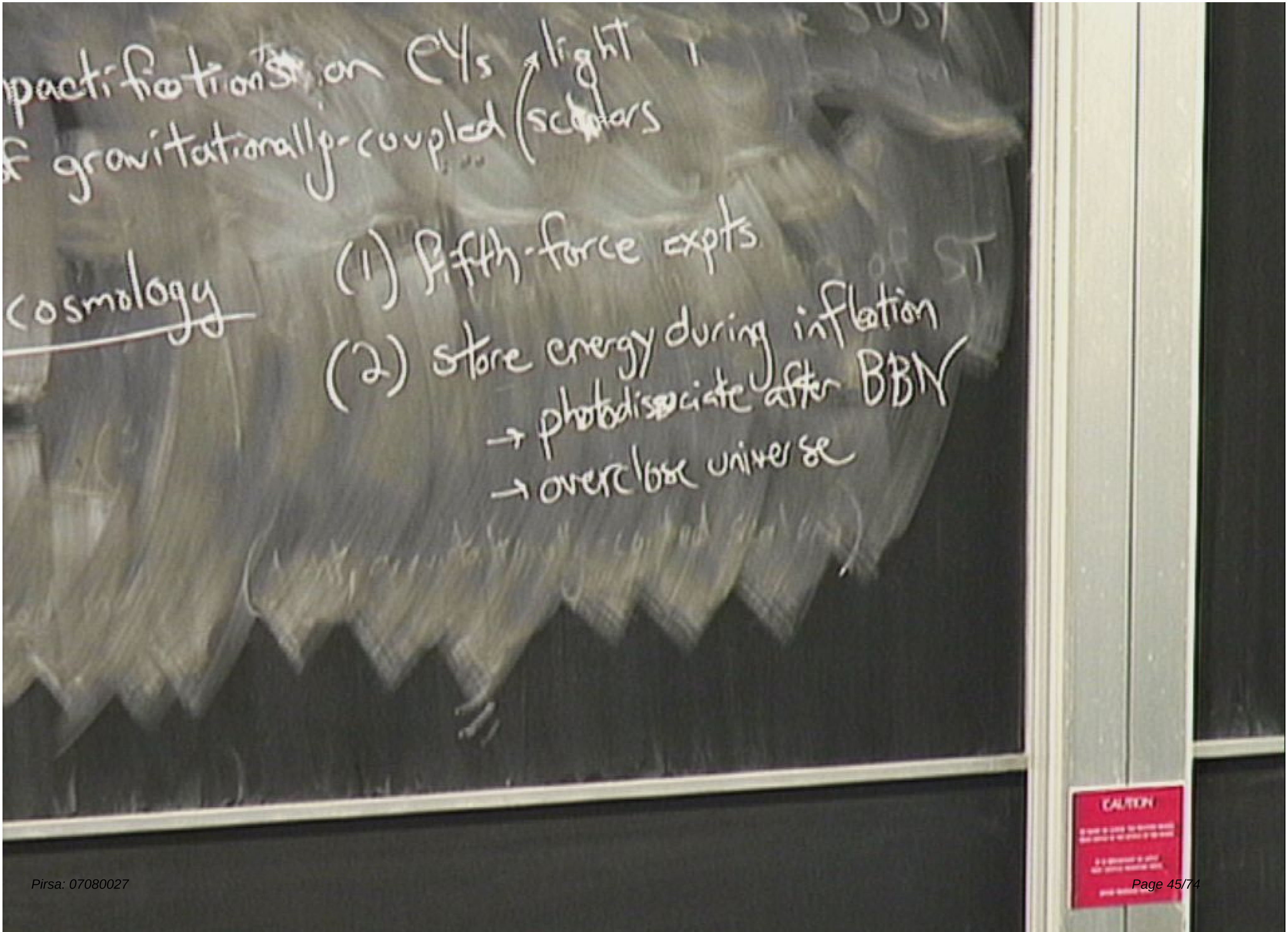
generic string compactifications on CYs light

have $\mathcal{O}$(100's) of gravitationally-coupled (scalars ric string compactifications on CY's light

ve $\mathcal{O}$(100's) of gravitationally-coupled (scalars

fatal in cosmology

(1) fifth-force expts


pactifications on CYs
light
f gravitationally-coupled (scalars
cosmology
(1) fifth-force expts
(2) store energy during inflation
→ photodissociate after BBN
→ overclose universe

fatal in cosmology

(1) fifth-force expts

(2) store energy durin

$\rightarrow$ photodissociate

$\rightarrow$ overclose univ

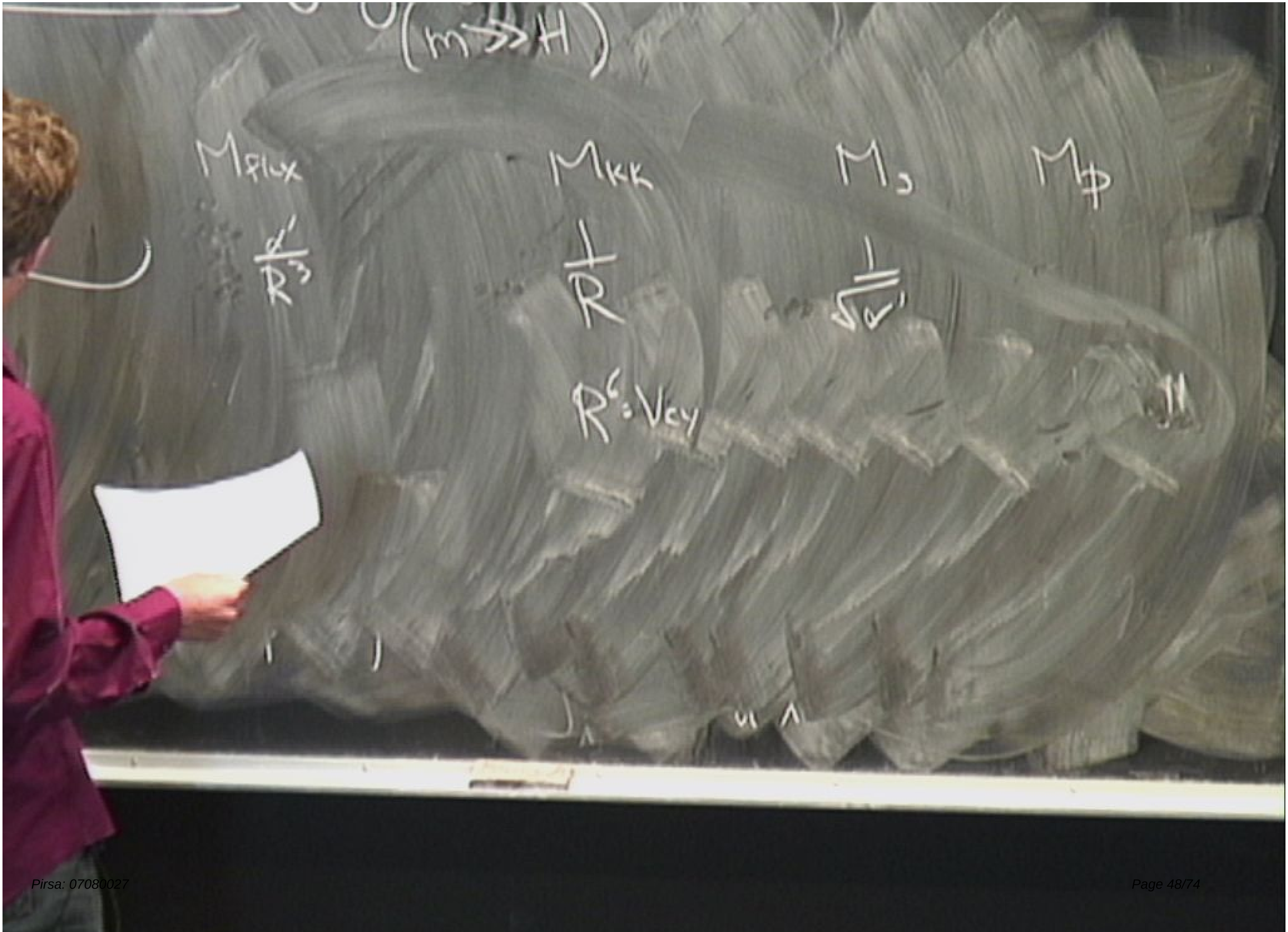
(2): $m \gg 30\,\text{TeV}$

$\tau \ll \ldots s$

$m \gg H$: don't fluctuate

moduli stabilization: giving large masses to moduli

$(m \gg H)$


(m>>H)
M_flux
M_KK
M_s
M_P
α'/R^3
1/R
1/√α'
R^6 = V_CY

$(m \gg H)$

M_{flux} $\qquad$ M_{KK}

$\frac{\alpha'}{R^3}$ $\qquad$ $\frac{1}{R}$

EFT

in Stable compactification

$R^6 = V_{CY}$

M_{KK} $\quad M_s$ $\quad M_\phi$

$\frac{1}{R}$ $\quad \frac{1}{\sqrt{\alpha'}}$

$$M_\phi^2 = \frac{V_{cy}}{\alpha'^3}\,\frac{1}{\alpha'}\cdot\frac{1}{g_s^2}\,\frac{2}{(2\pi)^7}$$

$R^6 = V_{cy}$

Flux compactification

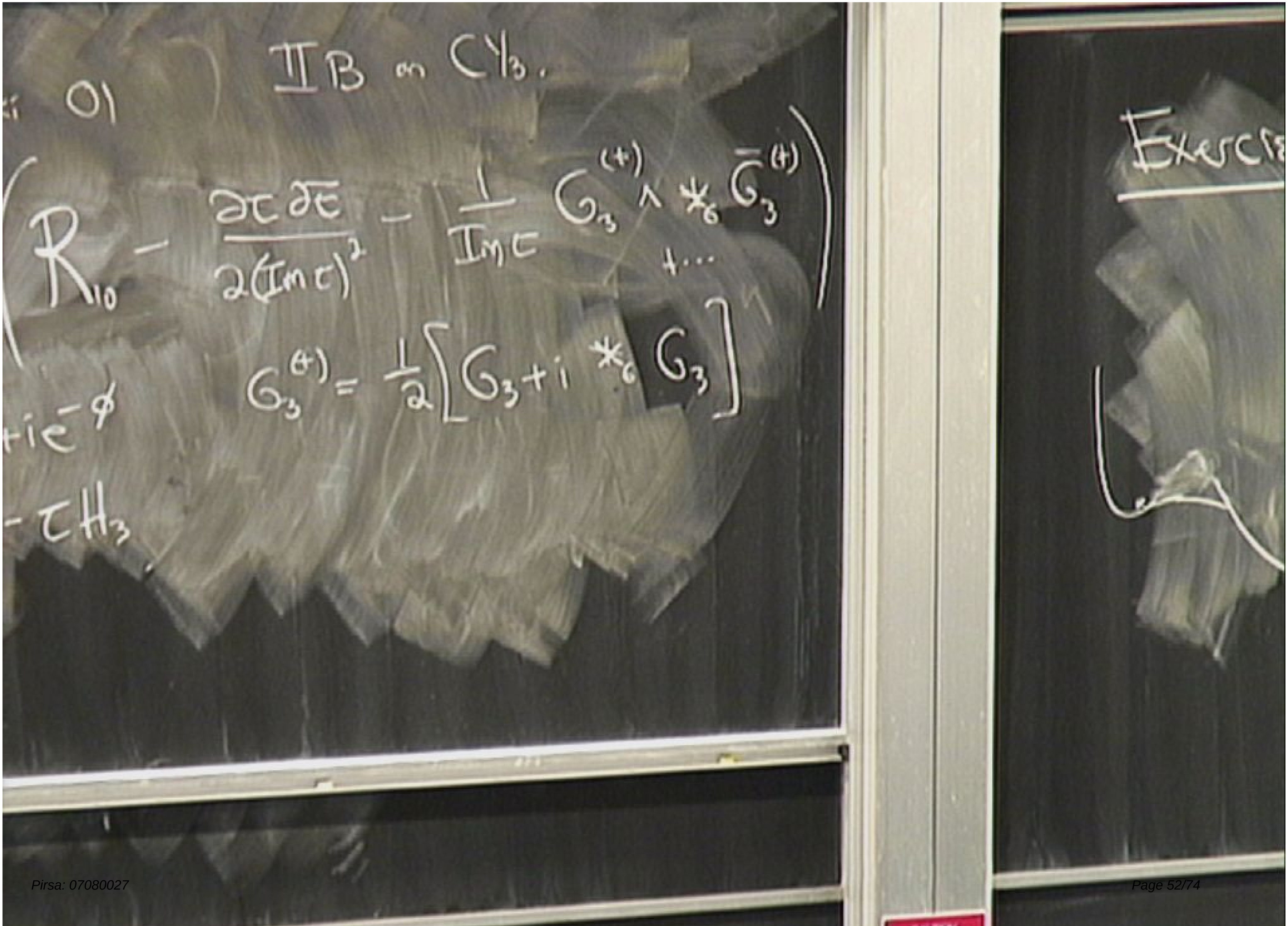
Giddings, Kachru, Polchinski 01

IIB on CY_3.

$$S_{IIB} = \frac{1}{2\kappa_{10}^2}\int d^{10}x\sqrt{g}\left(R_{10} - \frac{\partial\tau\,\partial\bar\tau}{2(\mathrm{Im}\,\tau)^2} - \frac{1}{\mathrm{Im}\,\tau}\,G_3^{(+)} \wedge *_6 \bar G_3^{(+)}\right.$$

$$\tau = C_0 + i e^{-\phi}$$

$$G_3 = F_3 - \tau H_3$$


IIB on CY3.
$R_{10} - \frac{\partial\tau\,\partial\bar\tau}{2(\mathrm{Im}\,\tau)^2} - \frac{1}{\mathrm{Im}\,\tau} G_3^{(+)} \wedge *_6 \bar{G}_3^{(+)} + \dots$
$G_3^{(+)} = \frac{1}{2}\left[G_3 + i *_6 G_3\right]$
$+ie^{-\phi}$
$-\tau H_3$
Exercis

$$R_{10} - \frac{\partial\tau\,\partial\bar\tau}{2(\mathrm{Im}\,\tau)^2} - \frac{1}{\mathrm{Im}\,\tau}\, G_3^{(+)} \wedge *_6 \bar G_3^{(+)} + \dots$$

$$G_3^{(+)} = \frac{1}{2}\left[G_3 + i *_6 G_3 \right]$$

$$\int_{\Sigma_3^{(\alpha)}} F_3 = (2\pi)^2 \alpha' N_F^{(\alpha)}$$

$$\int_{\Sigma_3^{(\alpha)}} H_3 = (2\pi)^2 \alpha' N_H^{(\alpha)}$$

3-form fluxes give a potential for all the complex structure moduli

Can show this V follows from $W = \int G \wedge \Omega$

give a potential for all the complex structure moduli

follows from $W = \int_{CY} G \wedge \Omega$ $\leftarrow$ hol (3,0) form

...tial for all the complex structure moduli

+ the dilaton.

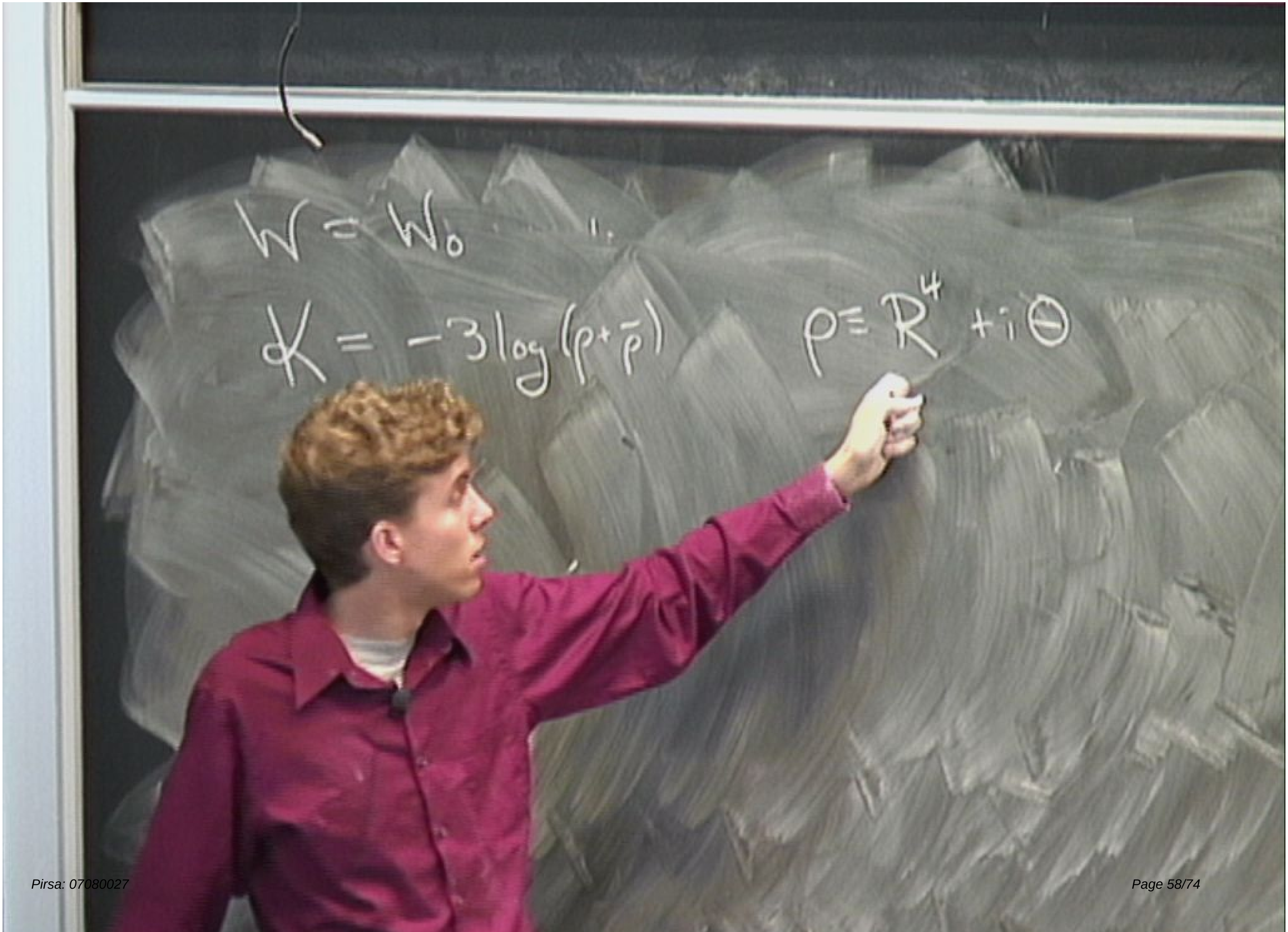
$$W = \int_{CY} G \wedge \Omega \equiv W_0$$

Ω ← hol (3,0) form

show this V follows from $W = \int_{CY} G \wedge \Omega \equiv W_0$

hol (3,0) form

<u>Left unfixed</u>: Kähler moduli "$\equiv$" overall volume


$W = W_0$
$K = -3 \log(\rho + \bar{\rho})$
$\rho \equiv R^4 + i\Theta$

$$
\begin{cases} W = W_0 \\ K = -3\log(\rho + \bar{\rho}) \end{cases} \qquad \rho \equiv R^4 + i\Theta, \quad \Theta \leftarrow \int_{\Sigma_4} C_4
$$

W <u>does not depend on R</u> (uses shift symmetry of Θ)

to any order in perturbation theory $\left(\frac{\alpha'}{R^2}\right)$

$\int_{\Sigma_4} C_4$

W does not depend on R. (cases shift

to any order in perturbation theory $\left(\frac{\alpha'}{R^2}\right)$

$$\Rightarrow W = W_0 + (?)\, e^{-R^{\#}}$$

KKLT 03

Consider $\mathcal{N}=1$ SU(N) SYM

with coupling g and cutoff M_{UV}. (NSVZ)

$$W = \left(16\pi^2 M_{UV}^3\right) e^{-\frac{8\pi^2}{Ng^2}}$$

KKLT 03

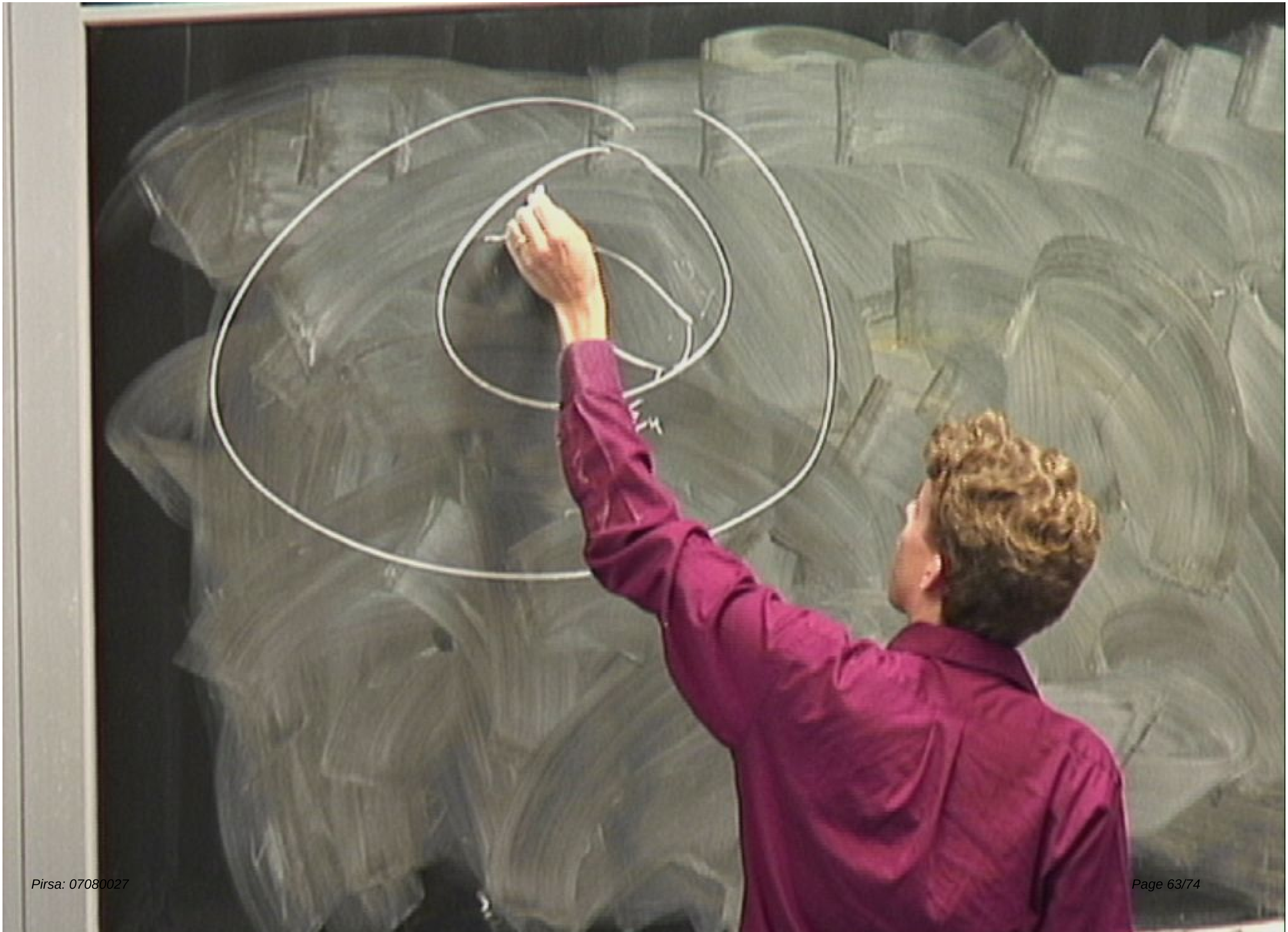
Consider $\mathcal{N}=1$ $SU(N)$ SYM

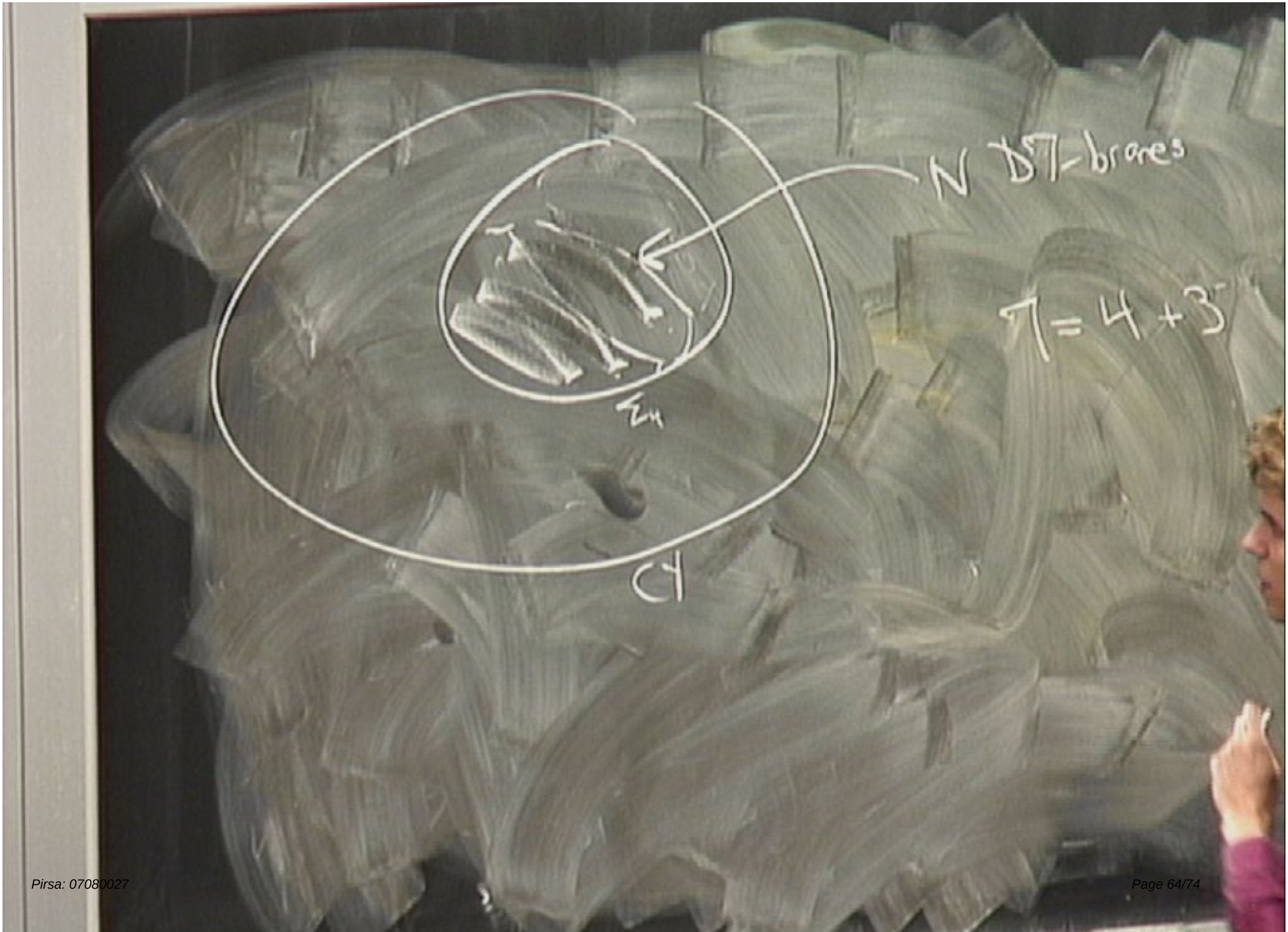
with coupling g and cutoff M_{uv}, (NSVZ

$$W \propto \left(16\pi^2 M_{uv}^3\right) e^{-\frac{8\pi^2}{Ng^2}}$$

"gaugino condensation"

$$W \propto \mathrm{tr}(\lambda\lambda)$$




N D7-branes
7 = 4 + 3
Σ4
CY

KKLT 03

Consider $\mathcal{N}=1$ $SU(N)$

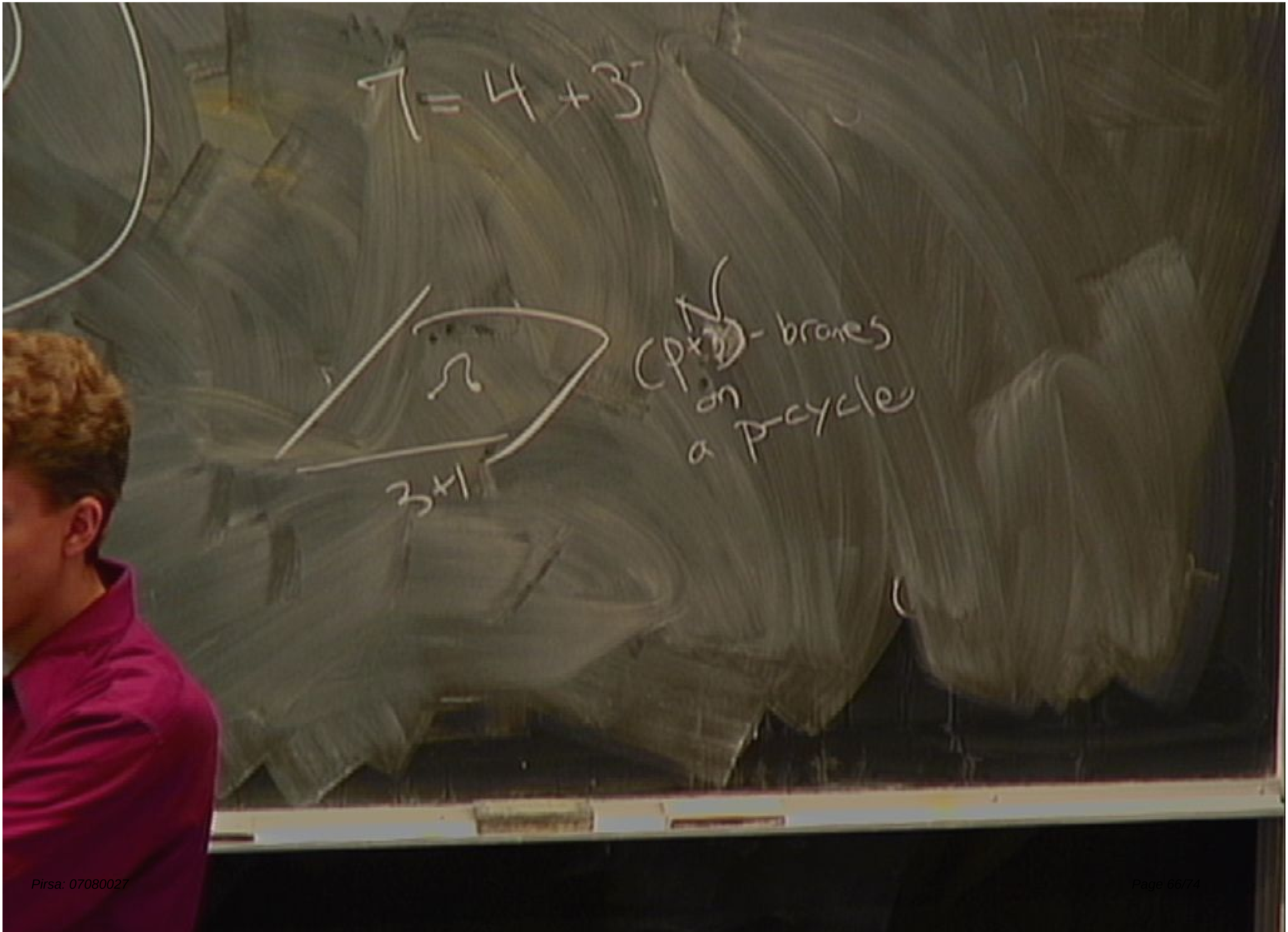
with coupling g and cutoff M_{UV}, (NSVZ)

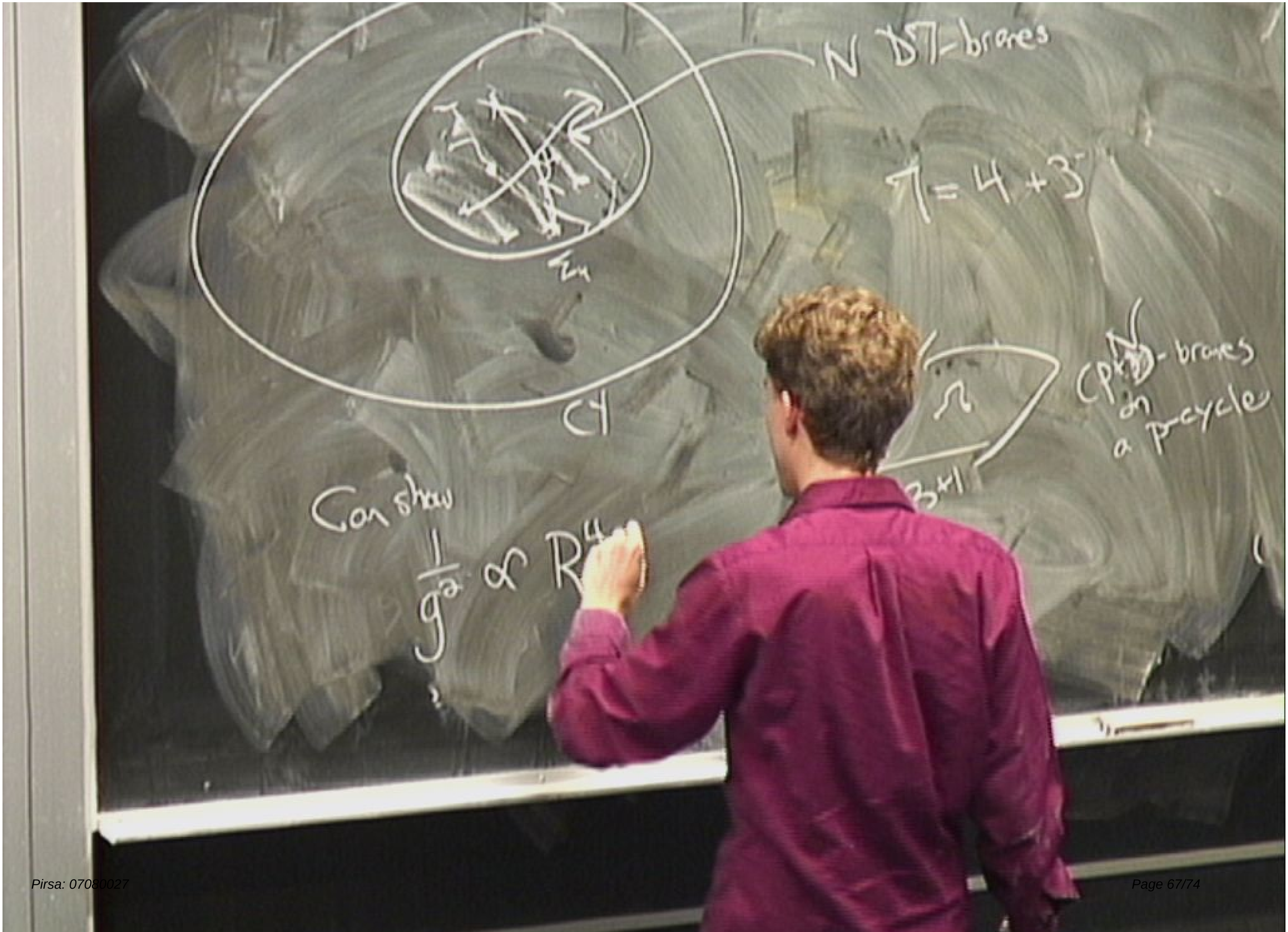
$$W \sim \left(16\pi^2 M_{UV}^3\right) e^{-\frac{8\pi^2}{N g^2}}$$

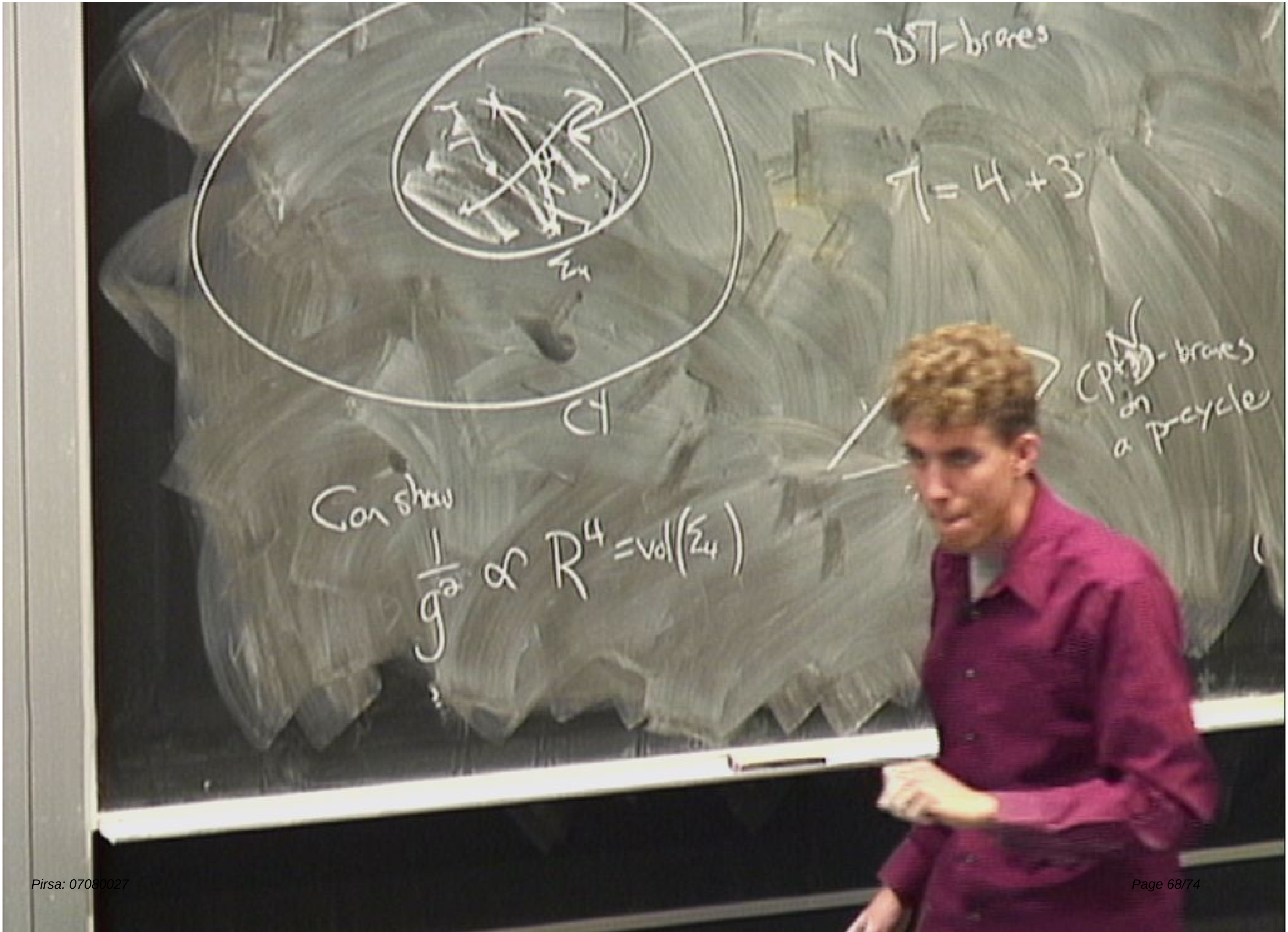
"gaugino condensation"

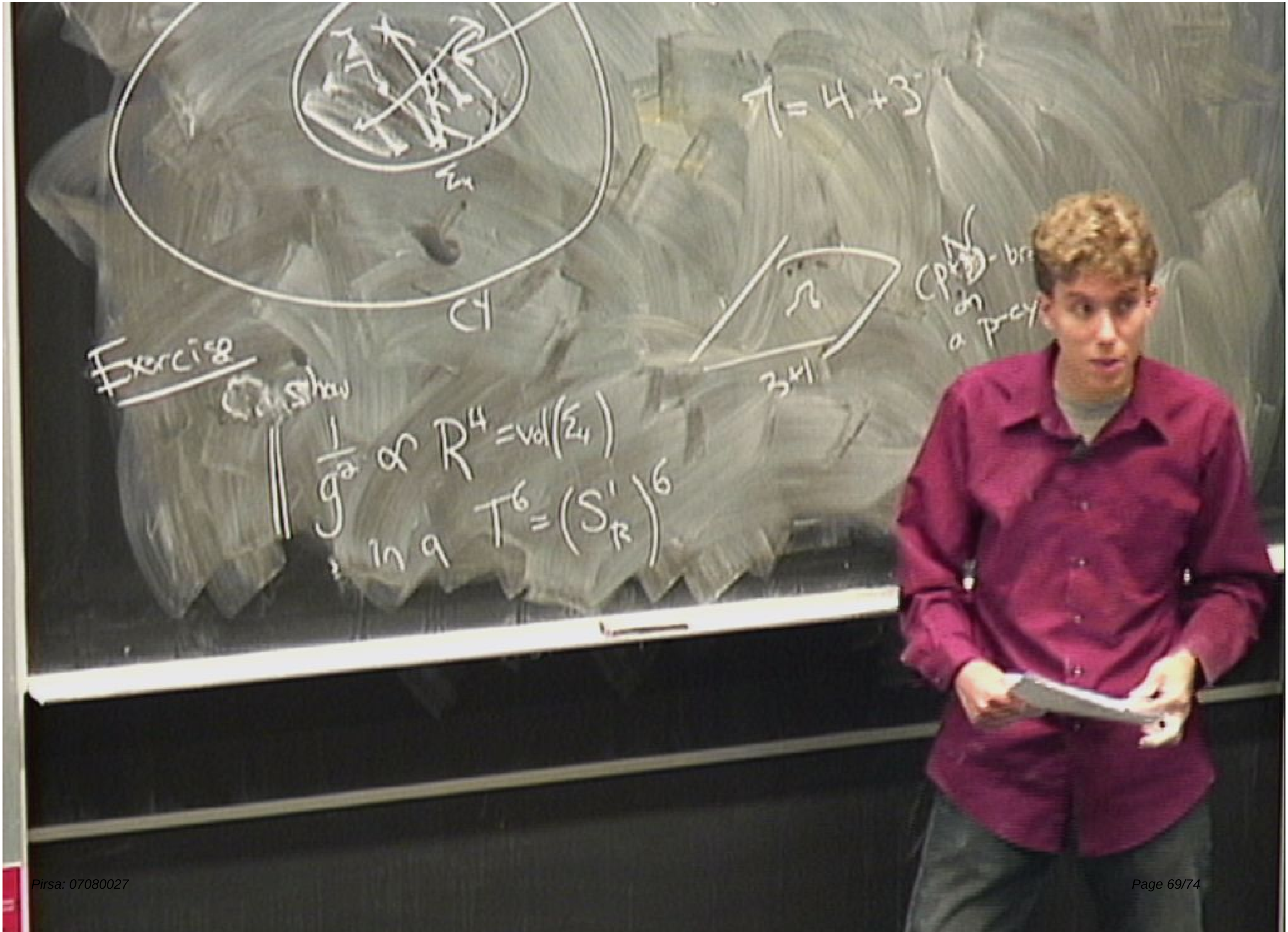
$$W \propto \mathrm{tr}(\lambda\lambda)$$

$$7 = 4 + 3$$


7 = 4 + 3
Ω
3+1
N (p+3)-branes
on
a p-cycle


N D7-branes
τ = 4 + 3
CY
Can show
1/g² ∝ R⁴
- branes
on
a p-cycle


N D7-branes
7 = 4 + 3
Σ4
CY
N
(p+3)-branes
on
a p-cycle
Can show
1/g² ∝ R⁴ = vol(Σ4)


CY
Σ_4
Exercise
show
$\frac{1}{g^2} \propto R^4 = \mathrm{vol}(\Sigma_4)$
in a $T^6 = (S^1_R)^6$
3+1
a p-cy

3-form fluxes to stabilize cx str moduli + dilaton

$$W_{flux} = \int G \wedge \Omega \equiv W_0$$

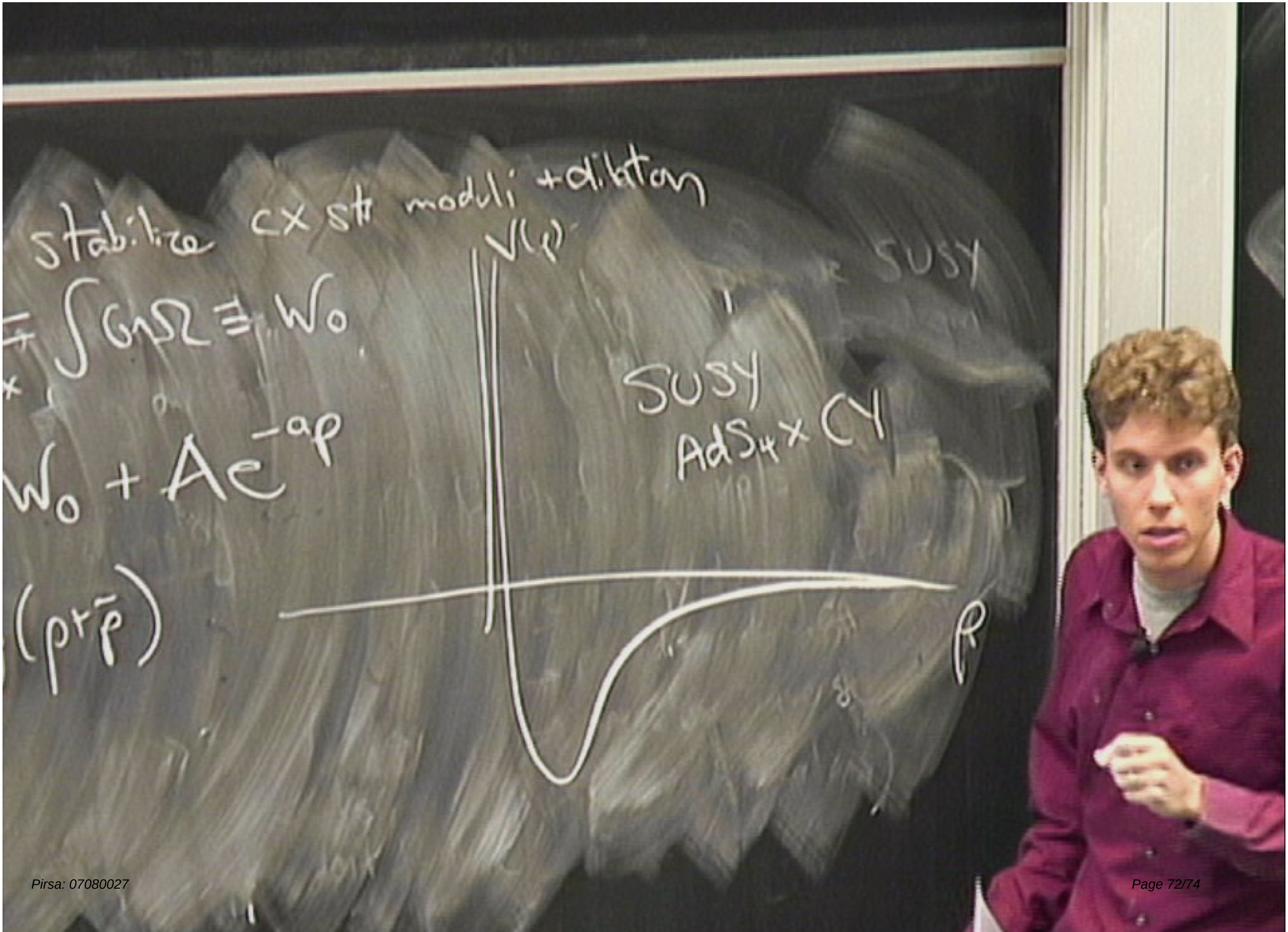
$$W_{total} = W_0 + A e^{-a\rho}$$

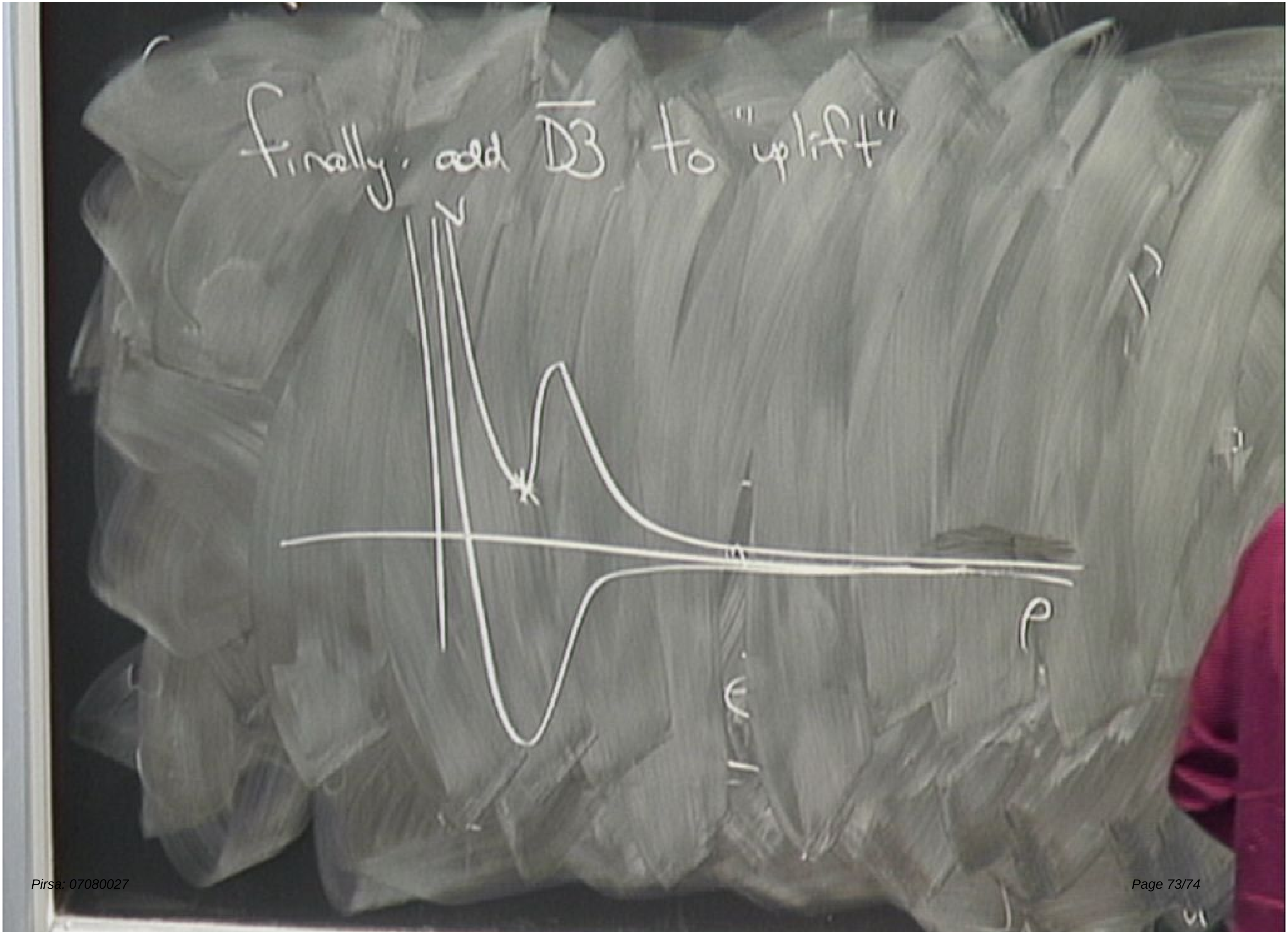
3-form fluxes to stabilize cx str moduli + dilaton

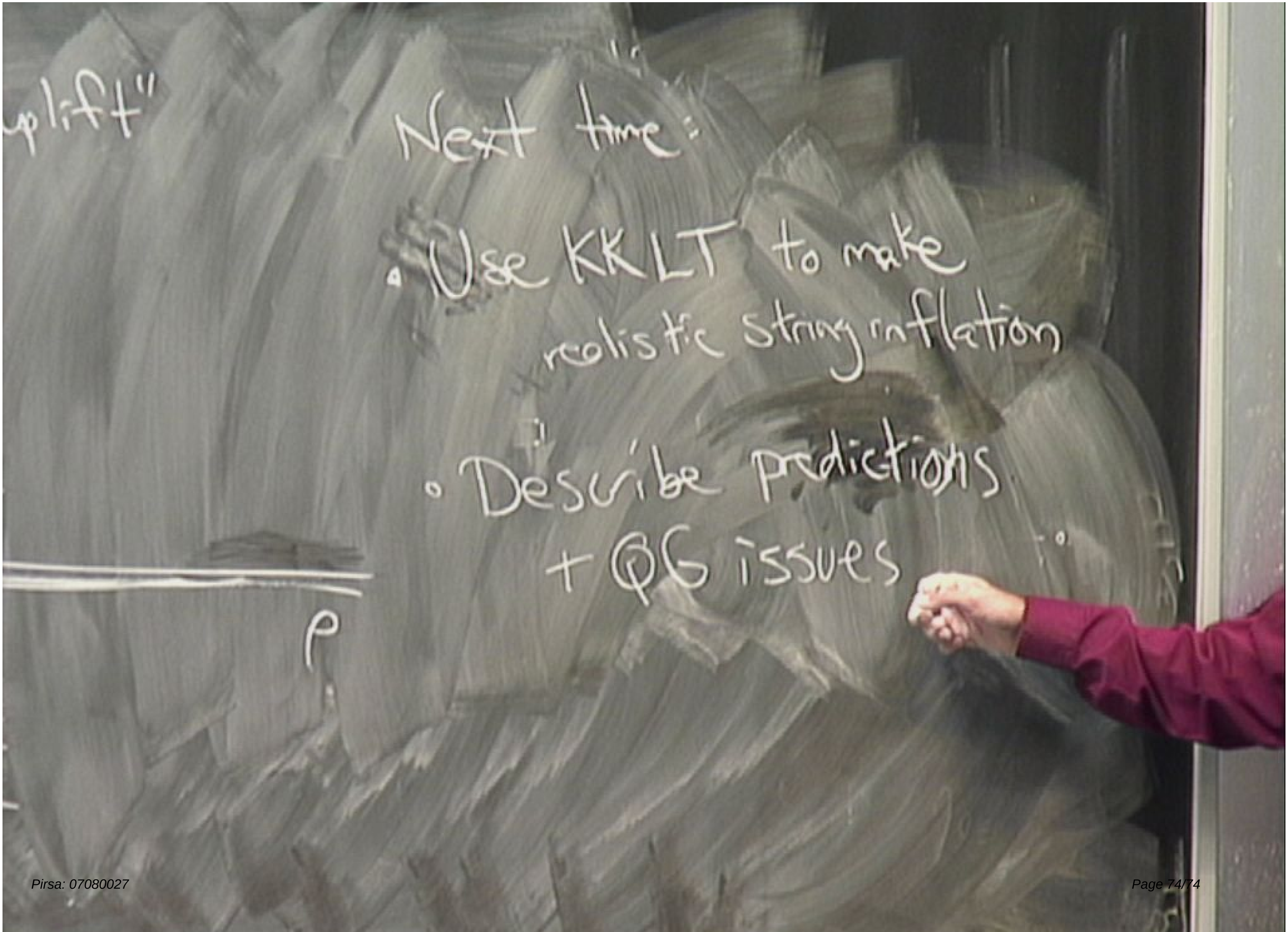
$$W_{flux} = \int G \wedge \Omega \equiv W_0$$

$$W_{total} = W_0 + Ae^{-a\rho}$$

$$K = -3\log(\rho + \bar{\rho})$$


stabilize cx str moduli + dilaton
$\int G \wedge \Omega \equiv W_0$
V(ρ)
SUSY
SUSY
AdS₄ × CY
$W_0 + Ae^{-a\rho}$
$(\rho + \bar{\rho})$
ρ


finally: add D3 to "uplift"
V
ρ


"uplift"
Next time:
• Use KKLT to make
realistic string inflation
• Describe predictions
+ QG issues
ρ