Title: Aspects of Moduli in String Compactifications - Lecture 2

Date: Jan 27, 2010 11:00 AM

URL: http://pirsa.org/10010100

Abstract:

ASPECTS OF MODULI IN STRING COMPACTIFICATIONS 2

$$K = -2\ln\left(\mathcal{V}(T_i,\bar{T}_i)\right) - \ln\left(\int \Omega\wedge\bar{\Omega}\right) - \ln(S+\bar{S})$$

$\mathcal{V}$ = volume of Calabi-Yau in string units

$$W = \underbrace{\int G_3\wedge\Omega} + \underbrace{\sum A_i e^{-a T_i}}_{KKLT}$$

$$\mathcal{V} = e^{\dots}\int_{CY}\sqrt{g} = \int J\wedge J\wedge J$$

$(W_0 = \langle \int G_3\wedge\Omega\rangle)$

	Fluxes	(KKLT) Fluxes+non-perturb.
Vacuum energy:	0	$-3m_{3/2}^2 M_P^2$
Gravitino mass:	$\frac{W_0}{\mathcal{V}}$	$\sim\frac{W_0}{\mathcal{V}}$
Kähler moduli mass:	0 (unfixed)	$\sim m_{3/2}\ln\left(\frac{M_P}{m_{3/2}}\right)$
Dilaton/complex structure mass:	$\sim\frac{DDW}{\mathcal{V}}\sim m_{3/2}$	$\sim\frac{DDW}{\mathcal{V}}\sim m_{3/2}$
Susy broken:	Yes, $F^T \neq 0$	No

ASPECTS OF MODULI IN STRING COMPACTIFICATIONS 2

$$K = -2\ln\left(\mathcal{V}(t,\bar{t}) + \frac{\xi}{g_s^{3/2}}\right) - \ln\left(\int \Omega\wedge\bar{\Omega}\right) - \ln(S+\bar{S})$$

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Large volume

$\rightarrow$ include α'^3 correction to Kähler potential

$$W = \int G_3 \wedge \Omega + \sum A_i e^{-a_i T_i}$$

KKLT

in string units

$$V = e^{\phi} \int_{CY} \sqrt{g} = \int J \wedge J \wedge J$$

$(W_0 = \langle \int G_3 \wedge \Omega \rangle)$

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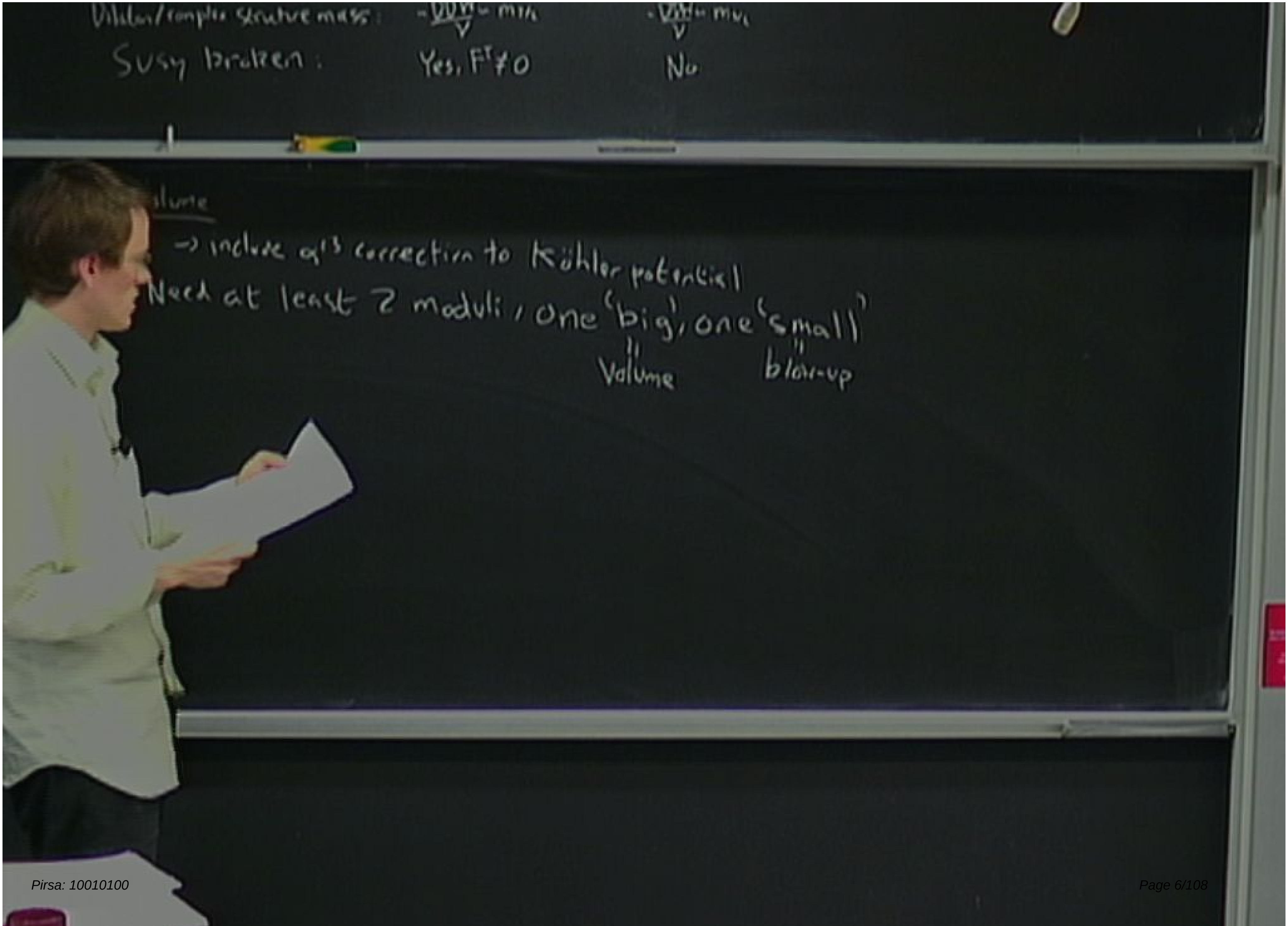
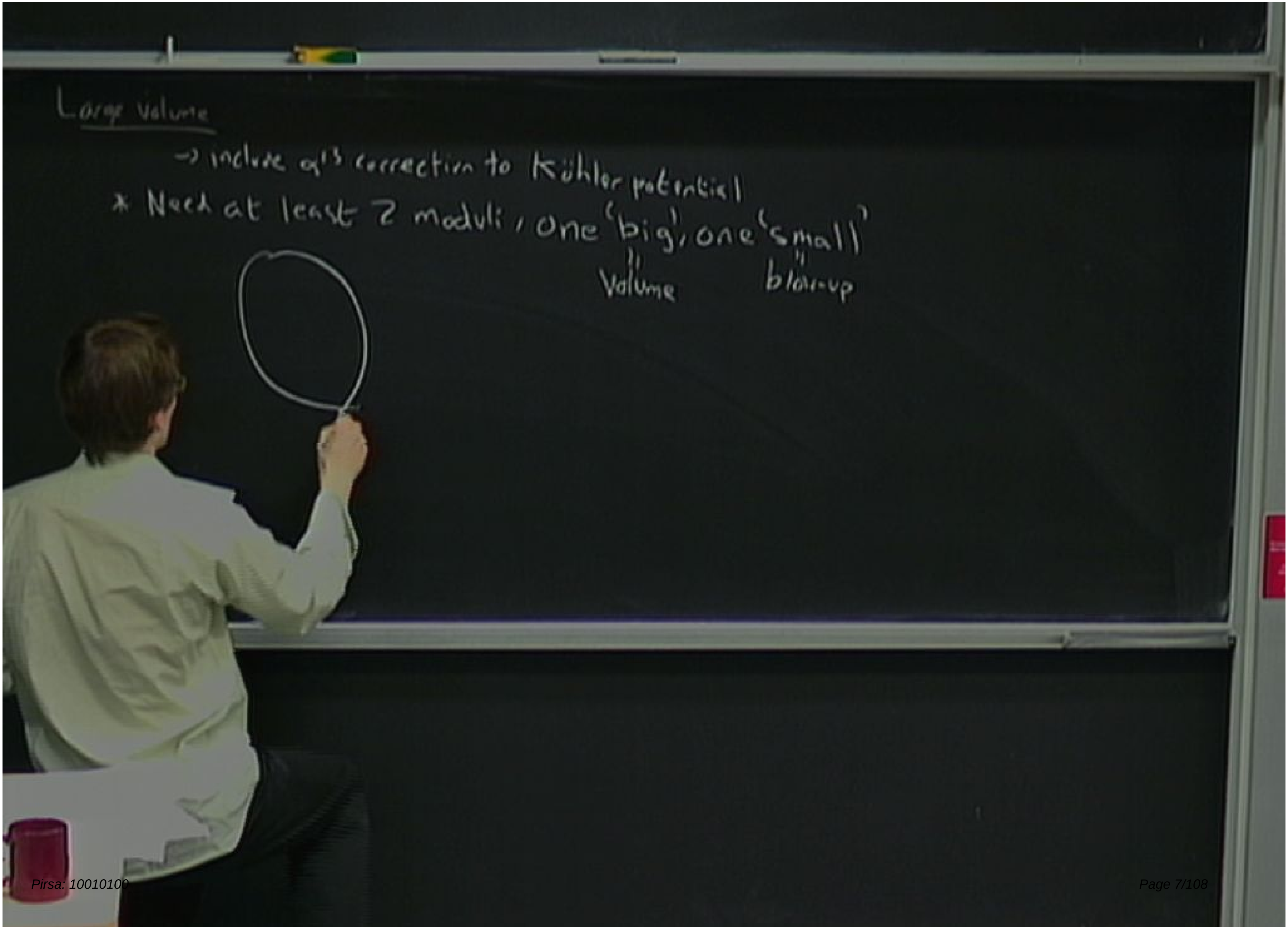

Kähler/complex structure mass: ~ DDW/V ~ m3/2 ~ DDW/V ~ m3/2
Susy broken: Yes, F^T ≠ 0 No
Volume
→ include α'^3 correction to Kähler potential
Need at least 2 moduli, one 'big', one 'small'
Volume
blow-up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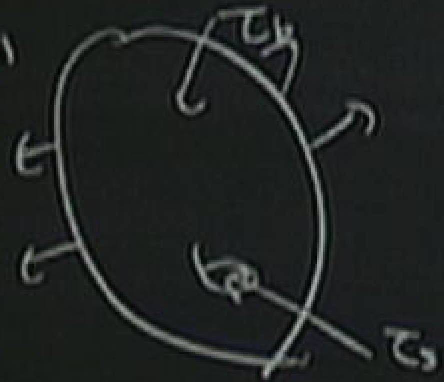
* Need at least 2 moduli, one 'big', one 'small'

one 'big' = volume, one 'small' = blow-up

"Swiss-cheese"



simplest case $\mathbb{P}^4_{[1,1,1,6,9]}$

$$V = \frac{1}{9\sqrt{2}}\left(\tau_b^{3/2} - \tau_s^{3/2}\right)$$

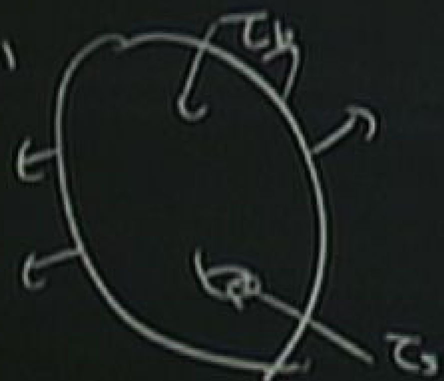
Large Volume

→ include α'^3 correction to Kähler potential

* Need at least 2 moduli, one 'big', one 'small'

'big' = volume, 'small' = blow-up

"Swiss-cheese"



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$$V = \frac{1}{9\sqrt{2}}\left(\tau_b^{3/2} - \tau_s^{3/2}\right)$$

* Fix dilaton + complex structure moduli:

$$D_S W = D_U W = 0$$

Large Volume

→ include α'^3 correction to Kähler potential

* Need at least 2 moduli, one 'big', one 'small'

'big' = volume, 'small' = blow-up

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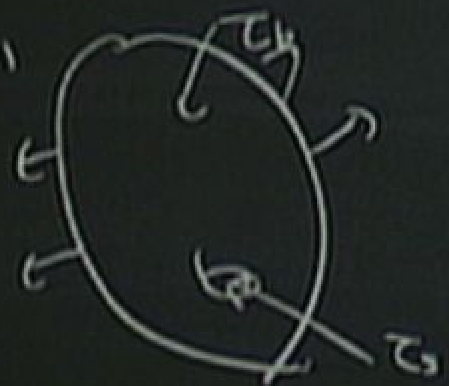

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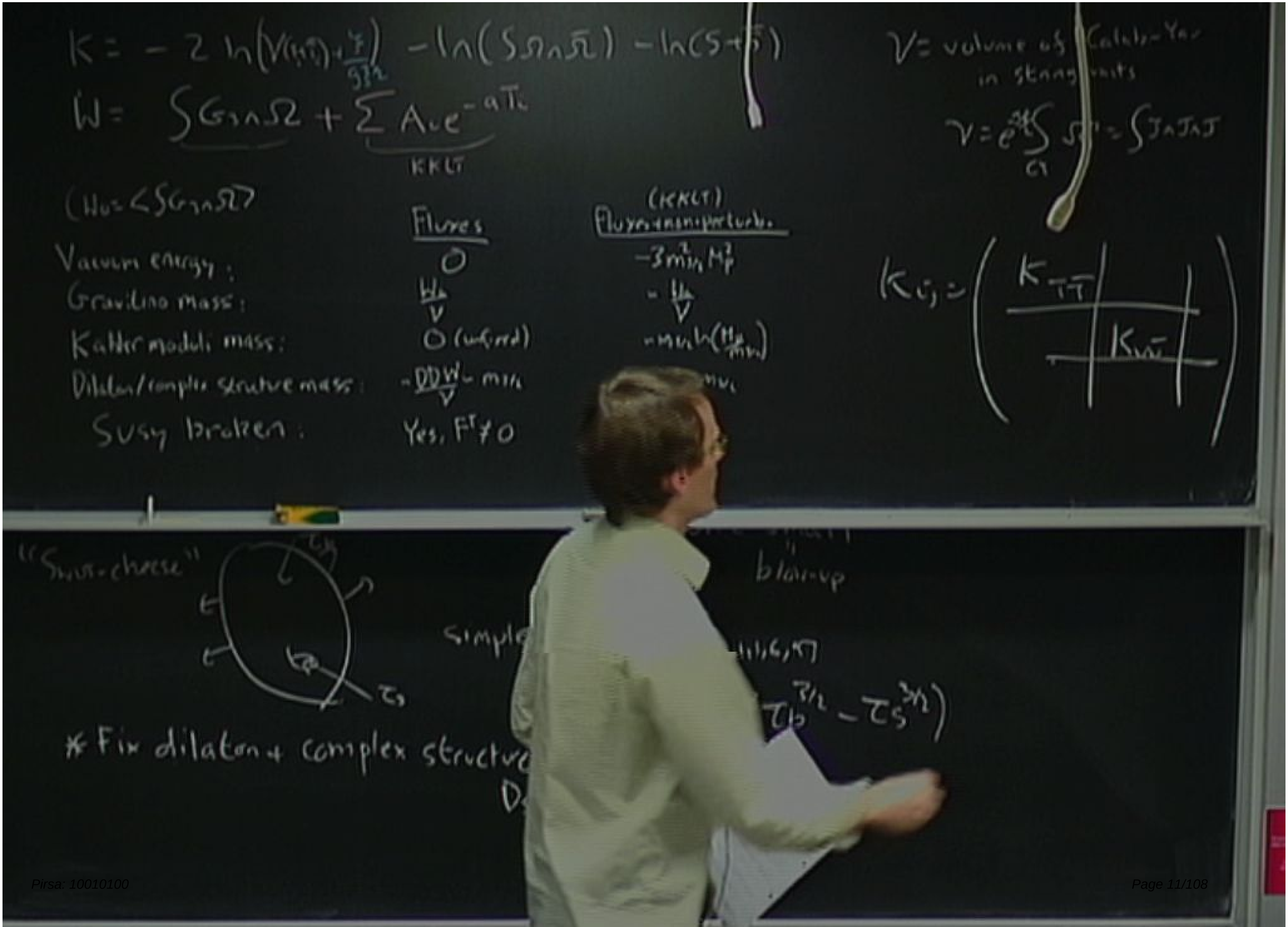
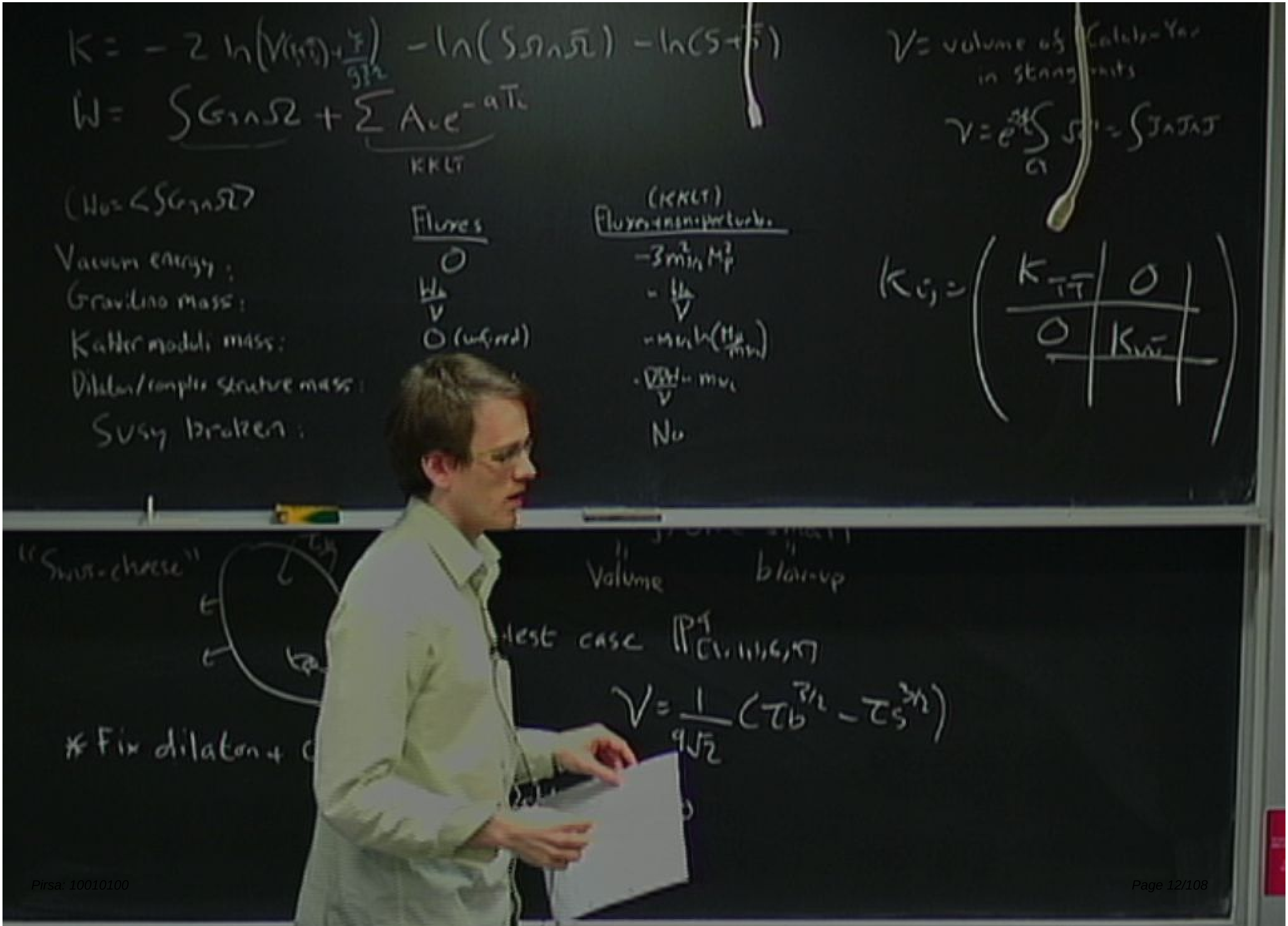

K = − 2 ln(V + ...) − ln(∫ Ω ∧ Ω̄) − ln(S + S̄)
W = ∫ G₃ ∧ Ω + Σ Aᵢ e^(−aTᵢ)
KKLT
V = volume of Calabi-Yau in string units
(W₀ = <∫G₃∧Ω>)
Fluxes
(KKLT) Fluxes + non-perturb.
Vacuum energy:
Gravitino mass:
Kahler moduli mass:
Dilaton/complex structure mass:
Susy broken:
Yes, F^T ≠ 0
"Swiss-cheese"
blow-up
* Fix dilaton + complex structure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Vacuum energy:
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Susy broken:
No
"Swiss-cheese"
Volume
blow-up
simplest case
* Fix dilaton +

$$K = -2\ln\left(\mathcal{V}(T_i) + \frac{\xi}{g_s^{3/2}}\right) - \ln\left(\int \Omega \wedge \bar{\Omega}\right) - \ln(S + \bar{S})$$

$\mathcal{V}$ = volume of CY in string units

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$$\mathcal{V} = e^{\ldots}\int_{CY} \ldots = \int J \wedge J \wedge J$$

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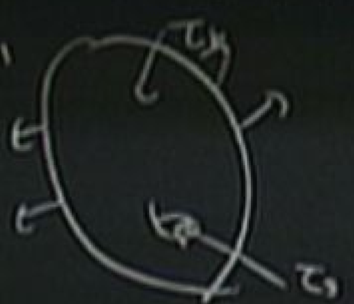
Susy broken:	Yes, $F^T \neq 0$	No

$$K_{i\bar{j}} = \begin{pmatrix} K_{T\bar{T}} & 0 \\ 0 & K_{u\bar{u}} \end{pmatrix}$$

... at least 2 moduli, one 'big', one 'small'
= Volume = blow-up

"Swiss-cheese"



simplest case $\mathbb{P}^4_{[1,1,1,6,9]}$

$$\mathcal{V} = \frac{1}{9\sqrt{2}}\left(\tau_b^{3/2} - \tau_s^{3/2}\right)$$

* Fix dilaton + complex structure moduli:

$$D_S W = D_U W = 0$$

$$K = -2\ln\left(\left(T_b+\bar{T}_b\right)^{3/2} - \left(T_s+\bar{T}_s\right)^{3/2} + \frac{\xi}{2}\right)$$

$$W = W_0 + Ae^{-aT_s}$$

$$K = -2\ln\left(\left(T_b+\bar{T}_b\right)^{3/2} - \left(T_s+\bar{T}_s\right)^{3/2} + \xi\right)$$

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$\longrightarrow$ work out scalar potential

$$V = \frac{\sqrt{\tau_s}\,A^2 e^{-2a\tau_s}}{\mathcal{V}} - a\tau_s \frac{A e^{-a\tau_s} W_0}{\mathcal{V}^2} + \frac{\xi W_0^2}{\mathcal{V}^3} \qquad + \text{axion}$$

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* axion part of T_s has been put to its minimum

* $O(1)$ factors left out.

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terms suppressed by $\frac{1}{\mathcal{V}}$ are dropped

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$$W = \underbrace{W_0}_{1} + \underbrace{Ae^{-aT_s}}_{\frac{1}{V}}$$

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$$V = \frac{\sqrt{\tau_s}A^2 e^{-2a\tau_s}}{V} - \frac{a\tau_s A e^{-a\tau_s} W_0}{V^2} + \frac{\xi W_0^2}{V^3}$$

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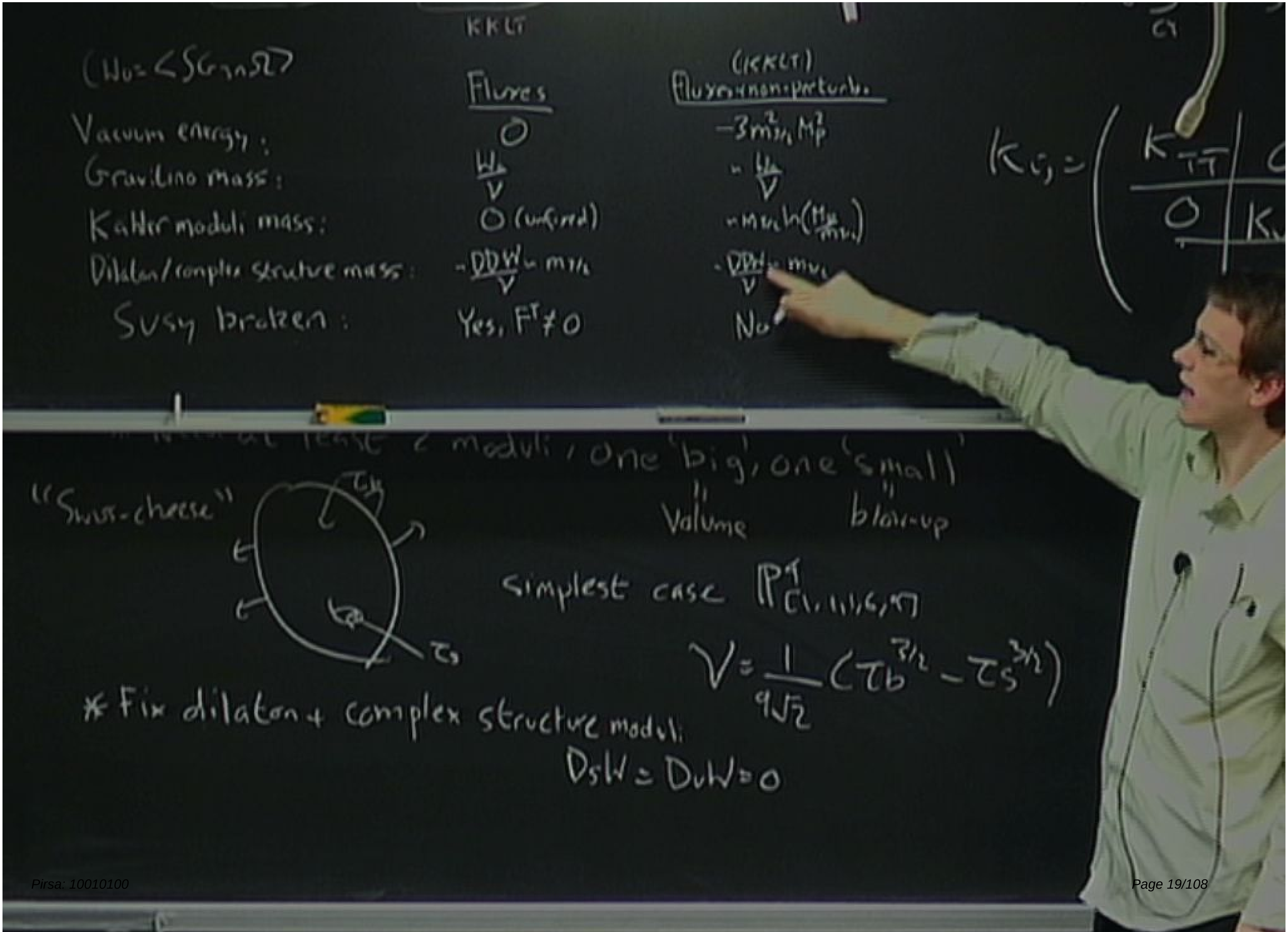
KKLT
(KKLT)
Fluxes
Fluxes + non-perturb.
Vacuum energy:
Gravitino mass:
Kähler moduli mass:
Dilaton/complex structure mass:
Susy broken:
Yes, $F^T \neq 0$
No
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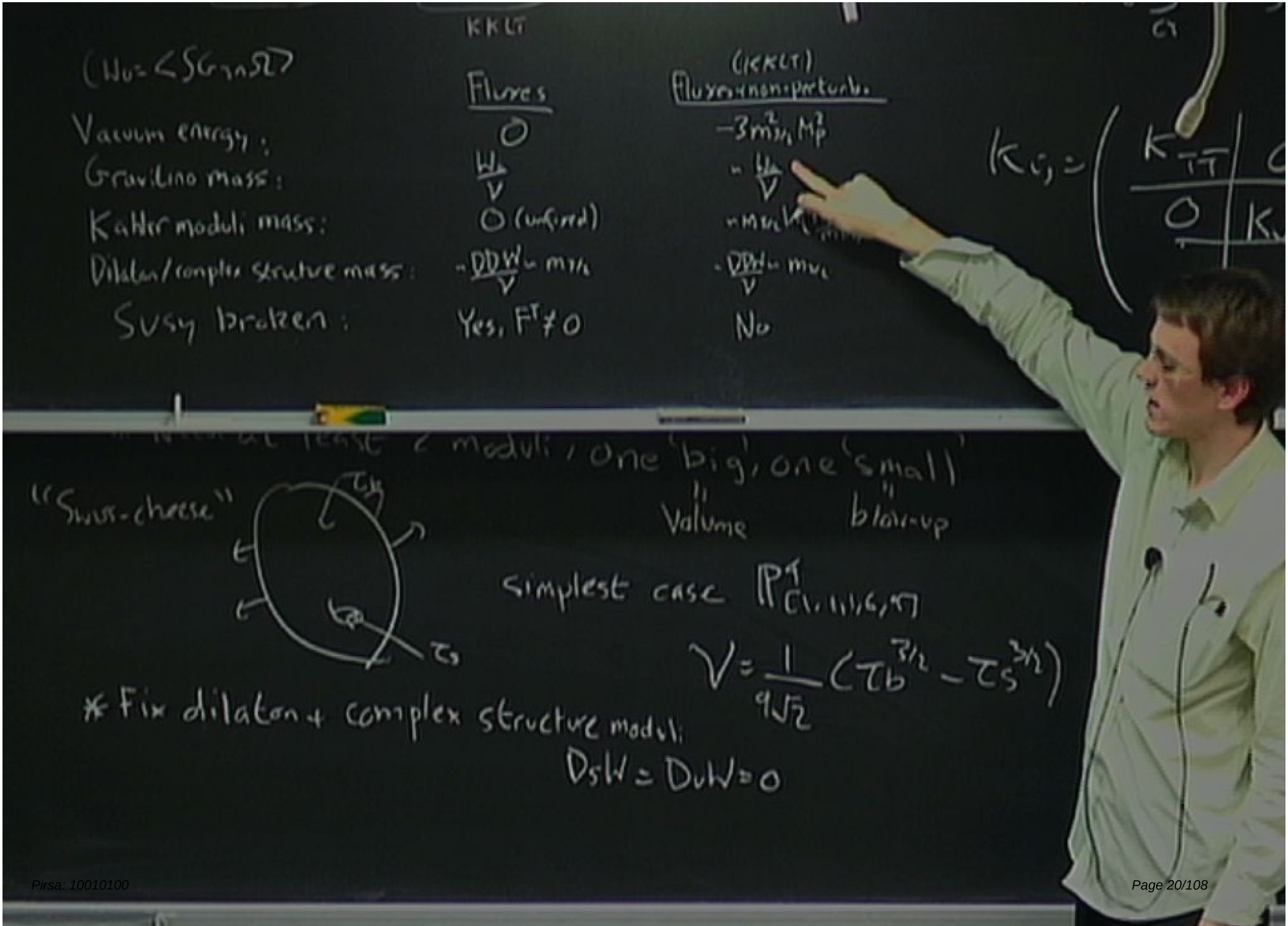
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Kahler moduli mass:
0 (unfixed)
Dilaton/complex structure mass:
$\sim \frac{DDW}{V} \gg m_{3/2}$
Susy broken:
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Volume
blow-up
τ_b
τ_s
Simplest case $\mathbb{P}^4_{[1,1,1,6,9]}$
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$$W = \underbrace{W_0}_{1} + \underbrace{Ae^{-aT_s}}_{\frac{1}{V}}$$

→ work out scalar potential

$$V = \frac{\sqrt{\tau_s}A^2 e^{-2a\tau_s}}{V} - a\tau_s\frac{Ae^{-a\tau_s}W_0}{V^2} + \frac{\xi W_0^2}{V^3}$$

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* axion part of T_s has been put to its minimum

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* large-volume limit:

terms suppressed by $\frac{1}{V}$ are dropped

$$e^{a\tau_s}$$

$$\frac{\partial V}{\partial \tau_s} = \frac{\partial V}{\partial \tau_b} = 0$$

Minimum exists at $\tau_s \sim \frac{\xi^{2/3}}{g_s}$, $V \sim W_0 \exp(a_s \tau_s)$

$$W = W_0 + A e^{-a\tau_s} + \underline{A_2 e^{-a\tau_b}}$$

→ Work out scalar potential

$$V = \frac{\sqrt{\tau_s} A^2 e^{-2a\tau_s}}{\mathcal{V}} - \frac{a\tau_s A e^{-a\tau_s} W_0}{\mathcal{V}^2} + \frac{\xi W_0^2}{\mathcal{V}^3}$$

$$\frac{\partial V}{\partial \tau_s} = \frac{\partial V}{\partial \tau_b} = 0$$

Minimum exists at $\tau_s \sim \frac{\xi^{2/3}}{g_s}$, $\mathcal{V} \sim W_0 \exp(a_s \tau_s)$

→ minimum is at exponentially large volume

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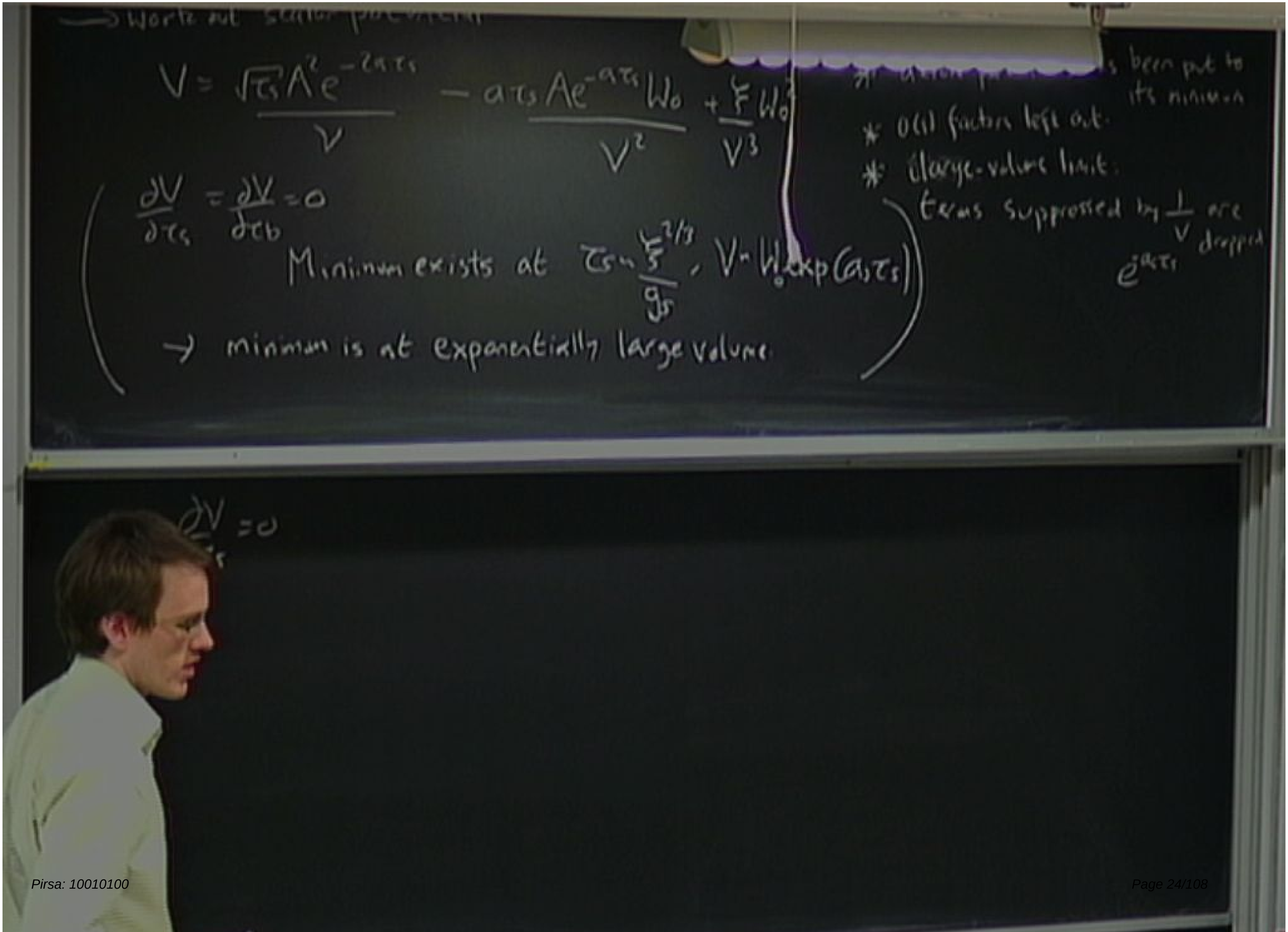
* large-volume limit: terms suppressed by $\frac{1}{\mathcal{V}}$ are dropped

$e^{a\tau_s}$


→ Work out scalar potential
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Minimum exists at $\tau_s \sim \frac{\xi^{2/3}}{g_s}$, $V \sim W_0 \exp(a_s\tau_s)$
→ minimum is at exponentially large volume
$\frac{\partial V}{\partial \tau_s} = 0$

$$\frac{\partial V}{\partial \tau_s} = \frac{\partial V}{\partial \tau_b} = 0$$

Minimum exists at $\tau_s \sim \frac{\xi^{2/3}}{g_s}$, $V \sim W_0 \exp(a_s \tau_s)$

$\rightarrow$ minimum is at exponentially large volume.

* large term

$\frac{\partial V}{\partial \ldots} = 0$ $\quad V \sim \exp(a_s \tau_s)$ $\quad$ integrate out τ_s

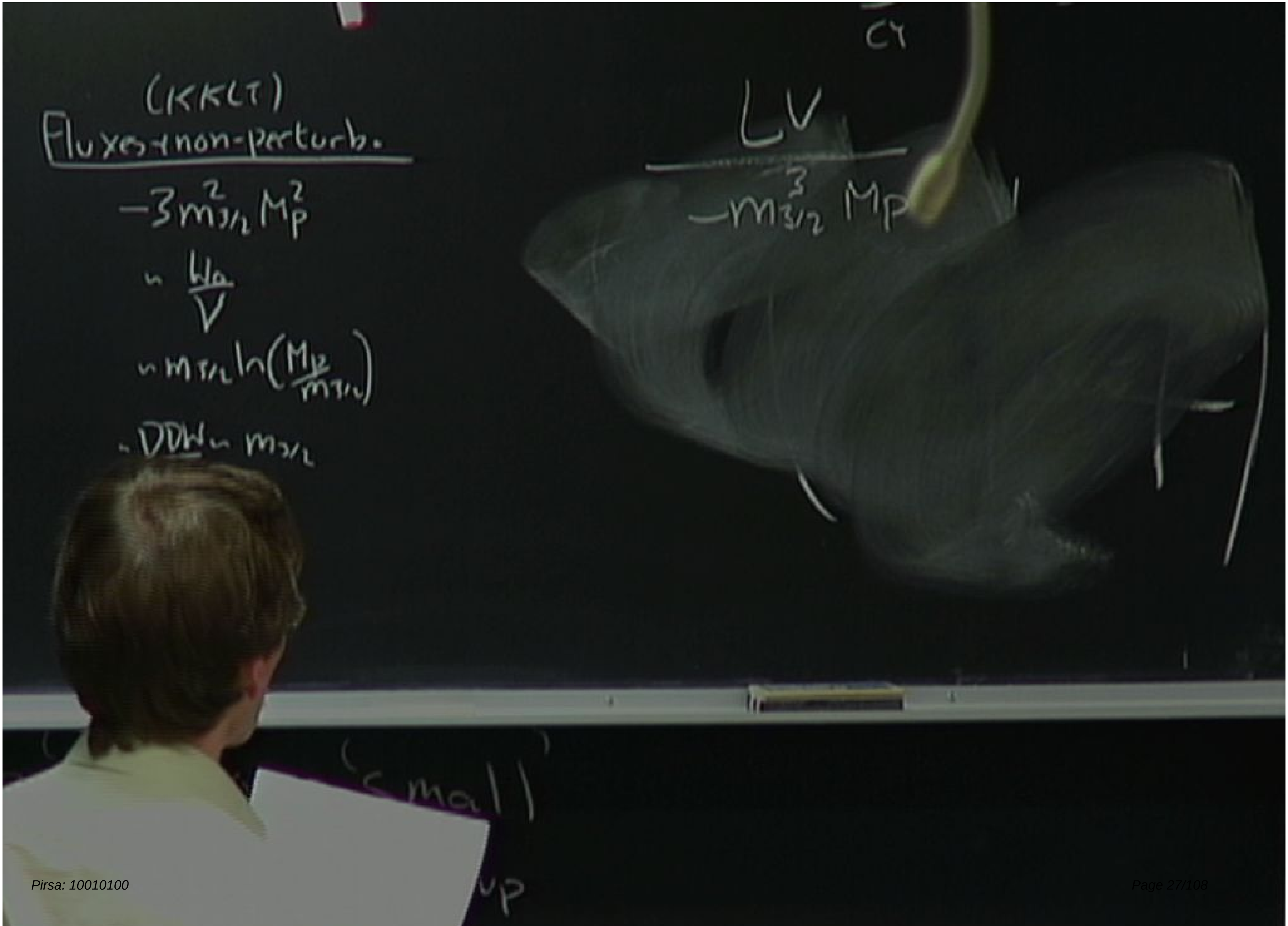
* large
term

$$\frac{\partial V}{\partial \tau_s} = \frac{\partial V}{\partial \tau_b} = 0$$

Minimum exists at $\tau_s \sim \frac{\xi^{2/3}}{g_s}$, $V \sim W_0 \exp(a_s \tau_s)$

$\rightarrow$ minimum is at exponentially large volume.

$$\underbrace{\frac{\partial V}{\partial \tau_s} = 0 \qquad V \sim \exp(a_s \tau_s) \quad \cdot \text{ integrate out } \tau_s}_{-\frac{(\ln V)^{3/2}}{V^3} + \frac{\xi}{V^3}}$$


CY
(KKLT)
Fluxes + non-perturb.
$-3m_{3/2}^2 M_p^2$
$\sim \frac{W_0}{V}$
$\sim m_{3/2} \ln\left(\frac{M_p}{m_{3/2}}\right)$
$\sim DDW \sim m_{3/2}$
LV
$-m_{3/2}^3 M_p$
(small)

(KKLT)

Fluxes + non-perturb.

$-3m_{3/2}^2 M_p^2$

$\sim \frac{W_0}{V}$

$\sim m_{3/2} \ln\left(\frac{M_p}{m_{3/2}}\right)$

$\sim \frac{DDW}{V} \sim m_{3/2}$

No.

CY

LV

$-m_{3/2}^3 M_p$

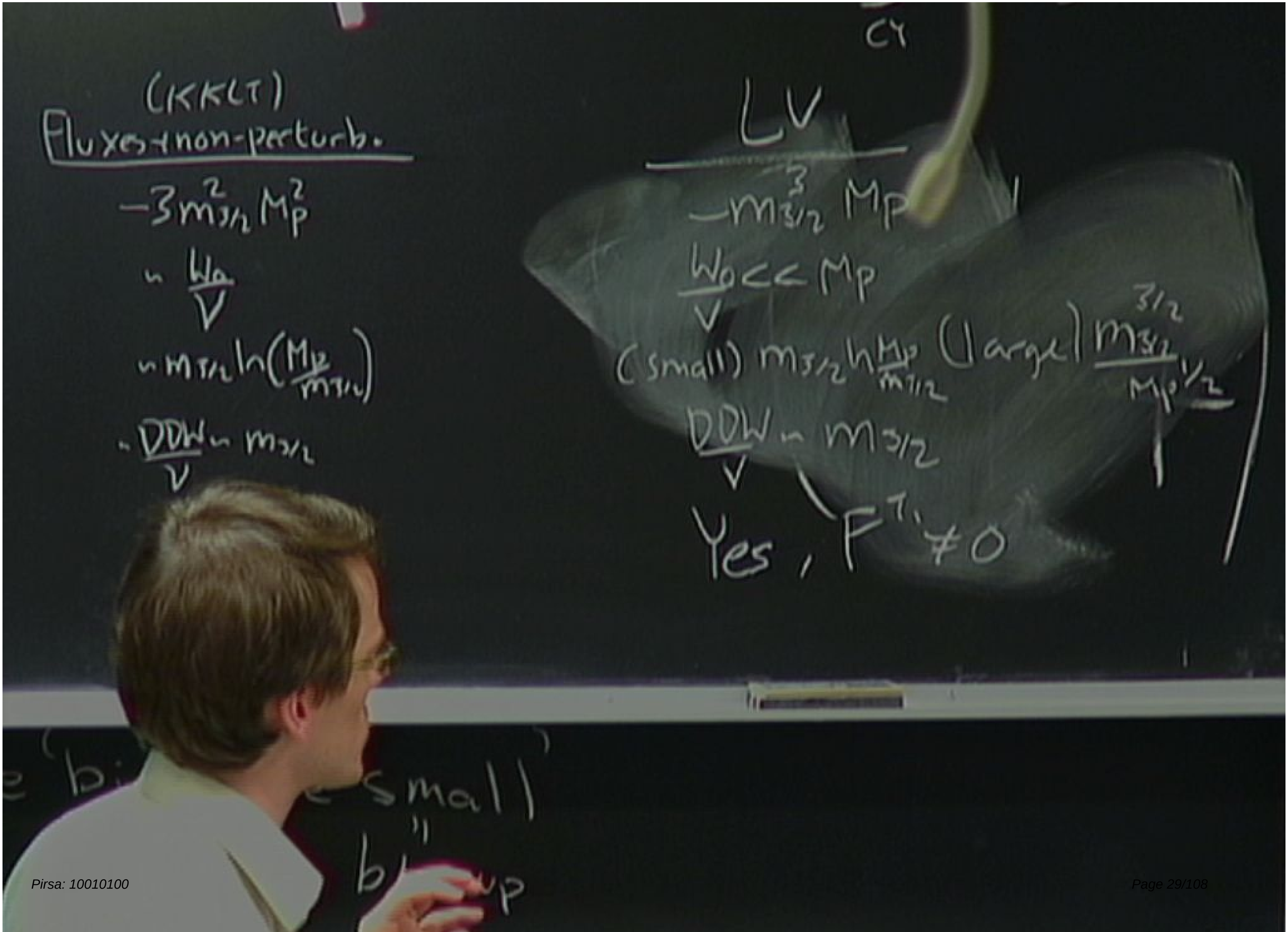
$\frac{W_0}{V} << M_p$

Yes, $F^{T_i} \neq 0$

e 'big', one 'small'

" Volume

" blow-up


CY
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Fluxes + non-perturb.
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LV
$-m_{3/2}^3 M_p$
$\frac{W_0}{V} << M_p$
(small) $m_{3/2} \ln \frac{M_p}{m_{3/2}}$ (large) $\frac{m_{3/2}^{3/2}}{M_p^{1/2}}$
$\frac{DDW}{V} \sim m_{3/2}$
Yes, $F^{T_i} \neq 0$
small

$\frac{\partial V}{\partial \tau_s} = 0$ $\quad V \sim \exp(a_s \tau_s)$ · integrate out τ_s

$$\underbrace{\qquad\qquad}_{-\frac{(\ln V)^{3/2}}{V^3} + \frac{\xi}{V^3}}$$

$O\,\tau_{a,i}$ $\quad O \quad g_2 \quad \rho_{a,i} \quad O \quad O$

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→ work out scalar potential

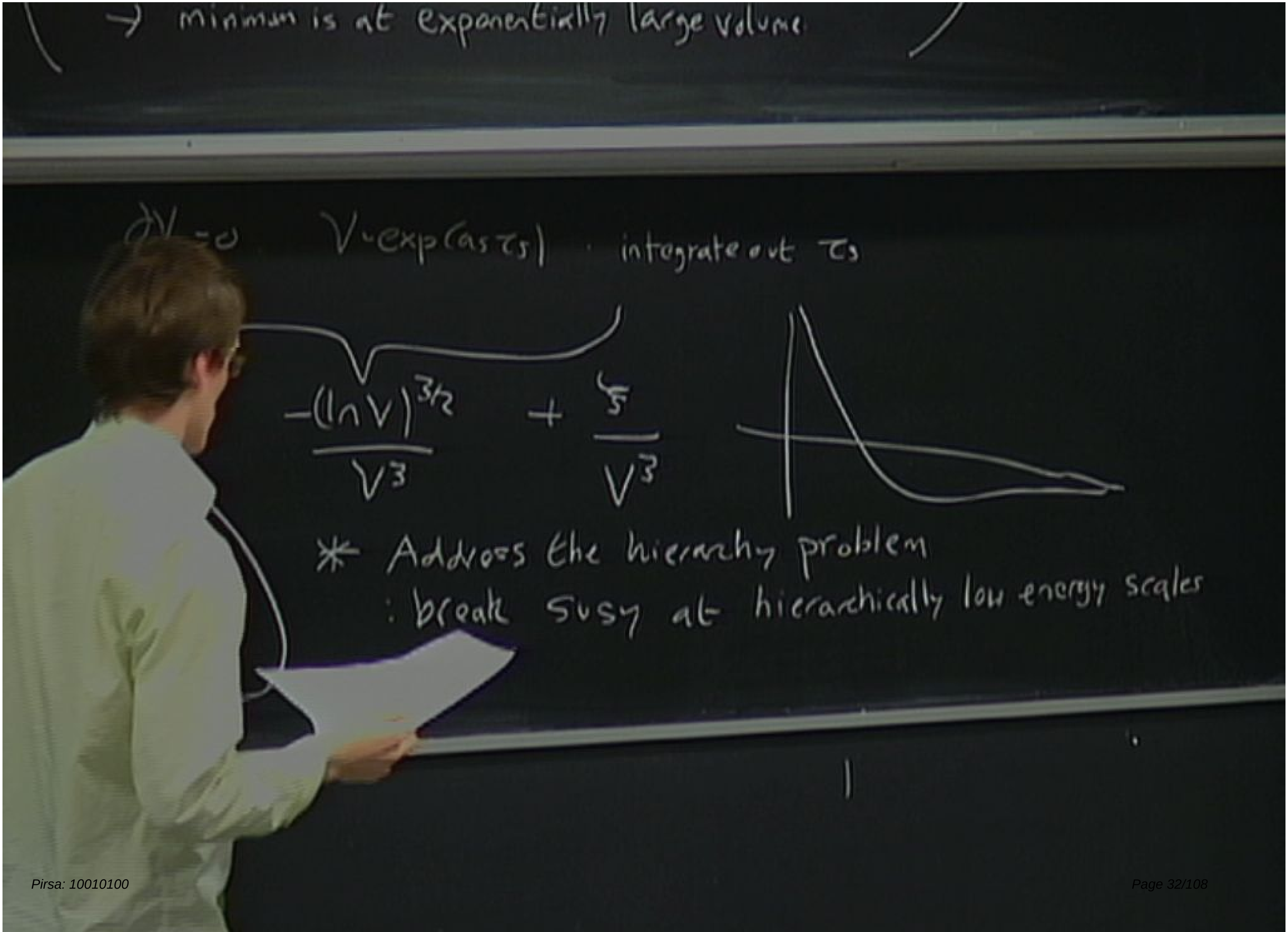
$$V = \frac{\sqrt{\tau_s}\, A^2 e^{-2a\tau_s}}{V} - a\tau_s \frac{A e^{-a\tau_s} W_0}{V^2} + \frac{\xi W_0^2}{V^3}$$

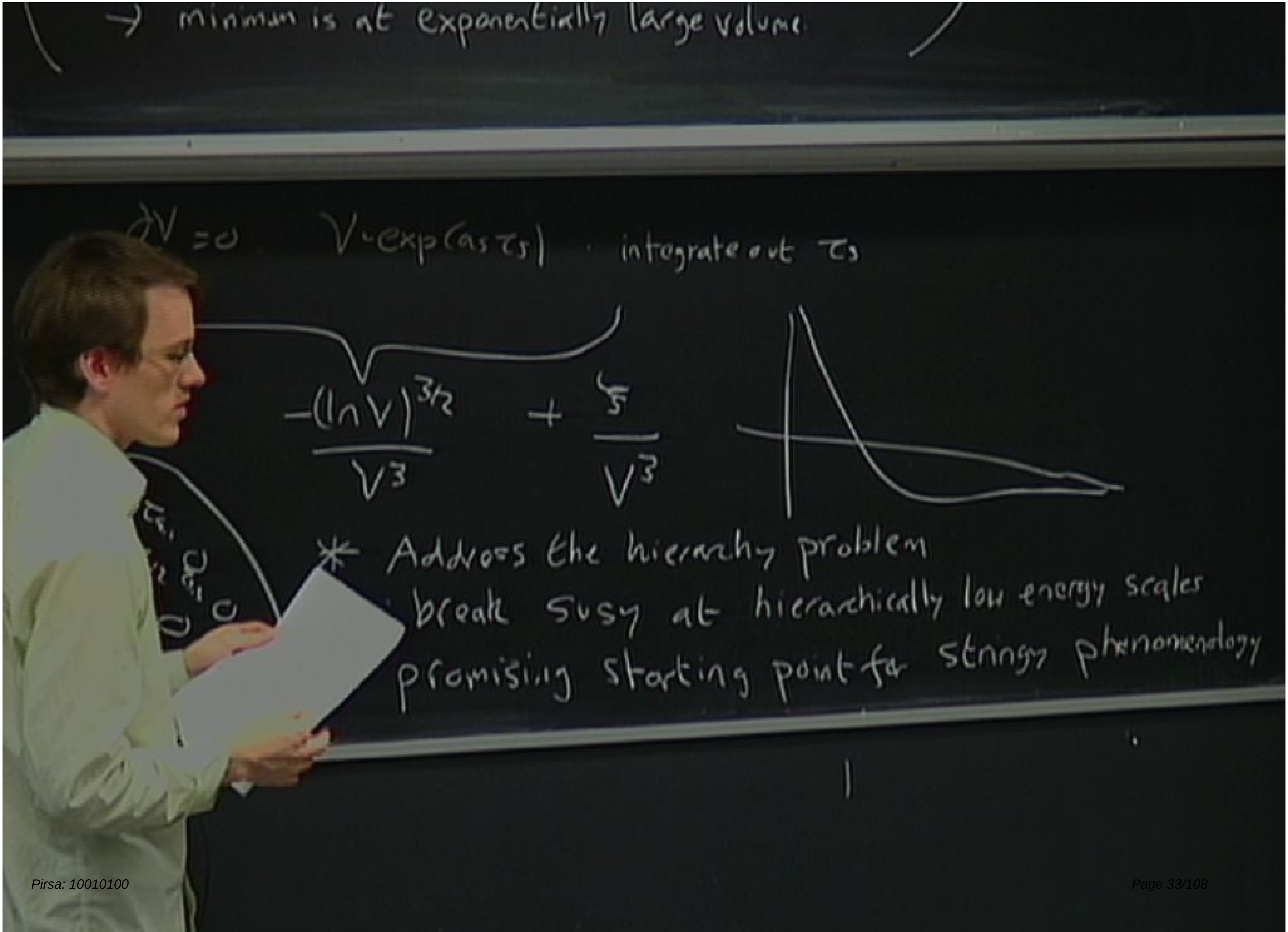
* axion part of T_s has been put to its minimum
* $O(1)$ factors left out.
* large-volume limit: terms suppressed by $\frac{1}{V}$ are dropped, $e^{-a\tau_s}$

$$\frac{\partial V}{\partial \tau_s} = \frac{\partial V}{\partial \tau_b} = 0$$

Minimum exists at $\tau_s \sim \frac{\xi^{2/3}}{g_s}$, $V \sim W_0 \exp(a_s \tau_s)$

→ minimum is at exponentially large volume

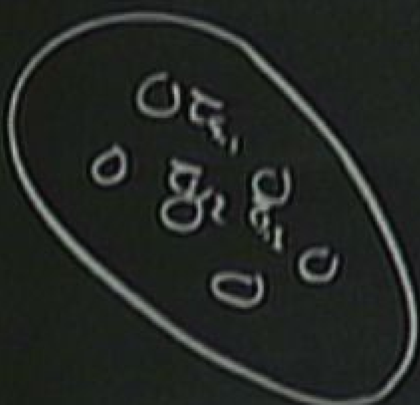

→ minimum is at exponentially large volume
V~exp(as τs)
integrate out τs
-(ln V)^3/2 / V^3 + ζs / V^3
* Address the hierarchy problem
: break susy at hierarchically low energy scales


→ minimum is at exponentially large volume
$\partial V = 0$ $V \sim \exp(a_s \tau_s)$ integrate out τ_s
$\frac{-(\ln V)^{3/2}}{V^3} + \frac{\zeta_s}{V^3}$
* Address the hierarchy problem
break susy at hierarchically low energy scales
promising starting point for stringy phenomenology

$\rightarrow$ minimum is at exponentially large volume

$$\underbrace{\frac{\partial V}{\partial \tau_s} = 0 \qquad \mathcal{V} \sim \exp(a_s \tau_s)}_{-\frac{(\ln \mathcal{V})^{3/2}}{\mathcal{V}^3} + \frac{\xi}{\mathcal{V}^3}}$$

· integrate out τ_s



* Address the hierarchy problem

: break susy at hierarchically low energy scales

* promising starting point for string phenomenology

$\rightarrow$ minimum is at exponentially large volume

$$\underbrace{\frac{\partial V}{\partial \tau_s} = 0 \qquad \mathcal{V} \sim \exp(a_s \tau_s)}_{-\frac{(\ln \mathcal{V})^{3/2}}{\mathcal{V}^3} + \frac{\xi}{\mathcal{V}^3}}$$

· integrate out τ_s

* Addresses the hierarchy problem
  : break susy at hierarchically low energy scales
* promising starting point for stringy phenomenology

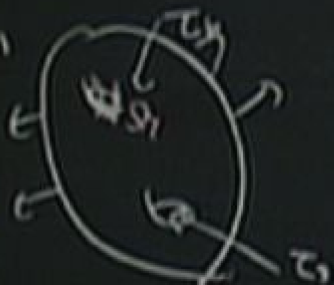
$(W_0 \sim \langle \int G_3 \wedge \Omega \rangle)$

	Fluxes	(KKLT) Fluxes+nonperturb.	LV
Vacuum energy:	0	$-3m_{3/2}^2 M_P^2$	$-m_{3/2}^3 M_P$
Gravitino mass:	$\frac{W_0}{V}$	$\sim \frac{W_0}{V}$	$\frac{W_0}{V} \ll M_P$
Kähler moduli mass:	0 (unfixed)	$\sim m_{3/2} \ln\left(\frac{M_P}{m_{3/2}}\right)$	(small) $m_{3/2} \ln \frac{M_P}{m_{3/2}}$, (large) $\frac{m_{3/2}^{3/2}}{M_P^{1/2}}$
Dilaton/complex structure mass:	$\sim \frac{DDW}{V} \sim m_{3/2}$	$\sim \frac{DDW}{V} \sim m_{3/2}$	$\frac{DDW}{V} \sim m_{3/2}$
SUSY broken:	Yes, $F^T \neq 0$	No	Yes, $F^{T_b} \neq 0$

→ include α'^3 correction to Kähler potential

* Need at least 2 moduli, one 'big', one 'small'
  - 'big' = volume
  - 'small' = blow-up

"Swiss-cheese"

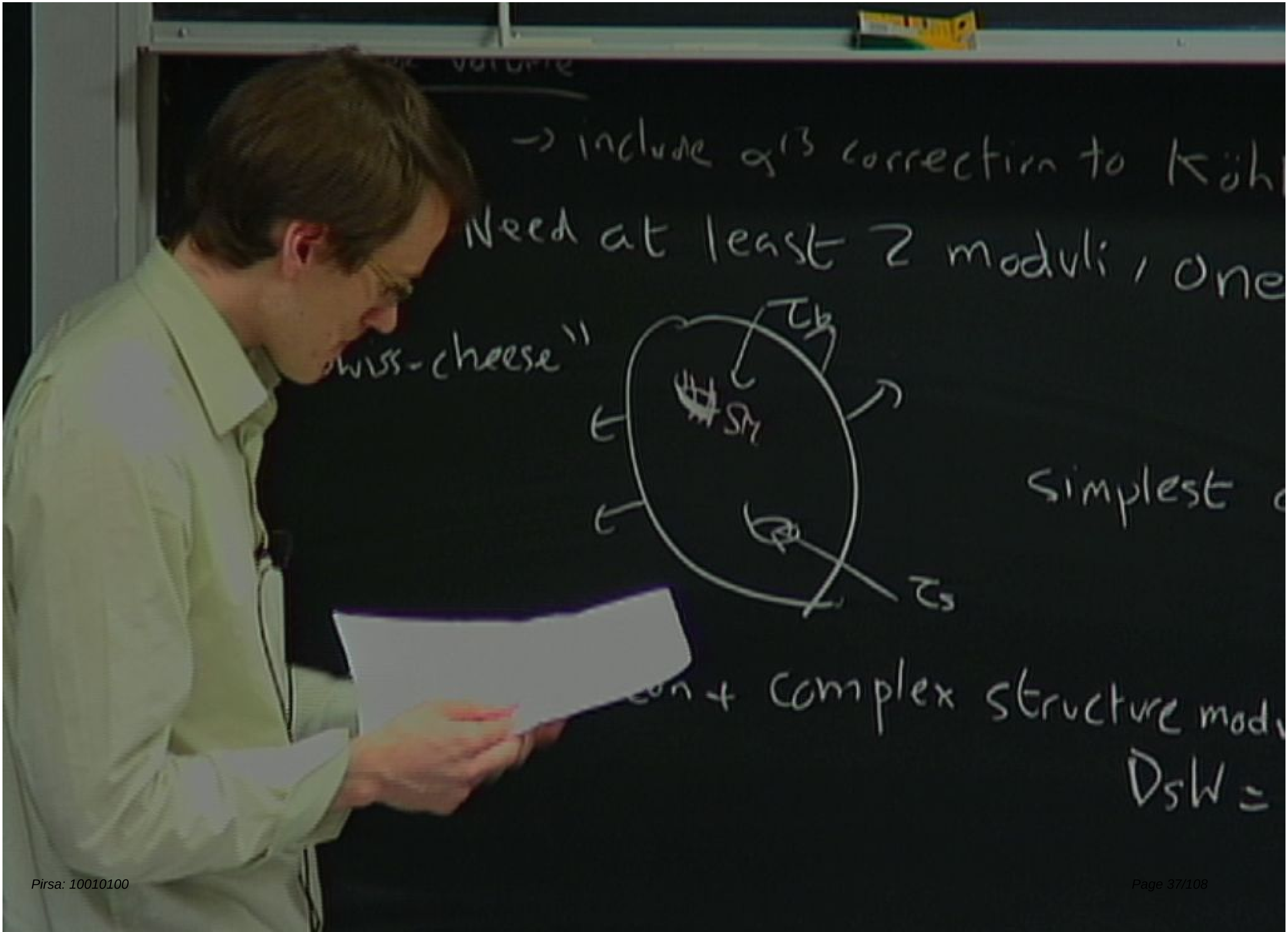


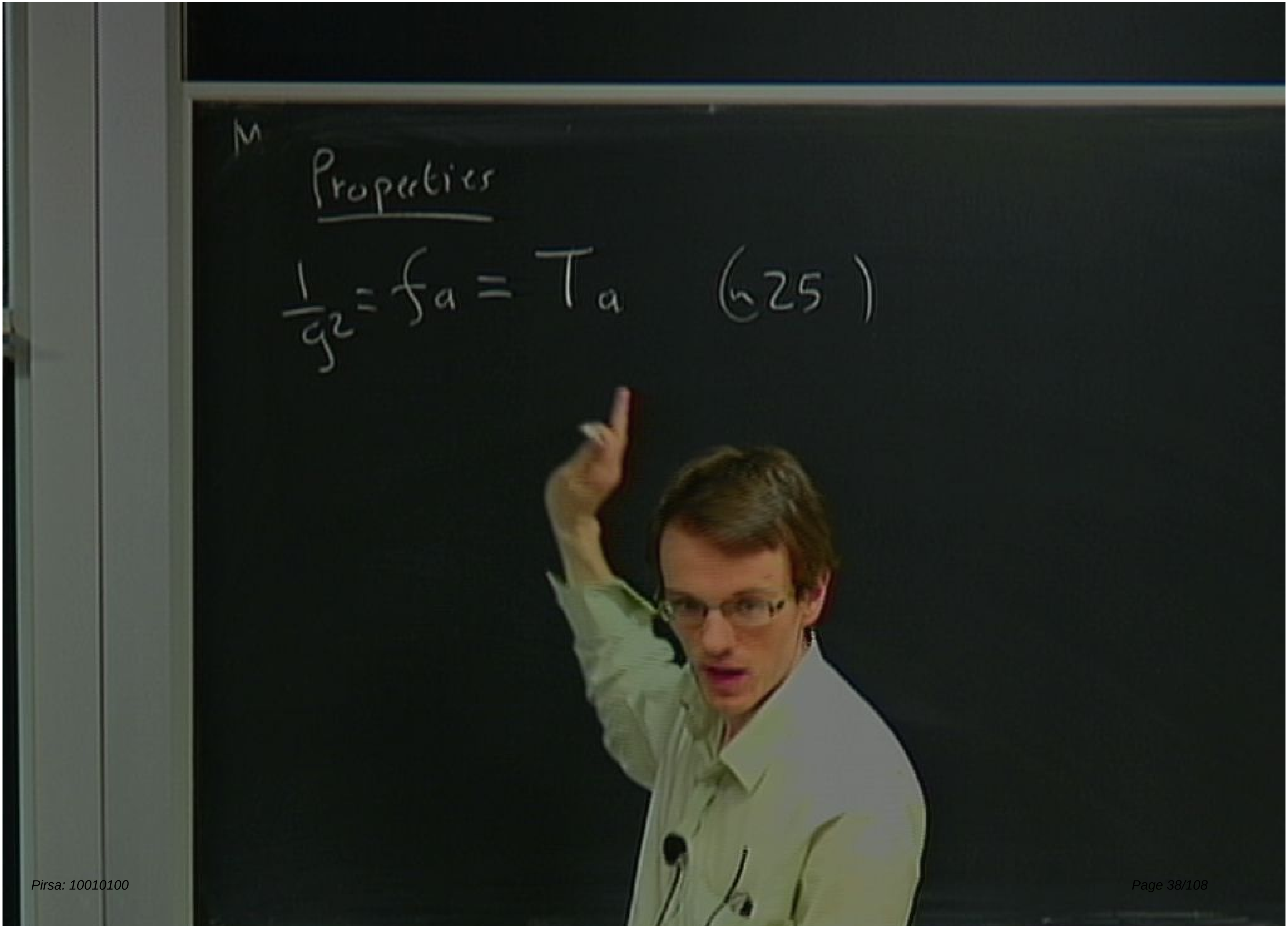
simplest case $\mathbb{P}^4_{[1,1,1,6,9]}$

$$V = \frac{1}{9\sqrt{2}}\left(\tau_b^{3/2} - \tau_s^{3/2}\right)$$

* dilaton + complex structure moduli:

$$D_S W = D_U W = 0$$

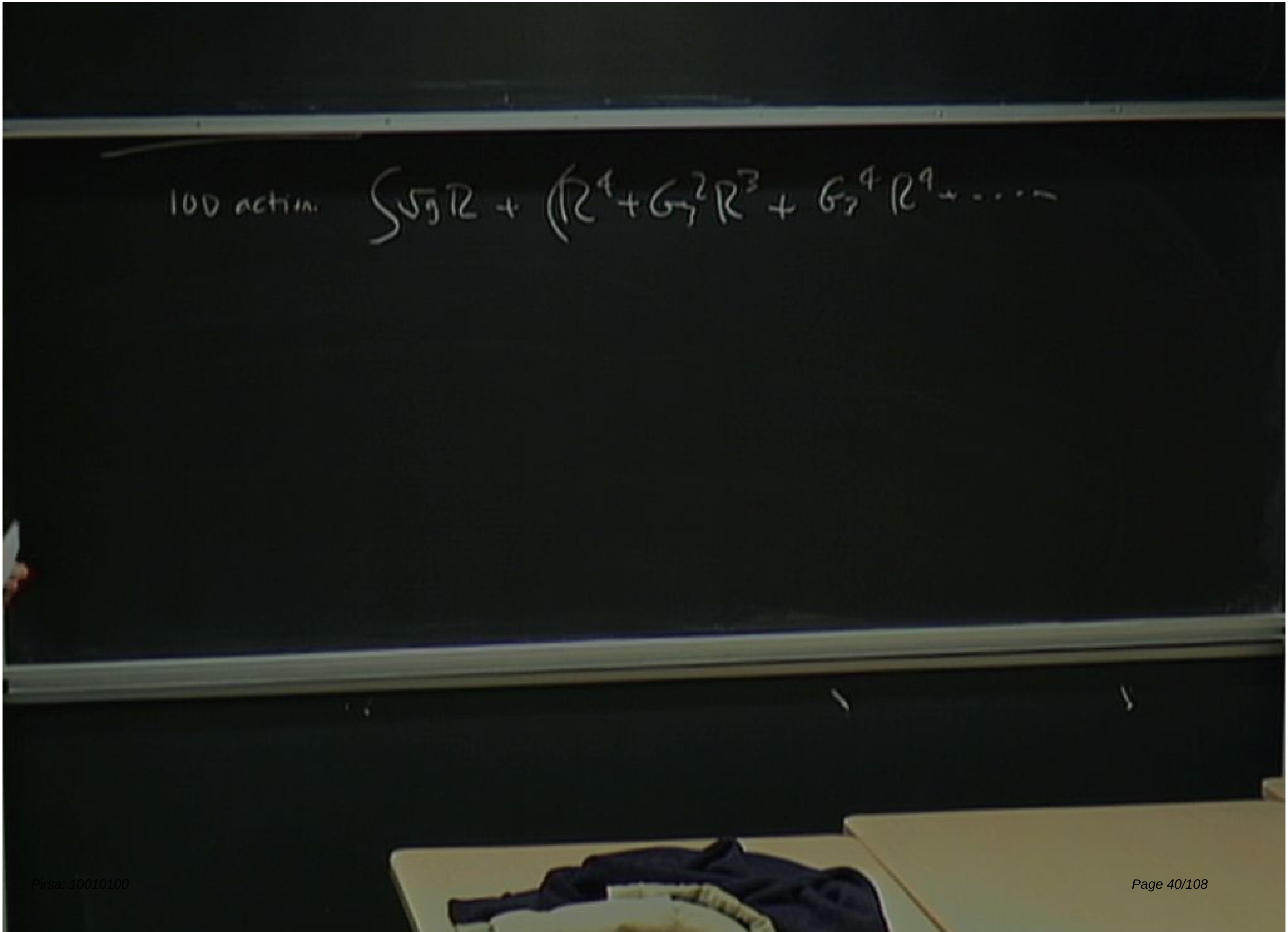

→ include α'³ correction to Käh
Need at least 2 moduli, one
"swiss-cheese"
τ_b
SM
τ_s
simplest
complex structure modu
D_S W =


M
Properties
$\frac{1}{g^2} = f_a = T_a$ (~25)

$$e^{-a_s T_s} = \frac{1}{V}$$

$$\overline{a_s T_s} \sim \ln V \qquad m_{3/2} = 1\,\mathrm{TeV}$$

$$\ln(10^{15}) \sim 30 \qquad V = 10^{15}$$


10D action: $\int\sqrt{g}R + (R^4 + g_s^2 R^3 + g_s^4 R^4 + \dots$

10D action: $\int \sqrt{g} R + \int \left(R^4 + \underline{G_3^2 R^3} + G_3^4 R^9 + \dots \right.$

Fluxes quantised on 3-cycles

$G_3 \sim \frac{1}{\sqrt{V_{3\text{-cycle}}}}$ $\qquad \int_{CY} \sqrt{g}\, G_3^2 R^3 \sim \underbrace{V}_{int} \times \underbrace{\frac{1}{V}}_{G_3^2} \times$

10D action: $\int \sqrt{g} R + \int \left(R^4 + \underline{G_3^2 R^3} + G_3^4 R^2 + \cdots \right)$

Fluxes quantised on 3-cycles

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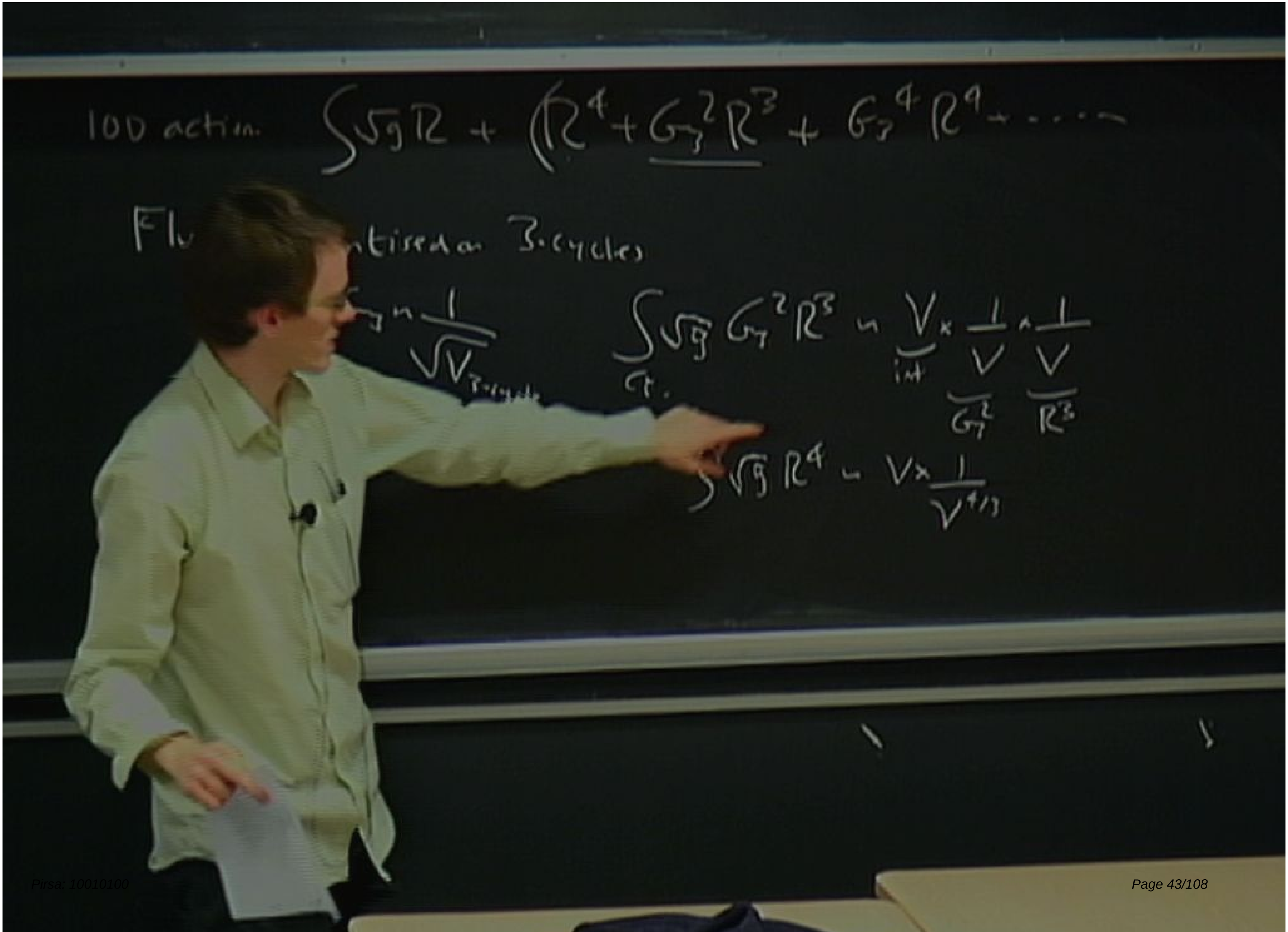
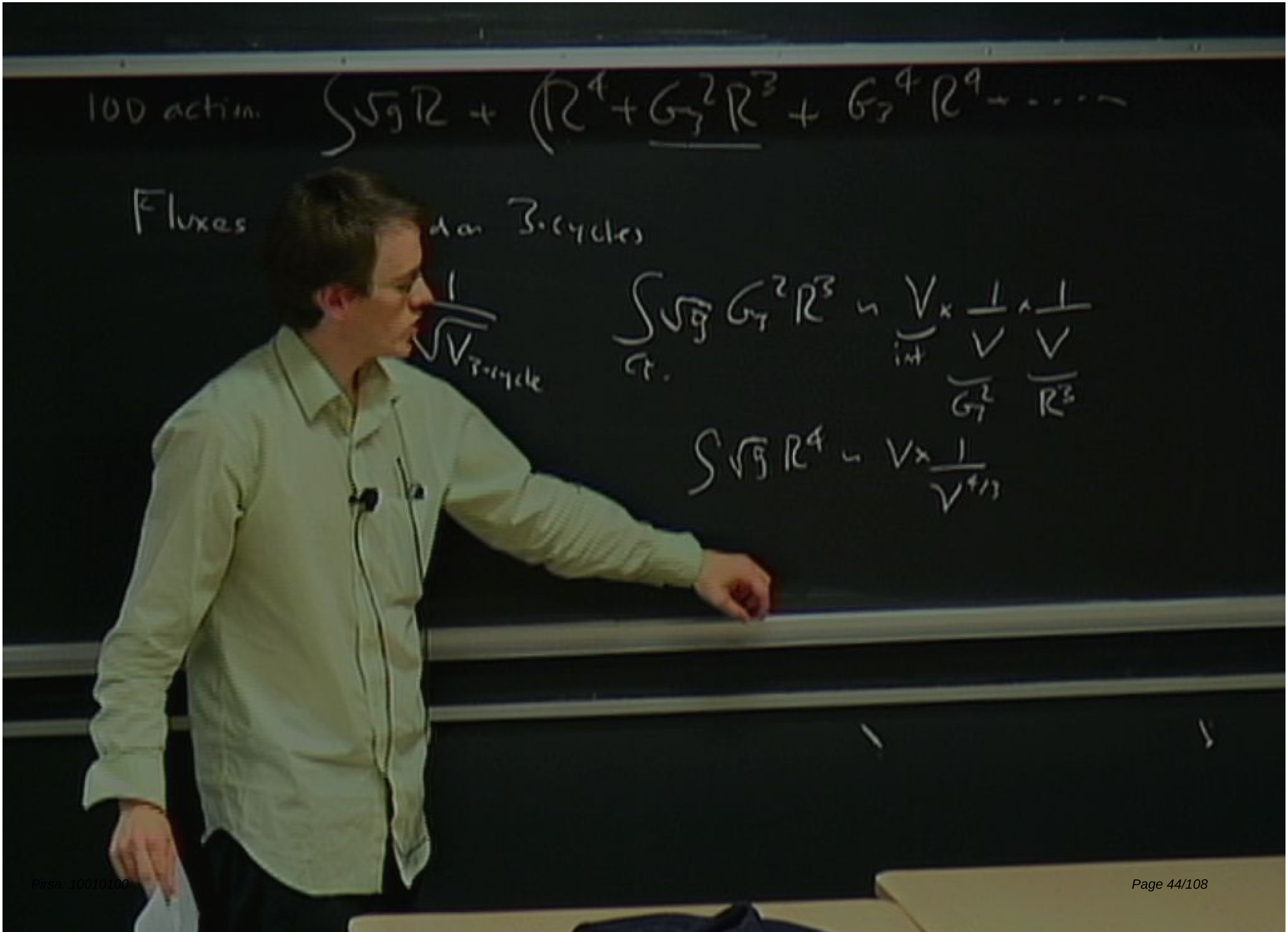
$$\int \sqrt{g} R^4 \sim$$


10D action $\int \sqrt{g} R + \int (R^4 + \underline{G_7^2 R^3} + G_7^4 R^4 + \dots$
tised on 3-cycles
$G_7 \sim \frac{1}{\sqrt{V_{3\text{-cycle}}}}$
$\int_{CY} \sqrt{g}\, G_7^2 R^3 \sim \underbrace{V}_{int} \times \underbrace{\frac{1}{V}}_{G_7^2} \times \underbrace{\frac{1}{V}}_{R^3}$
$\int \sqrt{g}\, R^4 \sim V \times \frac{1}{V^{4/3}}$


10D action
Fluxes
d on 3-cycles
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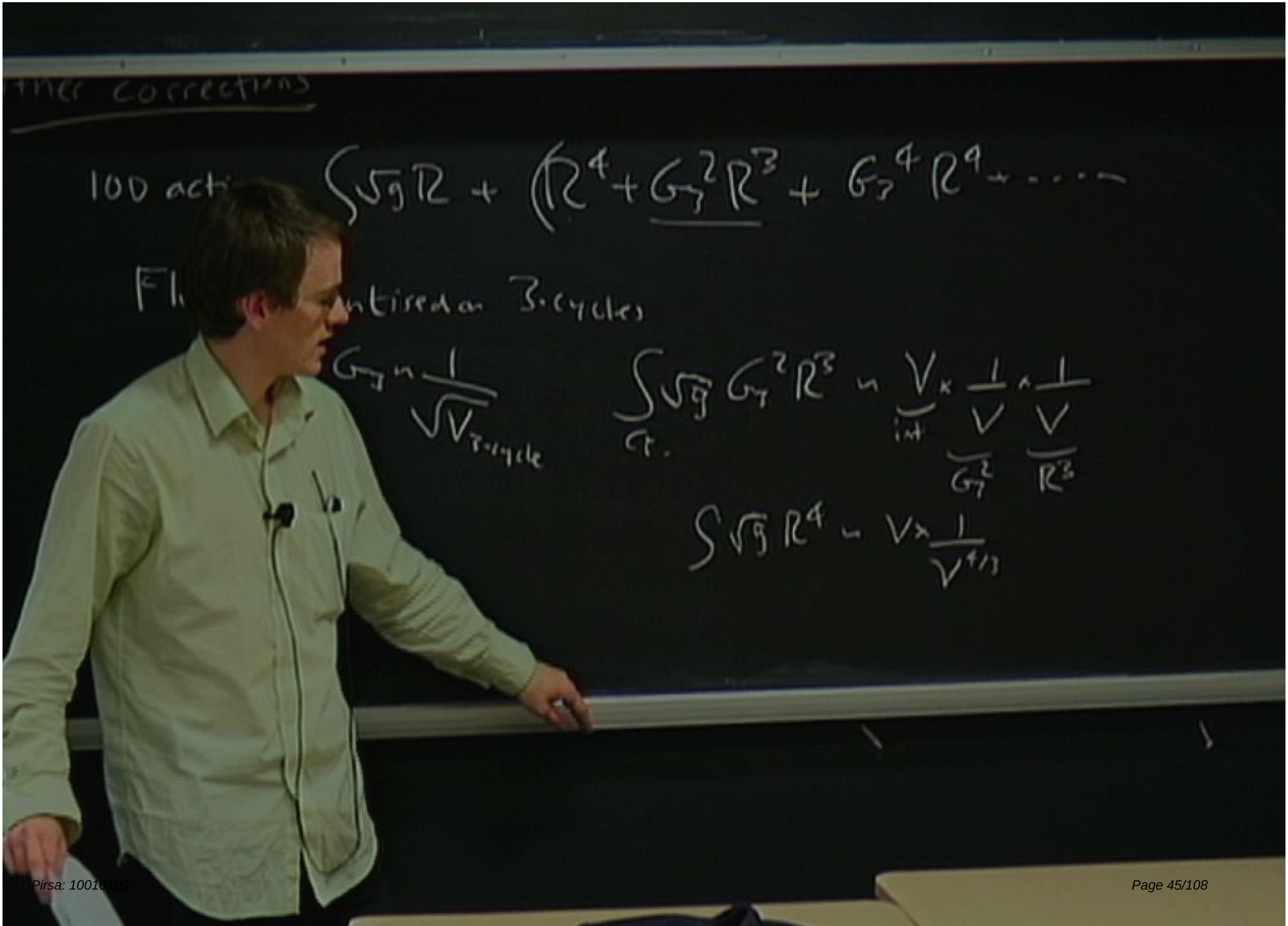
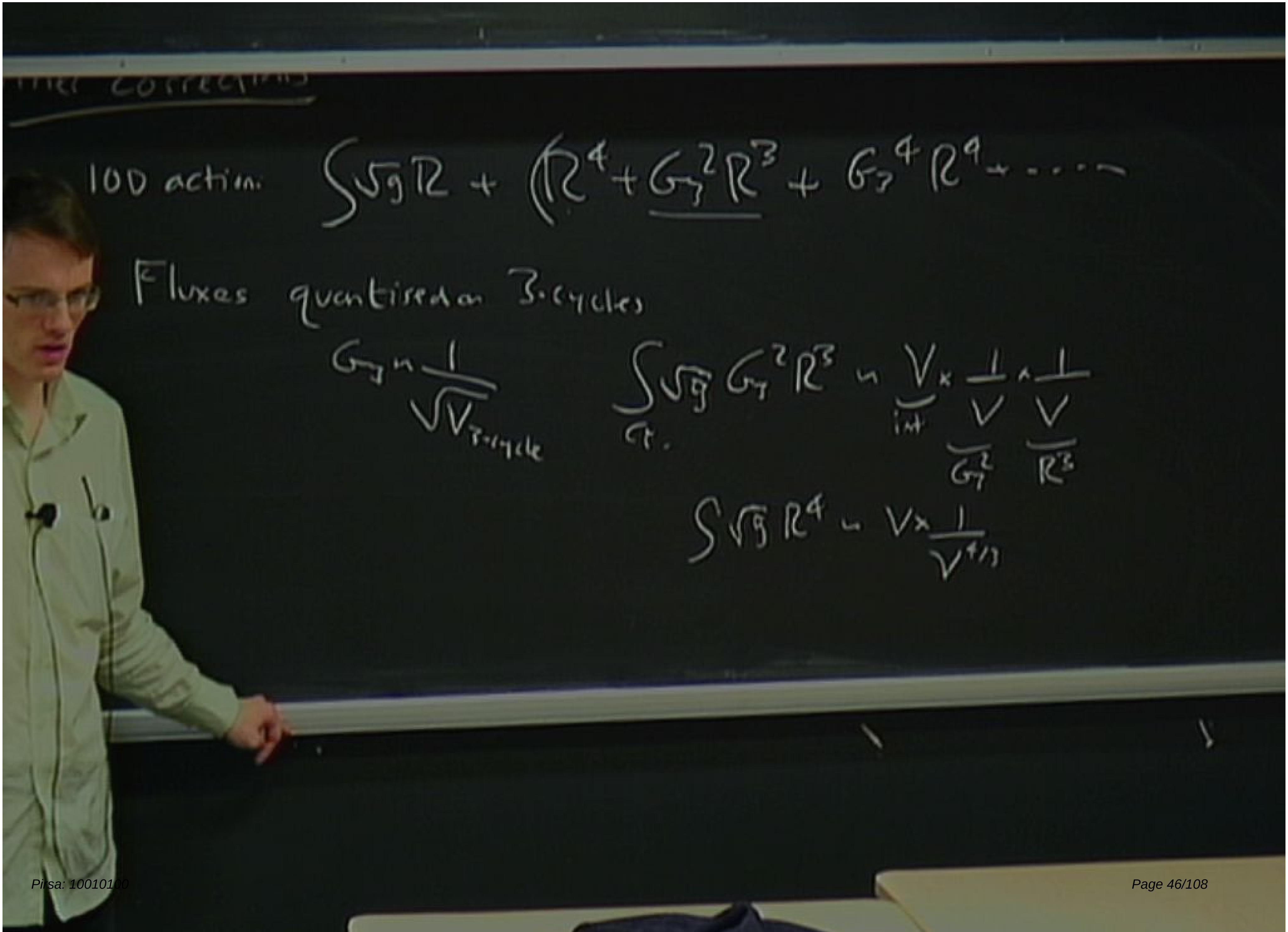
int



ther corrections
100 acti
$\int \sqrt{g} R + (R^4 + G_3^2 R^3 + G_3^4 R^4 + \dots)$
Fl
ntized on 3-cycles
$G_3 \sim \frac{1}{\sqrt{V_{3\text{-cycle}}}}$
$\int_{CY} \sqrt{g}\, G_3^2 R^3 \sim \underbrace{V}_{int} \times \underbrace{\frac{1}{V}}_{G_3^2} \times \underbrace{\frac{1}{V}}_{R^3}$
$\int \sqrt{g} R^4 \sim V \times \frac{1}{V^{4/3}}$


corrections
11D action: $\int \sqrt{g} R + (R^4 + G_7^2 R^3 + G_7^4 R^9 + \ldots$
Fluxes quantised on 3-cycles
$G_7 \sim \frac{1}{\sqrt{V_{3\text{-cycle}}}}$
$\int_{G_2} \sqrt{g}\, G_7^2 R^3 \sim V_{int} \times \underbrace{\frac{1}{V}}_{G_7^2} \times \underbrace{\frac{1}{V}}_{R^3}$
$\int \sqrt{g} R^4 \sim V \times \frac{1}{V^{4/3}}$

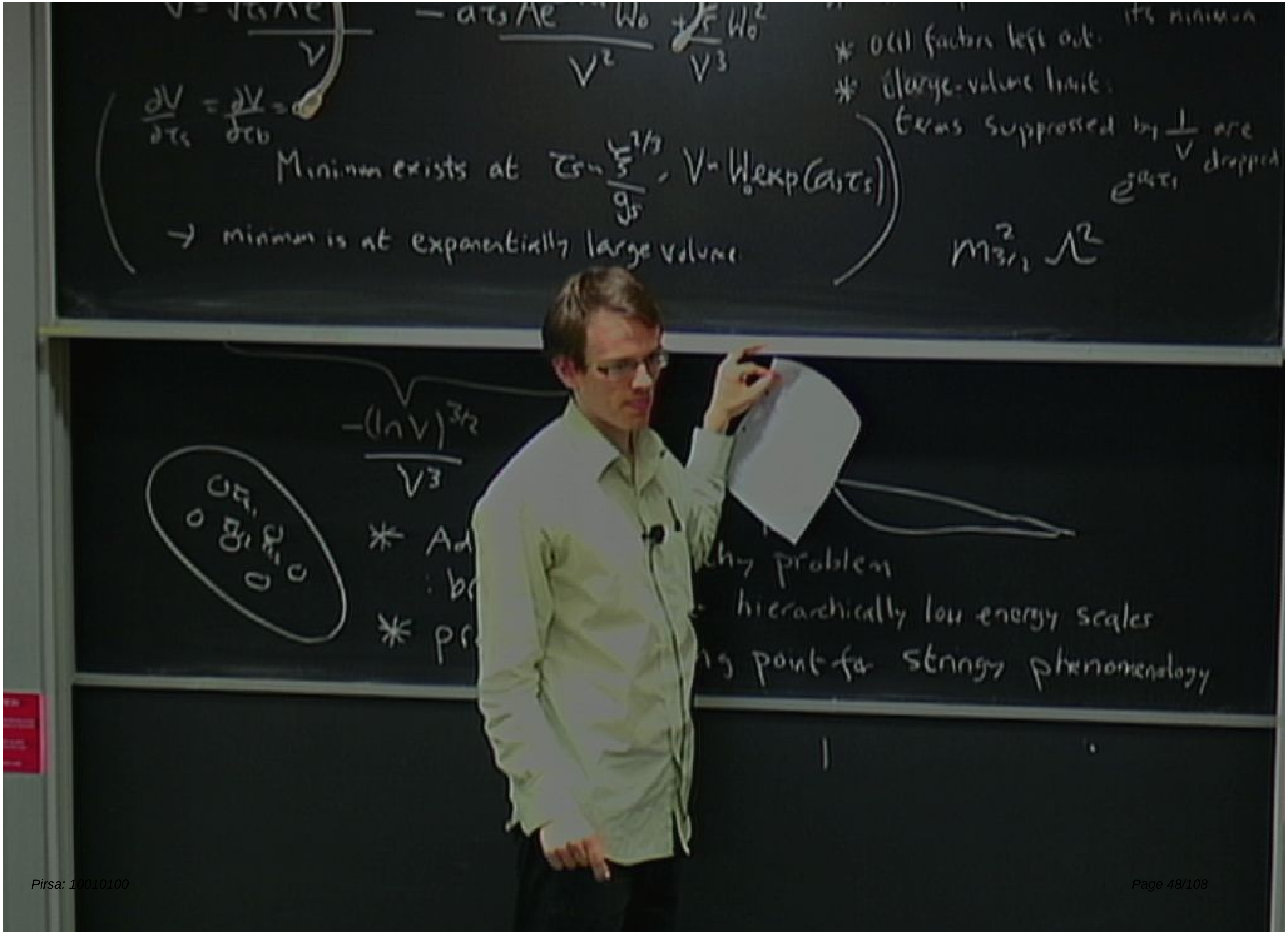
11D action: $\int \sqrt{g} R + \int \underline{R^4 + G_7^2 R^3} + G_7^4 R^4 + \cdots$

Fluxes quantised on 3-cycles

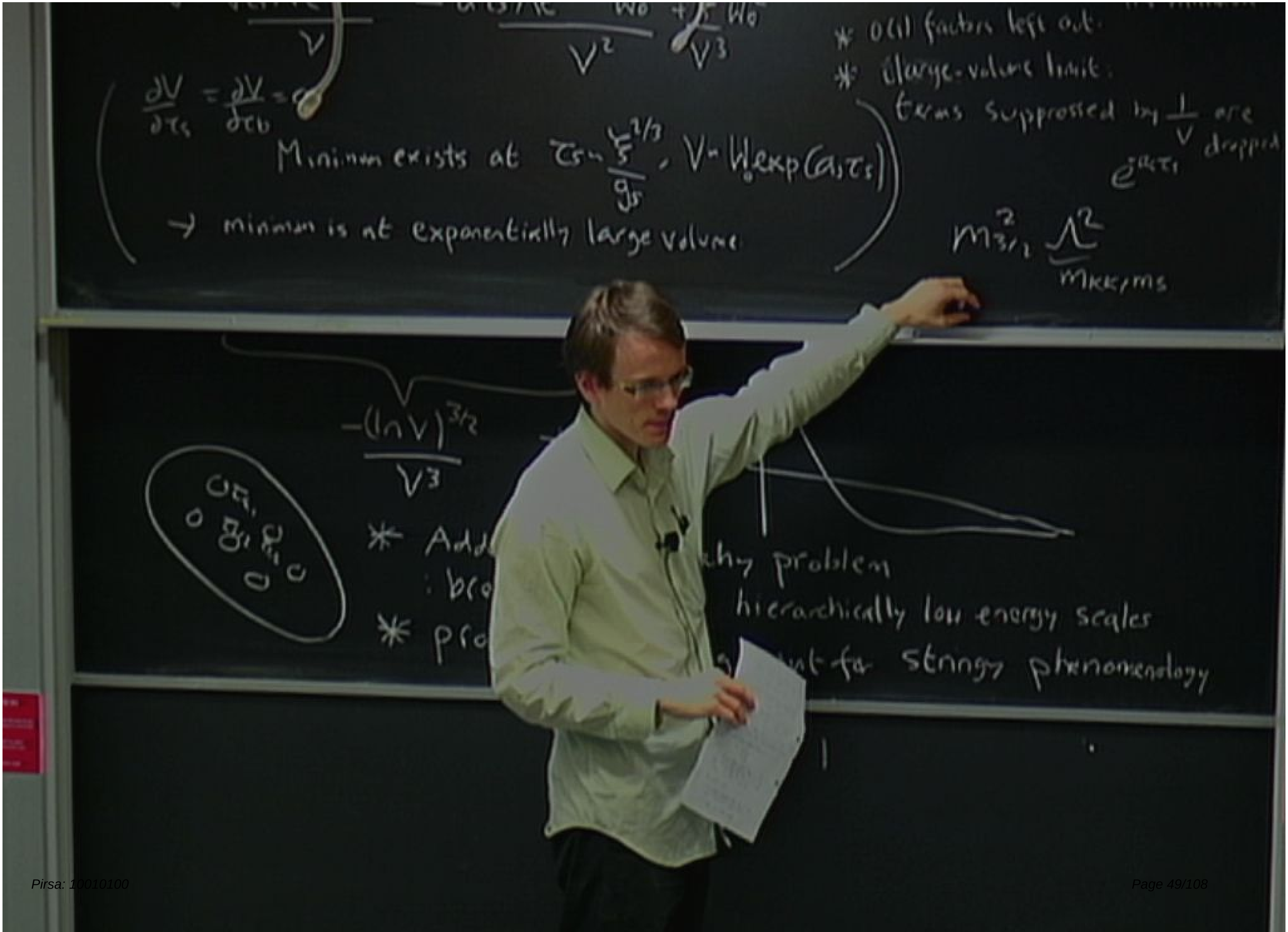
$$G_7 \sim \frac{1}{\sqrt{V_{3\text{-cycle}}}}$$

$$\int_{G_2} \sqrt{g}\, G_7^2 R^3 \sim \underbrace{V}_{int} \times \underbrace{\frac{1}{V}}_{G_7^2} \times \underbrace{\frac{1}{V}}_{R^3}$$

$$\int \sqrt{g}\, R^4 \sim V \times \frac{1}{V^{4/3}}$$



* O(1) factors left out.
* (large-volume limit.
terms suppressed by 1/V are dropped
Minimum exists at
→ minimum is at exponentially large volume
problem
hierarchically low energy scales
point for stringy phenomenology


* O(1) factors left out.
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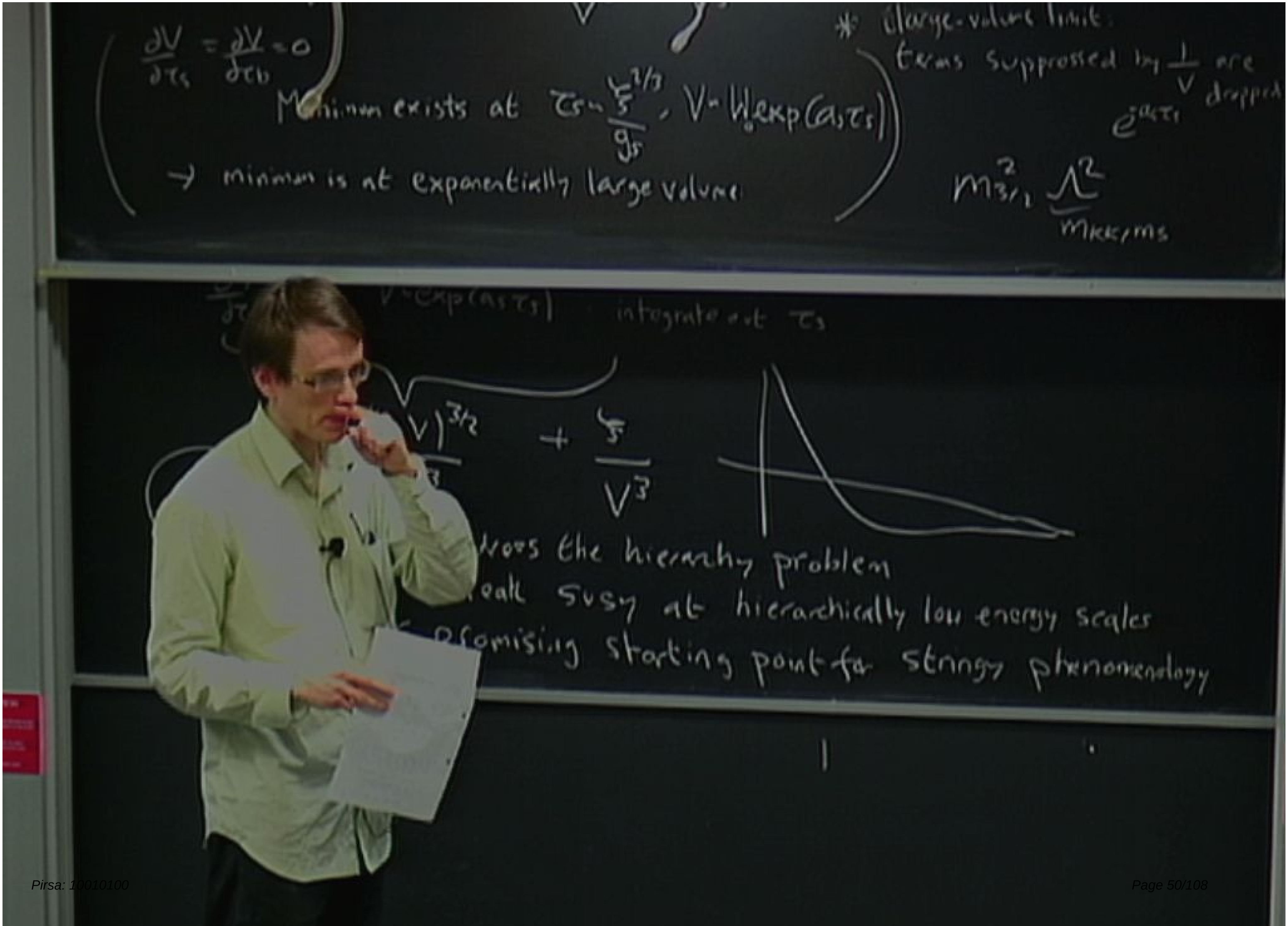
Minimum exists at
→ minimum is at exponentially large volume
* Add
hierarchy problem
hierarchically low energy scales
* pro
for stringy phenomenology



∂V/∂τs = ∂V/∂τb = 0
Minimum exists at τs ~ ξ^{2/3}/gs, V ~ W0 exp(as τs)
→ minimum is at exponentially large volume
* large-volume limit:
terms suppressed by 1/V are dropped
m3/2, Λ, mKK, ms
integrate out τs
+ ξ/V^3
solves the hierarchy problem
break susy at hierarchically low energy scales
promising starting point for stringy phenomenology

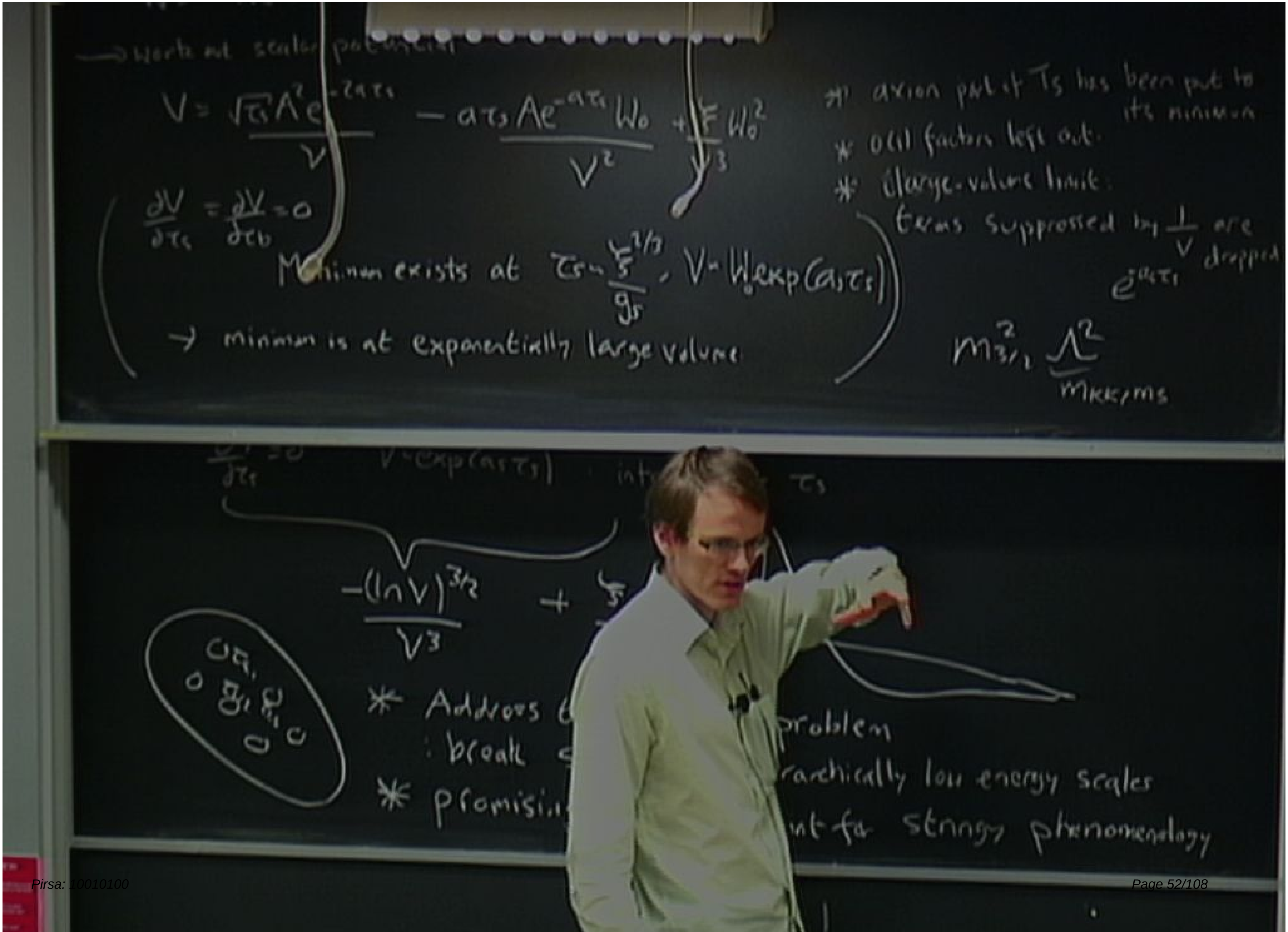
→ minimum is at exponentially large volume

$$m_{3/2}^2 \quad \frac{\Lambda^2}{m_{KK}/m_s}$$

$\frac{\partial V}{\partial \tau_s} = 0$ $\quad V \cdot \exp(a_s \tau_s)$ $\quad$ integrate out τ_s

$$\underbrace{\hphantom{xxxxxxxxxxxx}}\quad -\frac{(\ln V)^{3/2}}{V^3} + \frac{\xi}{V^3}$$

* Address the hierarchy problem
  : break susy at hierarchically low energy scales
* promising starting point for strings phenomenology


→ Work at scalar potential
V = √τs A² e^(-2aτs) / V − aτs A e^(-aτs) W0 / V² + ξ W0² / V³
* axion part of Ts has been put to its minimum
* O(1) factors left out.
* (large-volume limit:
terms suppressed by 1/V are dropped
∂V/∂τs = ∂V/∂τb = 0
Minimum exists at τs ~ ξ^(2/3) / gs , V ~ W0 exp(as τs)
→ minimum is at exponentially large volume
m3/2² ~ Λ² / MKK/ms
−(ln V)^(3/2) / V³
* Address
: break
* promisin
problem
rarchically low energy scales
nt for stringy phenomenology

$$\frac{\ldots A e^{-a\tau_s} W_0}{V^2} + \frac{\xi W_0^2}{V^3}$$

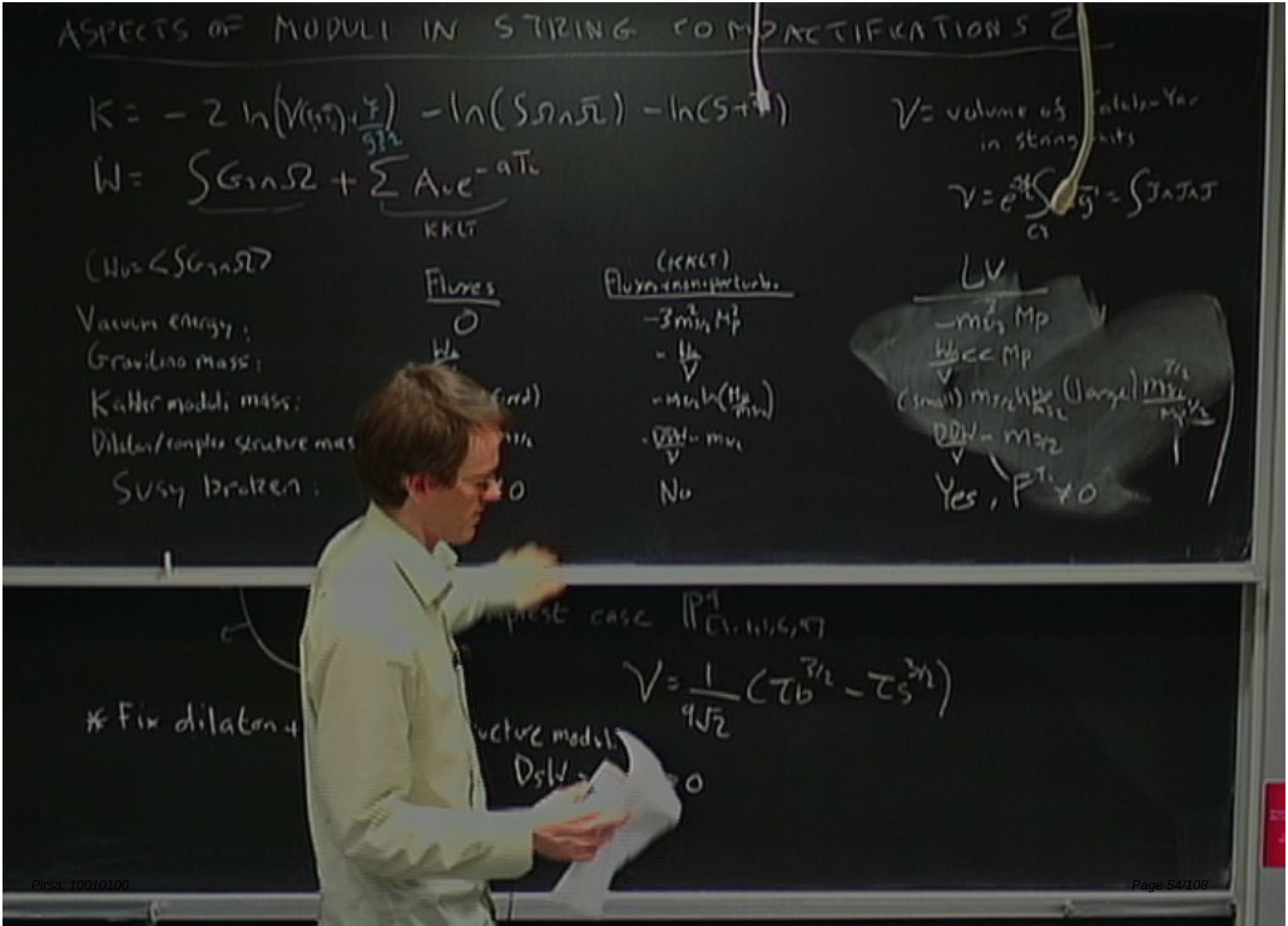
* axion part of T_s has been put to its minimum
* $O(1)$ factors left out.
* large-volume limit: terms suppressed by $\frac{1}{V}$ are dropped $e^{-a_s\tau_s}$

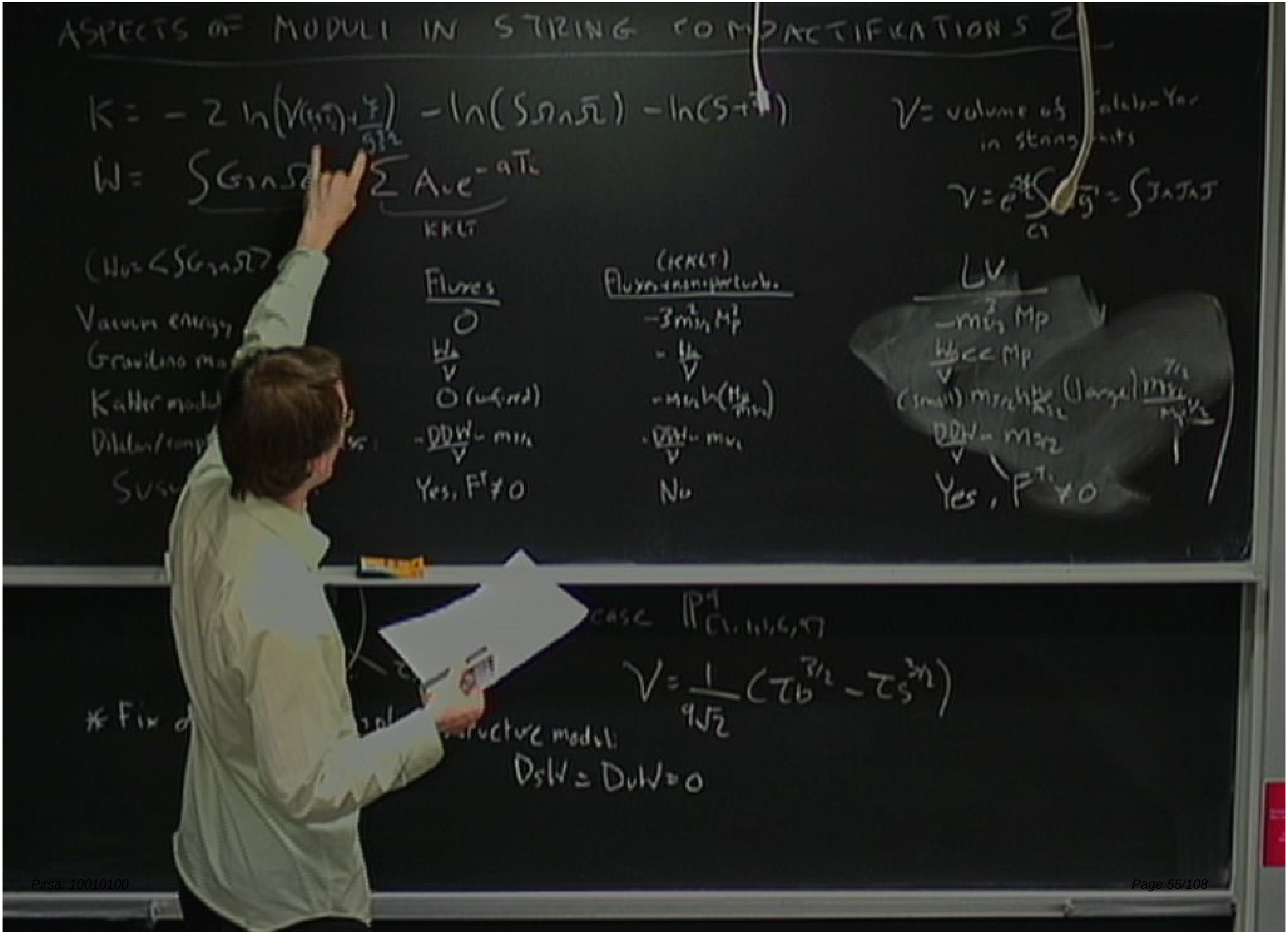
at $\tau_s \sim \frac{\xi^{2/3}}{g_s}$, $V \sim W_0 \exp(a_s \tau_s)$

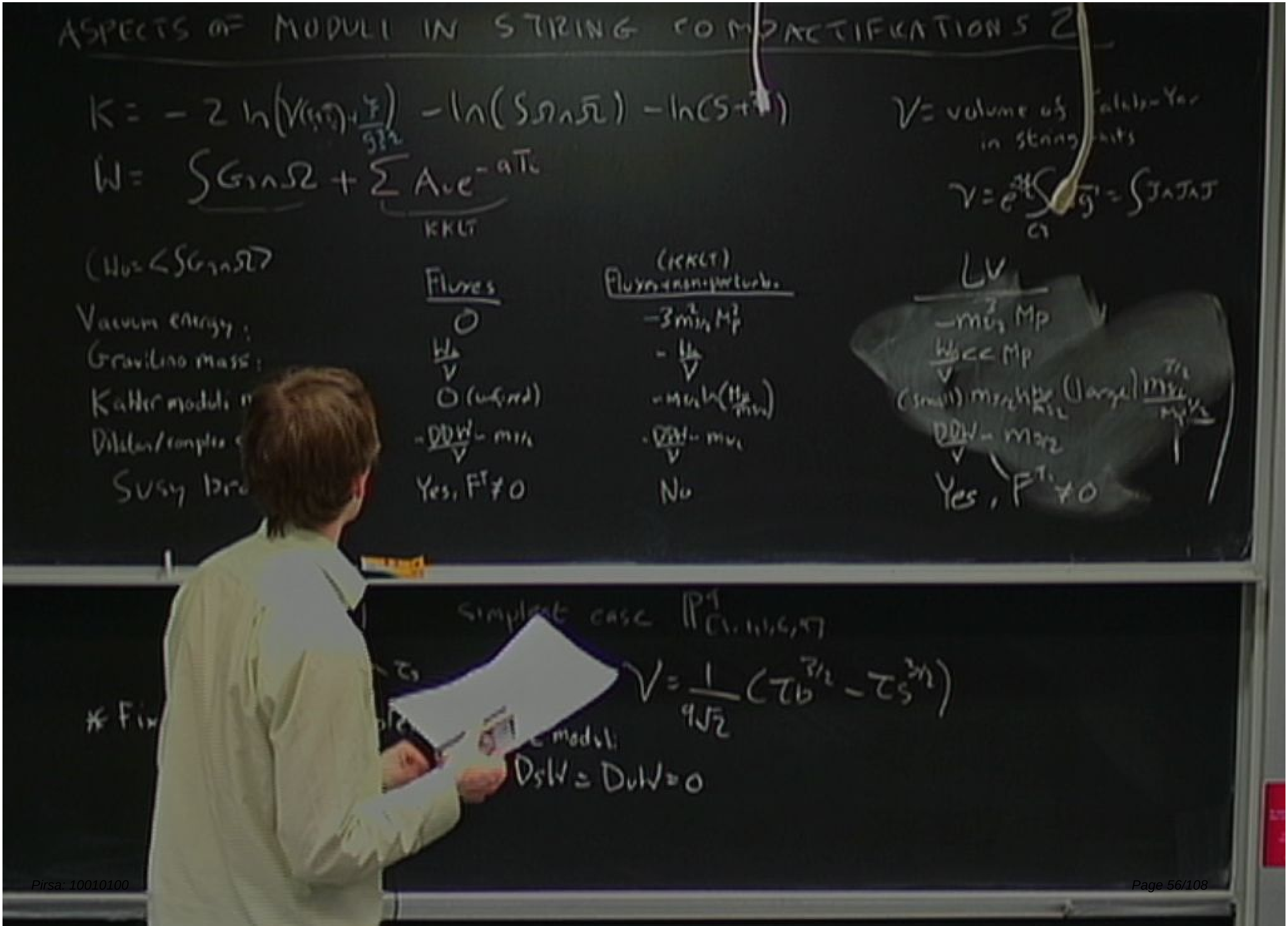
...ntially large volume.

$$m_{3/2}^2 \underbrace{\Lambda^2}_{m_{KK}, m_s}$$

$\ldots s\tau_s)|$ integrate out τ_s


ASPECTS OF MODULI IN STRING COMPACTIFICATIONS 2
V = volume of Calabi-Yau in string units
KKLT
Fluxes
(KKLT)
LV
Vacuum energy:
Gravitino mass:
Kahler moduli mass:
Susy broken:
No
Yes
simplest case
* Fix dilaton +


ASPECTS OF MODULI IN STRING COMPACTIFICATIONS 2
V = volume of Calabi-Yau
in string units
KKLT
(KKLT)
Fluxes
Fluxes + nonperturb.
LV
Vacuum energy
Gravitino mass
Kahler moduli
Dilaton/complex structure moduli
Yes, $F^T \neq 0$
No
* Fix dilaton and complex structure moduli
$D_S W = D_U W = 0$
$\mathcal{V} = \frac{1}{9\sqrt{2}}(\tau_b^{3/2} - \tau_s^{3/2})$


ASPECTS OF MODULI IN STRING COMPACTIFICATIONS 2
V = volume of Calabi-Yau
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KKLT
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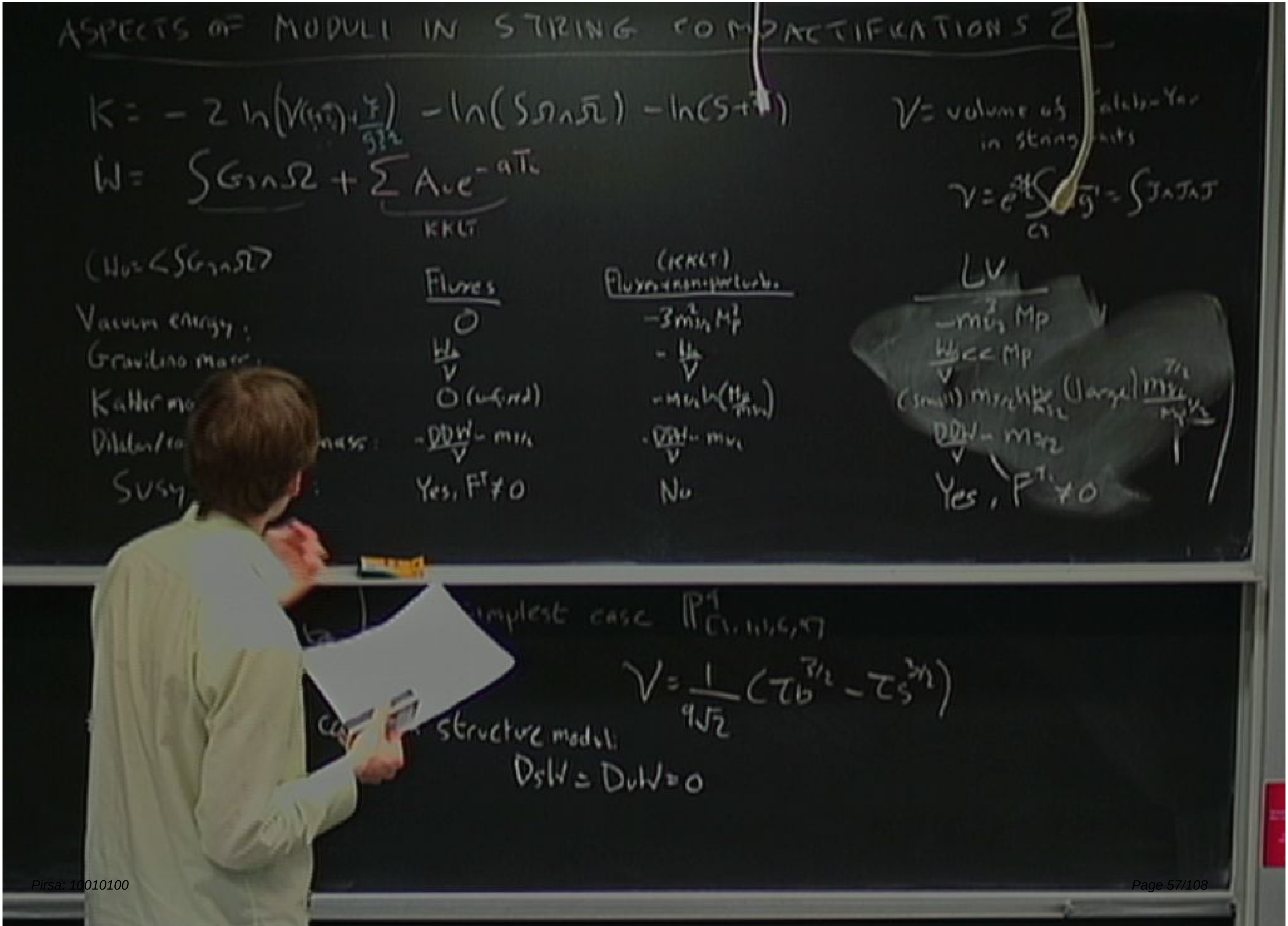
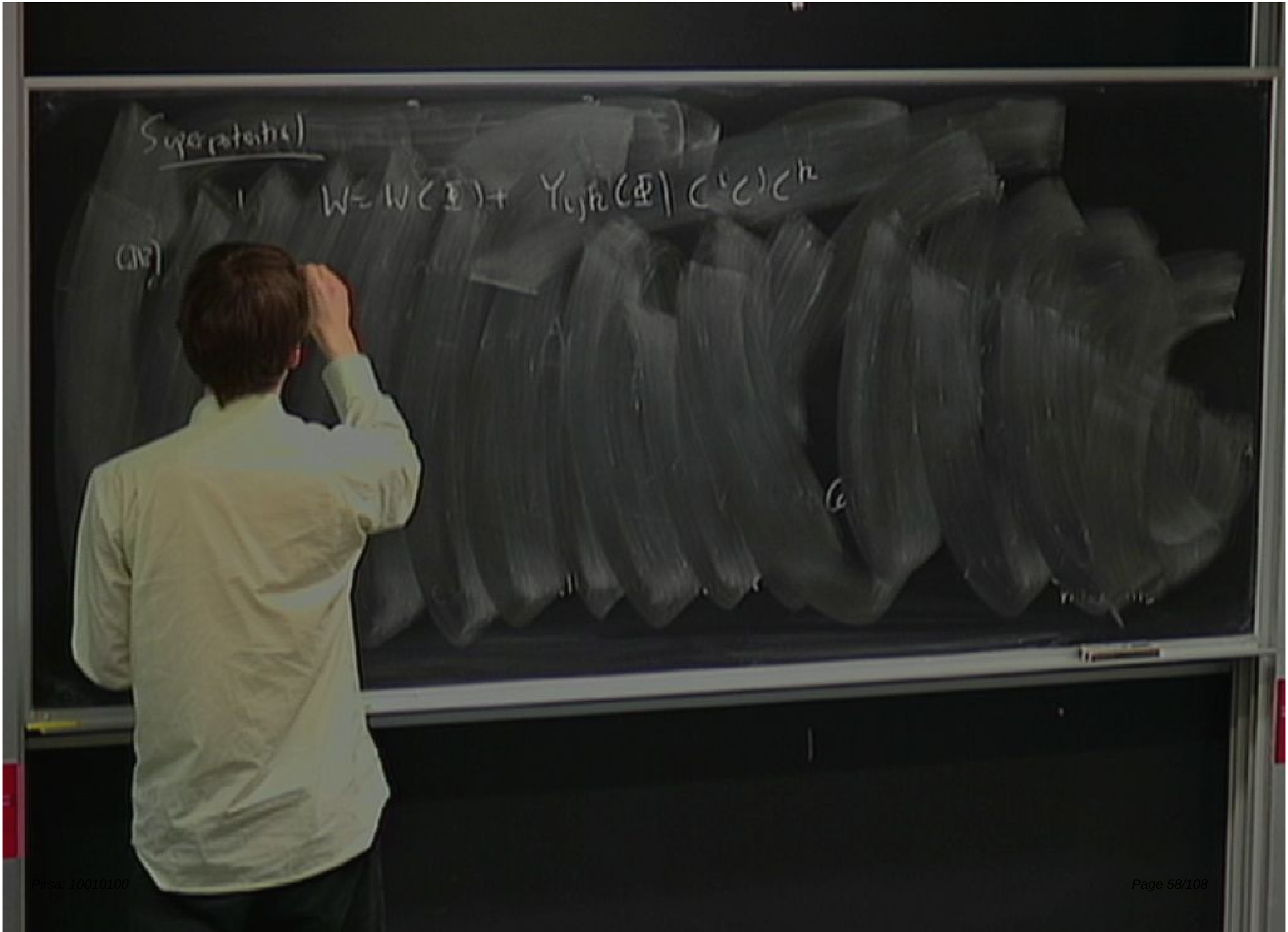
LV
Vacuum energy:
Gravitino mass:
Kahler moduli
Dilaton/complex
Susy
Yes, F^T ≠ 0
No
Yes, F^T ≠ 0
simplest case
modul
DsW = DuW = 0

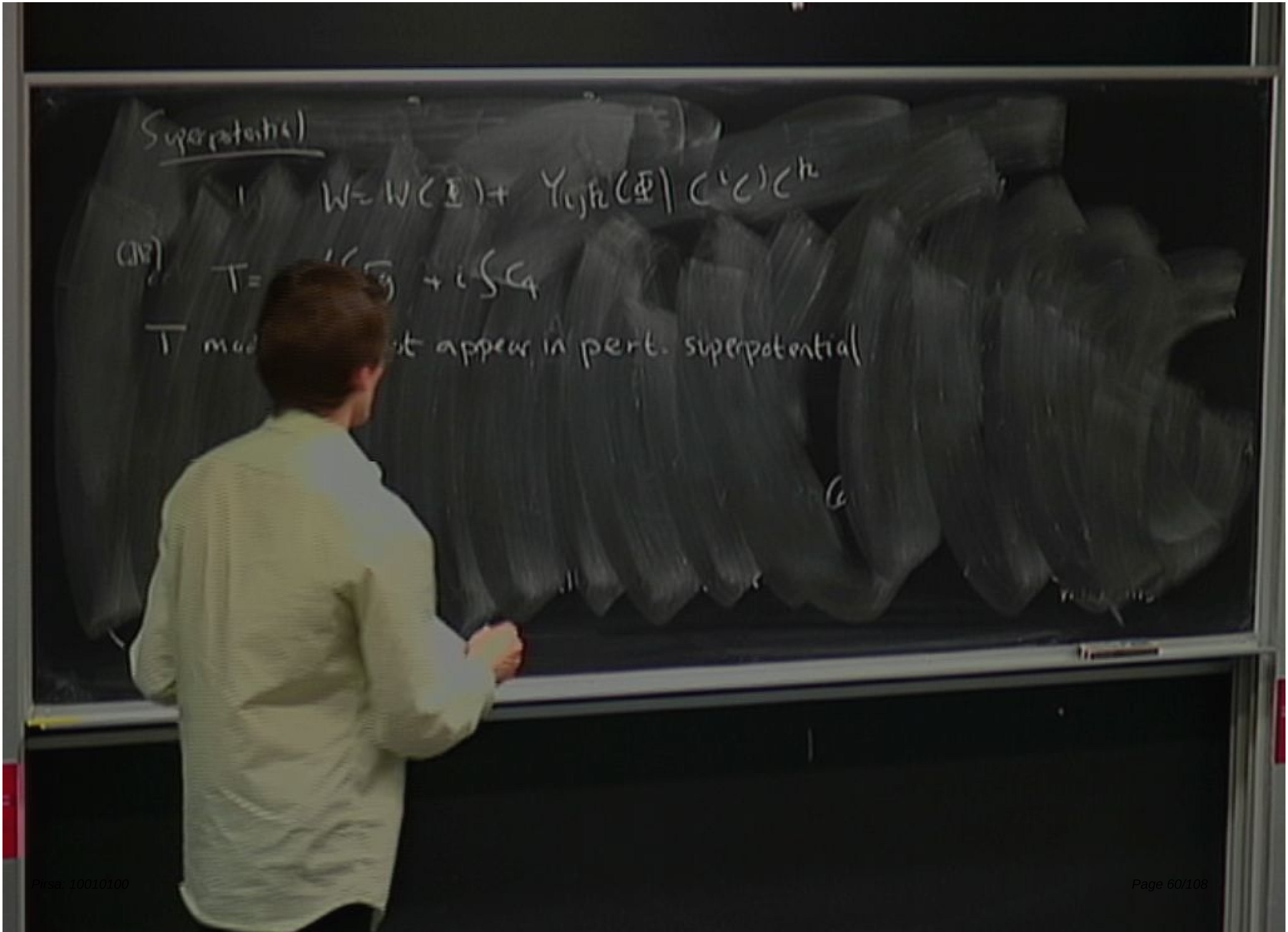

ASPECTS OF MODULI IN STRING COMPACTIFICATIONS 2
K = − 2 ln(V + ...) − ln(S Ω ∧ Ω̄) − ln(S + ...)
V = volume of Calabi-Yau in string units
W = ∫ G₃ ∧ Ω + Σ A e^(−aT)
KKLT
Fluxes
(KKLT)
Fluxes + non-perturb.
LV
Vacuum energy:
Gravitino mass:
Kahler mo
Dilaton/
Susy
O
−3 m²₃/₂ M²P
− m²₃/₂ MP
O (unfixed)
Yes, F^T ≠ 0
No
Yes, F^T ≠ 0
simplest case
V = 1/(9√2) (τb^(3/2) − τs^(3/2))
structure moduli
DsW = DuW = 0


Superpotential
W = W(Φ) + Y_{ijk}(Φ) C^i C^j C^k

Superpotential

$W = W(\Phi) + Y_{ijk}(\Phi)\, C^i C^j C^k$

(N=1) $T = e^{-\phi} \int \sqrt{g} + i \int C_4$


Superpotential
W = W(Φ) + Y_{ijk}(Φ) C^i C^j C^k
(IIB)
T =
+ i ∫ C_4
T
appear in pert. superpotential

Superpotential

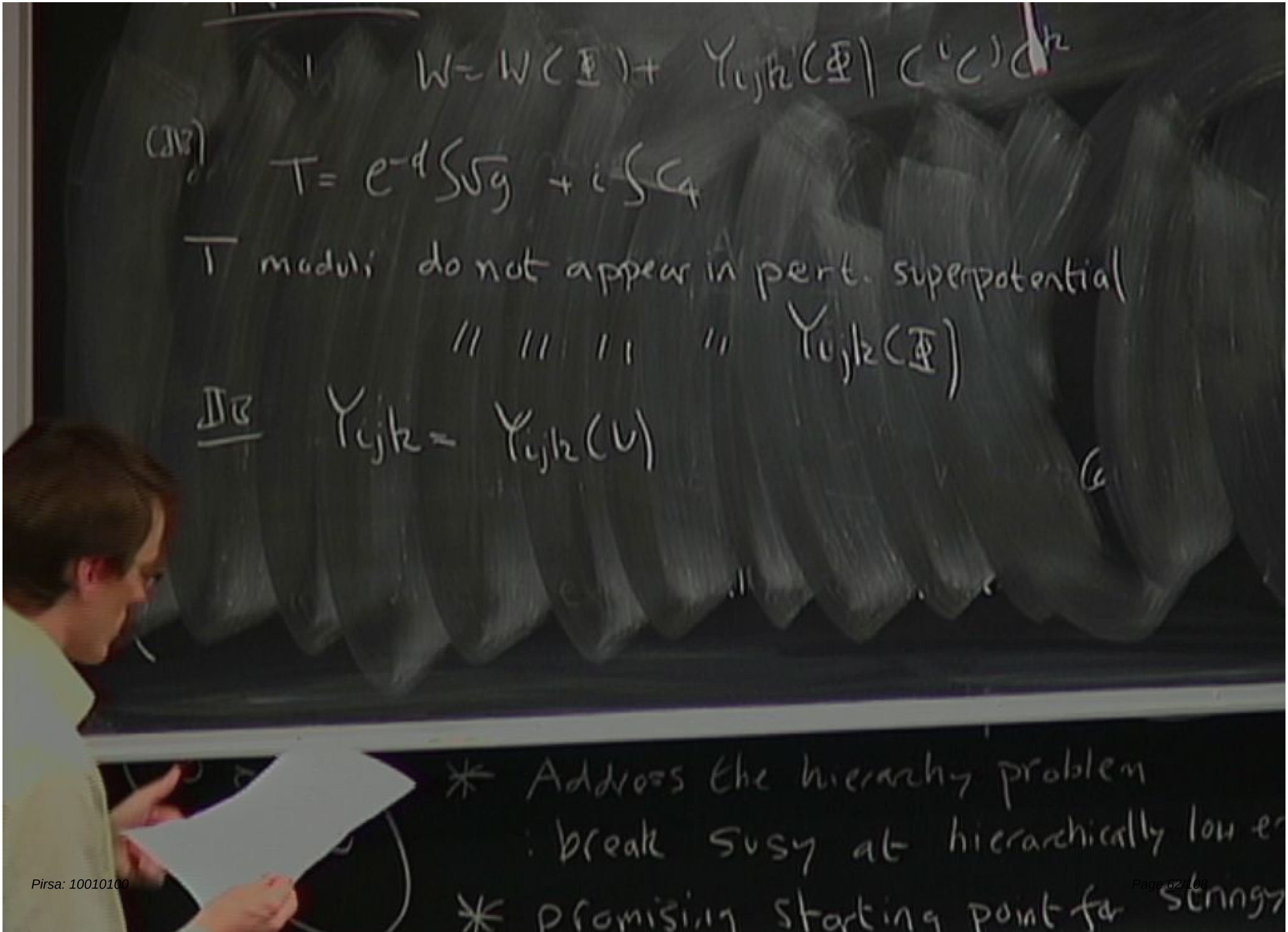
$$W = W(\Phi) + Y_{ijk}(\Phi)\, C^i C^j C^k$$

(IIB)

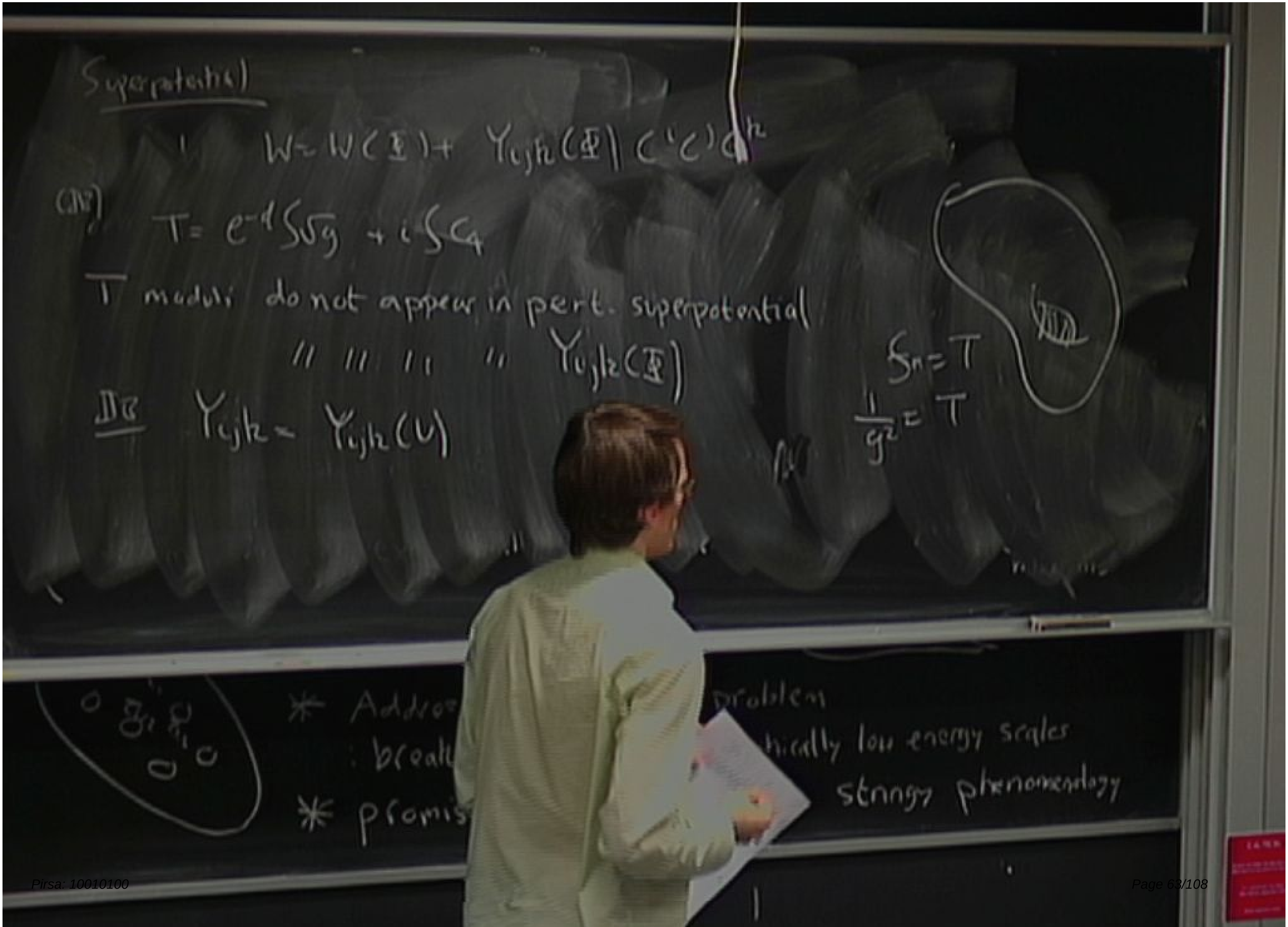
$$T = e^{-\phi} \int \sqrt{g} + i \int C_4$$

T moduli do not appear in pert. superpotential

" " " " $Y_{ijk}(\Phi)$



W = W(Φ) + Y_ijk(Φ) C^i C^j C^k
T = e^-φ ∫√g + i ∫C_4
T moduli do not appear in pert. superpotential
" " " " Y_ijk(Φ)
IIB Y_ijk = Y_ijk(U)
* Address the hierarchy problem
: break susy at hierarchically low
* promising starting point for


Superpotential
W = W(Φ) + Y_ijk(Φ) C^i C^j C^k
T = e^{-4φ} ∫√g + i ∫ C_4
T moduli do not appear in pert. superpotential
" " " " Y_ijk(Φ)
IIB Y_ijk = Y_ijk(U)
∫_Π = T
1/g^2 = T
problem
breaking
hierarchically low energy scales
promising
strings phenomenology

Superpotential

$$W = W(\Phi) + Y_{ijk}(\Phi)\, C^i C^j C^k$$

(IIB) $T = e^{-\phi}\int\sqrt{g} + i\int C_4$

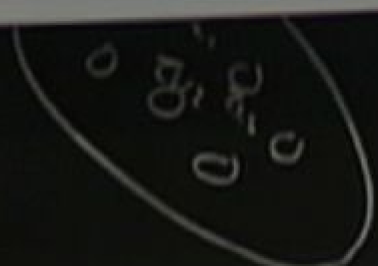
T moduli do not appear in pert. superpotential

" " " " $Y_{ijk}(\Phi)$

IIB $Y_{ijk} = Y_{ijk}(U)$

$\int_{\Sigma} = T$

$\frac{1}{\alpha} = \frac{4\pi}{g^2} = T_{\Sigma}$



* Addresses the hierarchy problem
: break susy at hierarchically low energy scales

* promising starting point for stringy phenomenology

$W = W(\Phi) + Y_{ijk}(\Phi)\, C^i C^j C^k$

(IIB) $T = e^{-\phi}\int\sqrt{g} + i\int C_4$

T moduli do not appear in pert. superpotential

" " " " $Y_{ijk}(\Phi)$

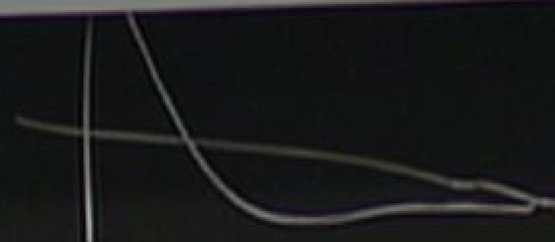
IIB $Y_{ijk} = Y_{ijk}(U)$

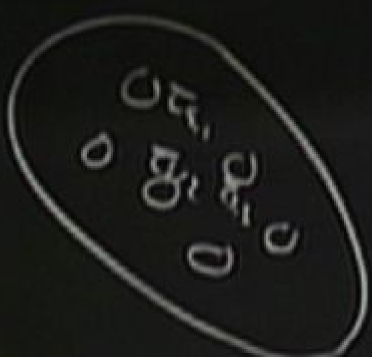
$f_{m} = T$

$\frac{1}{\alpha} = \frac{4\pi}{g^2} = T_{sm}$

* Can you get Yukawas as an expansion in α_{small}

$$-\frac{(\ln V)^{3/2}}{V^3} + \frac{\xi}{V^3}$$





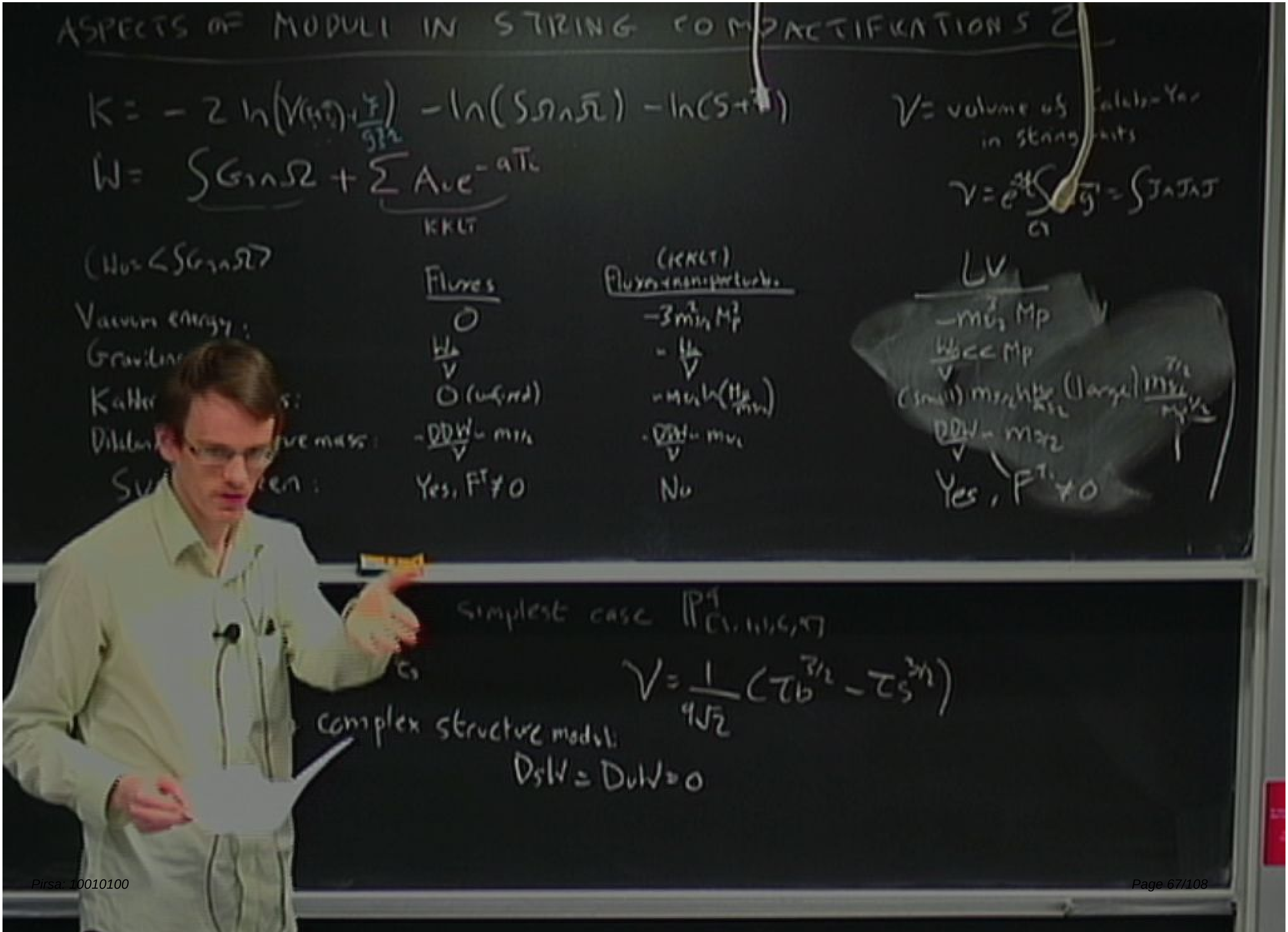
* Addresses the hierarchy problem
  : break susy at hierarchically low energy scales
* promising starting point for stringy phenomenology

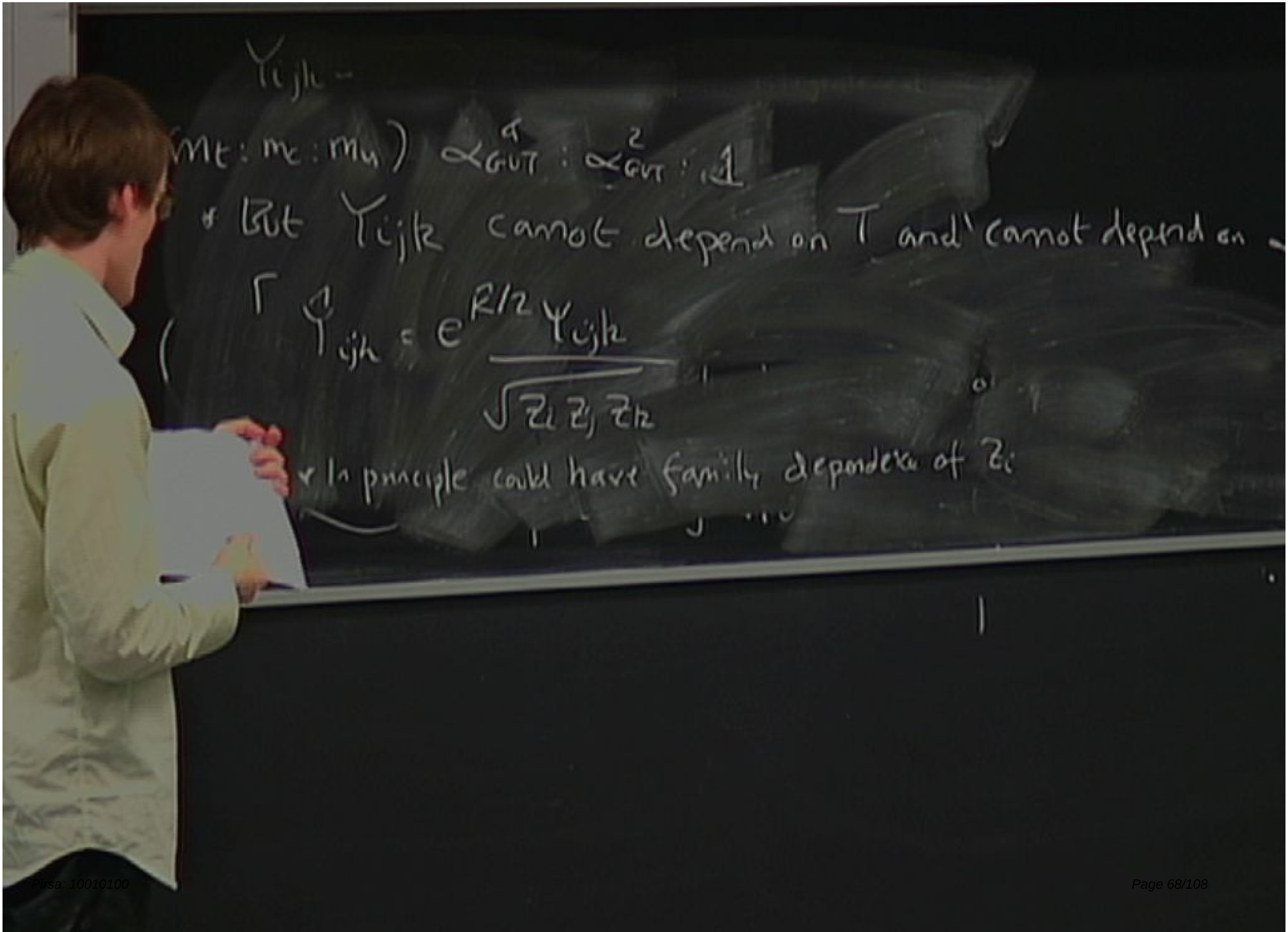
* Can you get Yukawas as an expansion in $\alpha_{overall}$

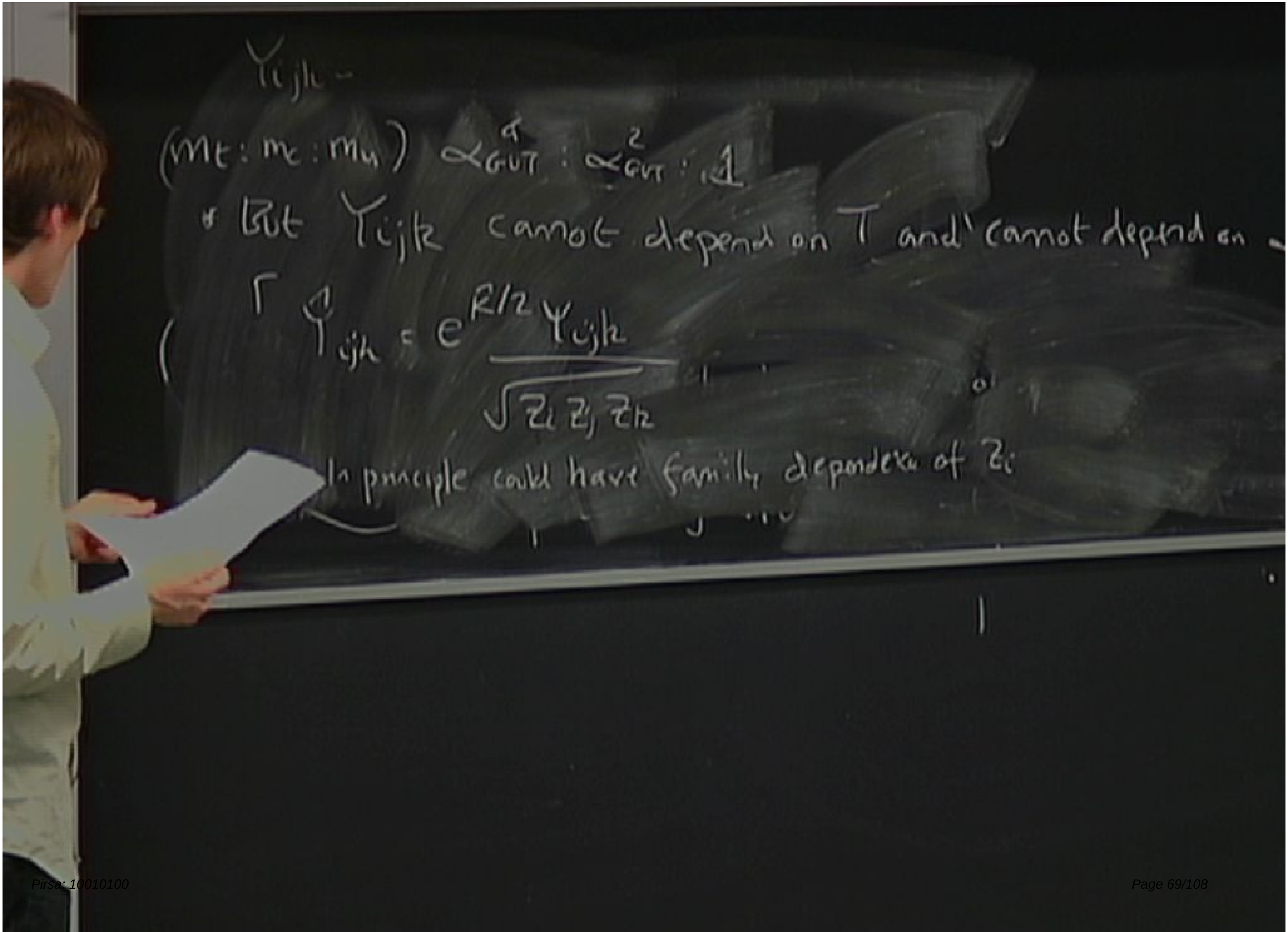
Y_{ijk} –

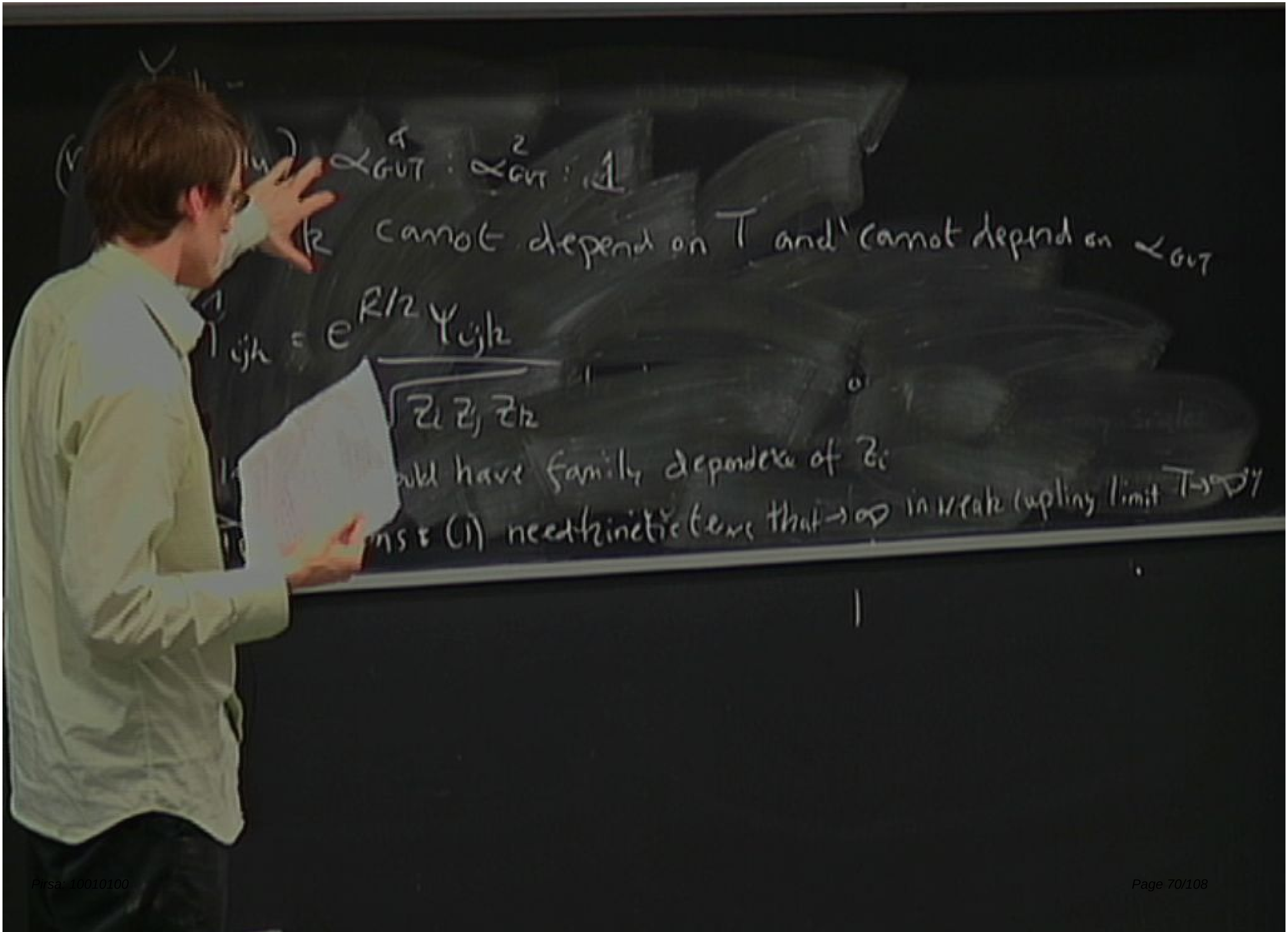
$(m_t : m_c : m_u)$ $\alpha_{GUT}^4 : \alpha_{GUT}^2 : 1$

* But Y_{ijk} cannot depend on T and cannot depend on α_{GUT}


ASPECTS OF MODULI IN STRING COMPACTIFICATIONS 2
K = - 2 ln(V + ...) - ln(S Ω∧Ω̄) - ln(S + S̄)
W = ∫ G3∧Ω + Σ Ai e^(-aTi)
KKLT
V = volume of Calabi-Yau in string units
V = ∫ J∧J∧J
(W0 = <∫ G3∧Ω>)
Fluxes
(KKLT) Fluxes+nonperturb.
LV
Vacuum energy:
0
-3 m3/2² Mp²
Yes, F^T ≠ 0
No
Yes, F^T ≠ 0
Simplest case P^4 [1,1,1,6,9]
V = 1/(9√2) (τb^(3/2) - τs^(3/2))
complex structure moduli:
DsW = DuW = 0


$Y_{ijk} \sim$
$(m_t : m_c : m_u)$ $\alpha_{GUT}^4 : \alpha_{GUT}^2 : 1$
* But Y_{ijk} cannot depend on T and cannot depend on
$\hat{Y}_{ijk} = e^{K/2} \frac{Y_{ijk}}{\sqrt{Z_i Z_j Z_k}}$
* In principle could have family dependence of Z_i


Yijk ~
(mt : mc : mu) αGUT^4 : αGUT^2 : 1
But Yijk cannot depend on T and cannot depend on
Yijk = e^(K/2) Yijk / √(Zi Zj Zk)
In principle could have family dependence of Zi



α_GUT^4 : α_GUT^2 : 1
cannot depend on T and cannot depend on α_GUT
e^{R/2} Y_ijk
√(Z_i Z_j Z_k)
have family dependence of Z_i
(1) need kinetic terms that → ∞ in weak coupling limit T → ∞

Y_{ijk} –

$(m_t : m_c : m_u)$ $\alpha_{GUT}^4 : \alpha_{GUT}^2 : 1$

* But Y_{ijk} cannot depend on T and cannot depend on α_{GUT}

$$\hat{Y}_{ijk} = e^{K/2} \frac{Y_{ijk}}{\sqrt{Z_i Z_j Z_k}}$$

* In principle could have family dependence of Z_i

Two problems: (1) need kinetic terms that $\to \infty$ in weak coupling limit $T \to \infty$

(2) this isn't seen in actual models

Y_{ijk} –

$(m_t : m_c : m_u) \quad \alpha_{GUT}^4 : \alpha_{GUT}^2 : 1$

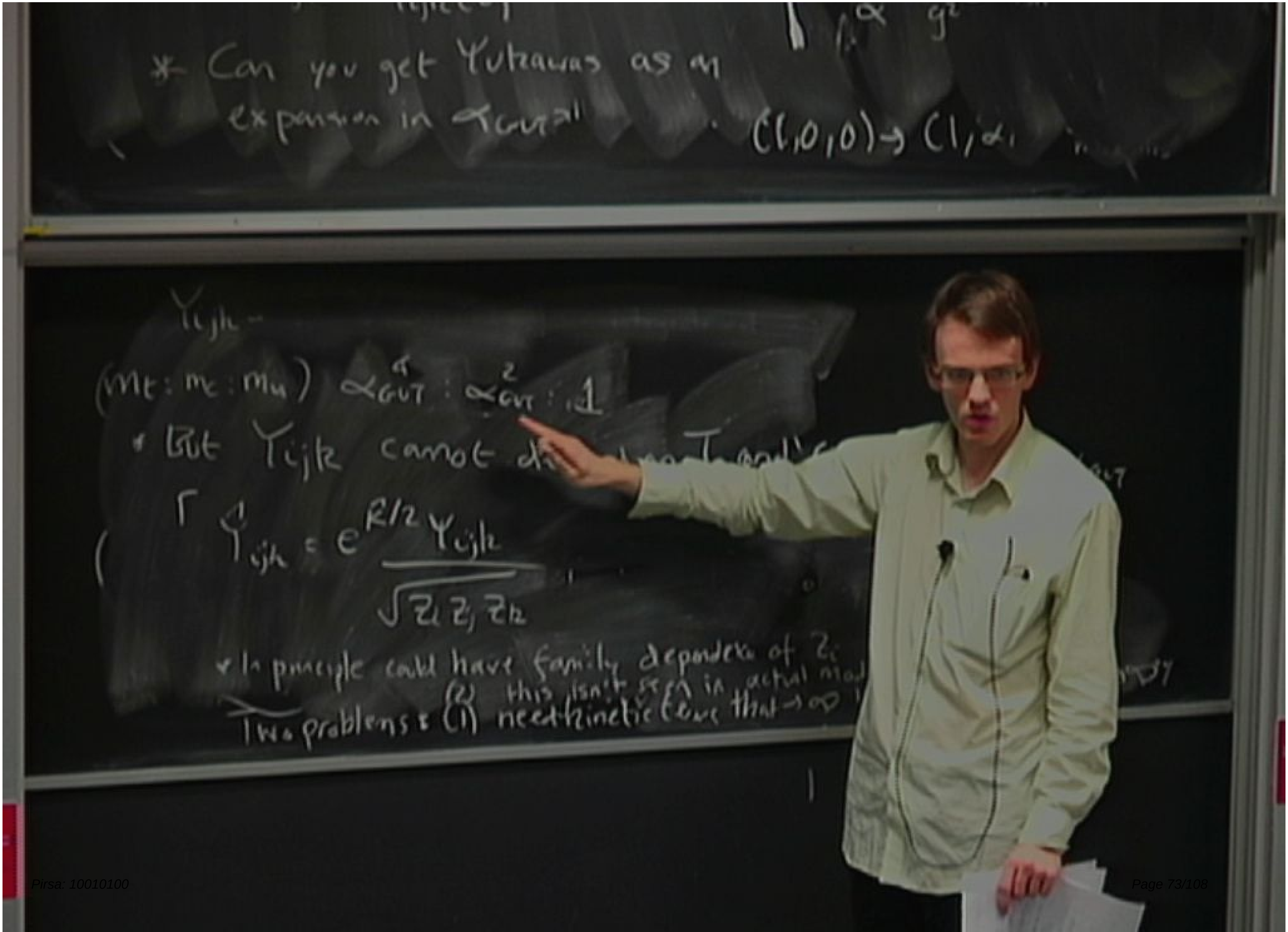
* But Y_{ijk} cannot depend on T and cannot depend on α_{GUT}

$$Y_{ijk} = e^{K/2} \frac{Y_{ijk}}{\sqrt{Z_i Z_j Z_k}}$$

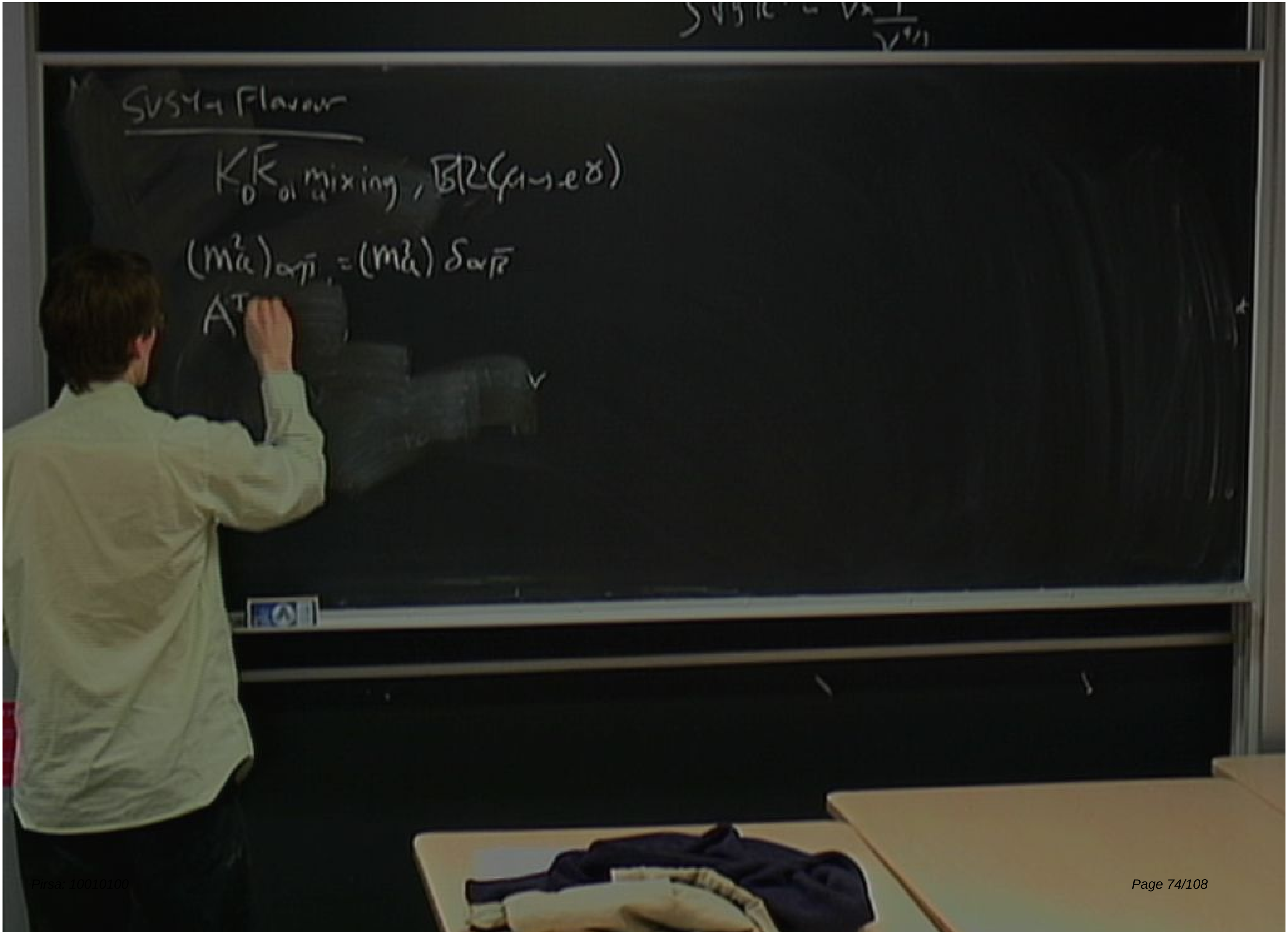
* In principle could have family dependence of Z_i

Two problems: (1) need kinetic term that $\to \infty$ in weak coupling limit $T \to \infty$ (?)

(2) this isn't seen in actual models



* Can you get Yukawas as an
expansion in αGUT?
(1,0,0) → (1, αi
Yijk ~
(mt : mc : mu) αGUT^4 : αGUT^2 : 1
* But Yijk cannot
Yijk = e^K/2 Yijk / √(Zi Zj Zk)
* In principle could have family dependence of Zi
Two problems: (1) need kinetic terms that → ∞
(2) this isn't seen in actual


SUSY + Flavour
K0 K0 mixing, BR(μ → e γ)
(m²ũ)αβ̄ = (m²ũ) δαβ̄

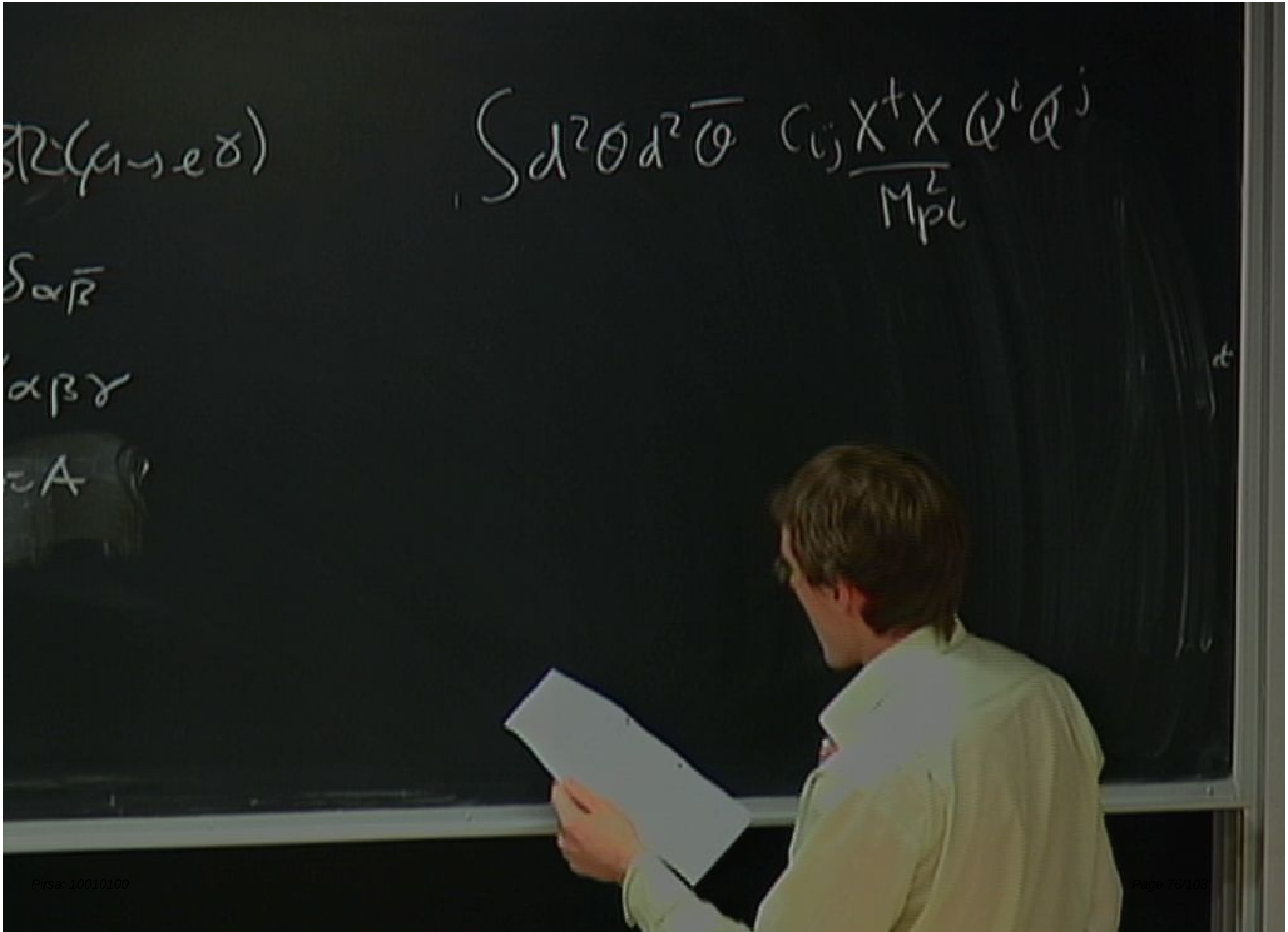
SUSY + Flavour

$K_0 \bar{K}_0$ mixing , $BR(\mu \to e\gamma)$

$$(m_a^2)_{\alpha\bar{\beta}} = (m_a^2)\,\delta_{\alpha\bar{\beta}}$$

$$A^I_{\alpha\beta\gamma} = A^I Y_{\alpha\beta\gamma}$$

$$\phi_{M_1} = \phi_{M_2} = \phi_{M_3} = A$$


$\int d^2\theta\, d^2\bar{\theta}\; c_{ij} \frac{X^\dagger X}{M_{pl}^2} Q^i Q^j$
$\delta_{\alpha\bar{\beta}}$
$\alpha\beta\gamma$
$= A$

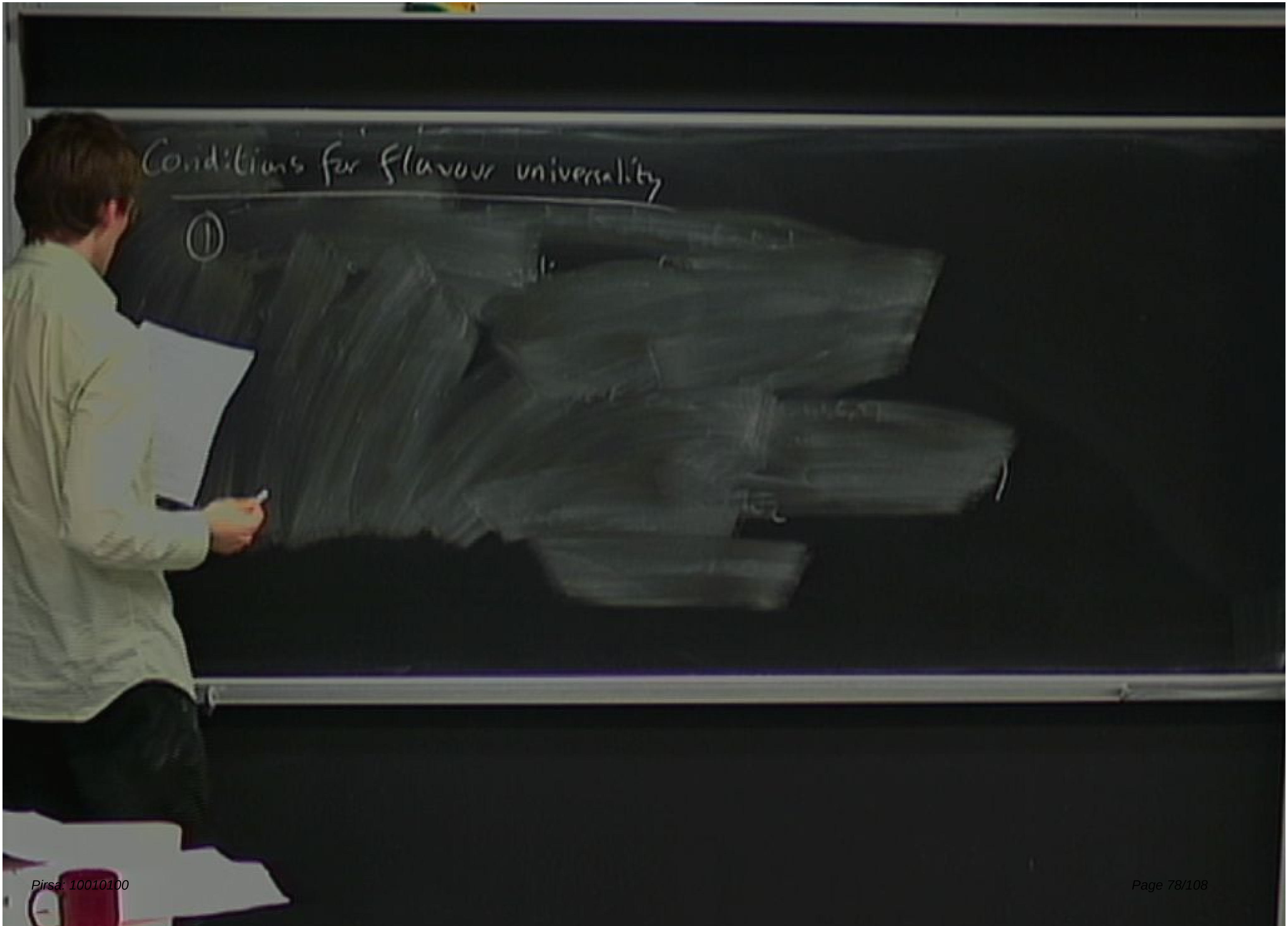
$$\int d^2\theta\, d^2\bar{\theta}\; c_{ij} \frac{X^\dagger X}{M_{pl}^2} Q^i Q^j$$

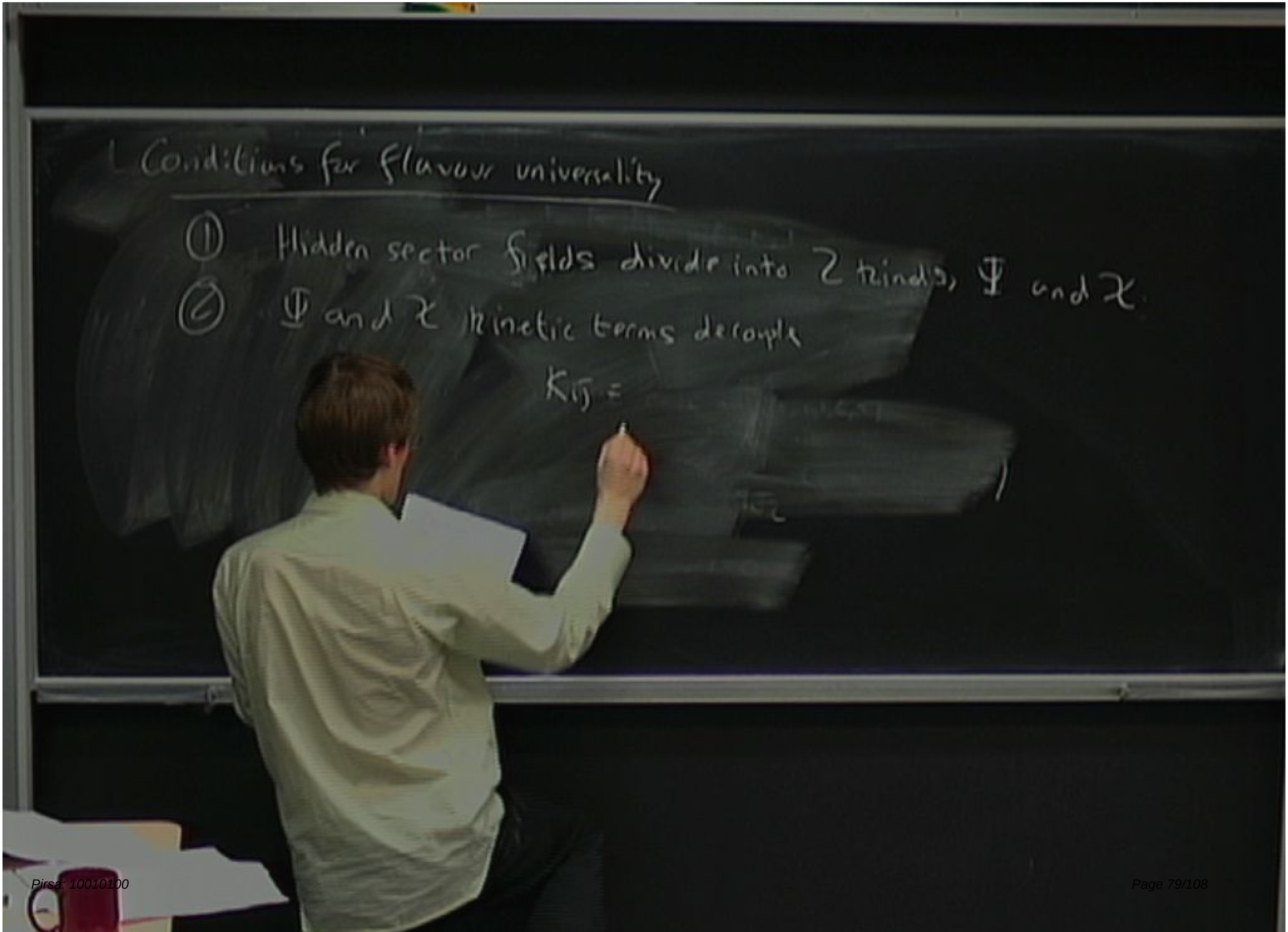
c_{ij} is generic $\Rightarrow$ arbitrary flavour violation

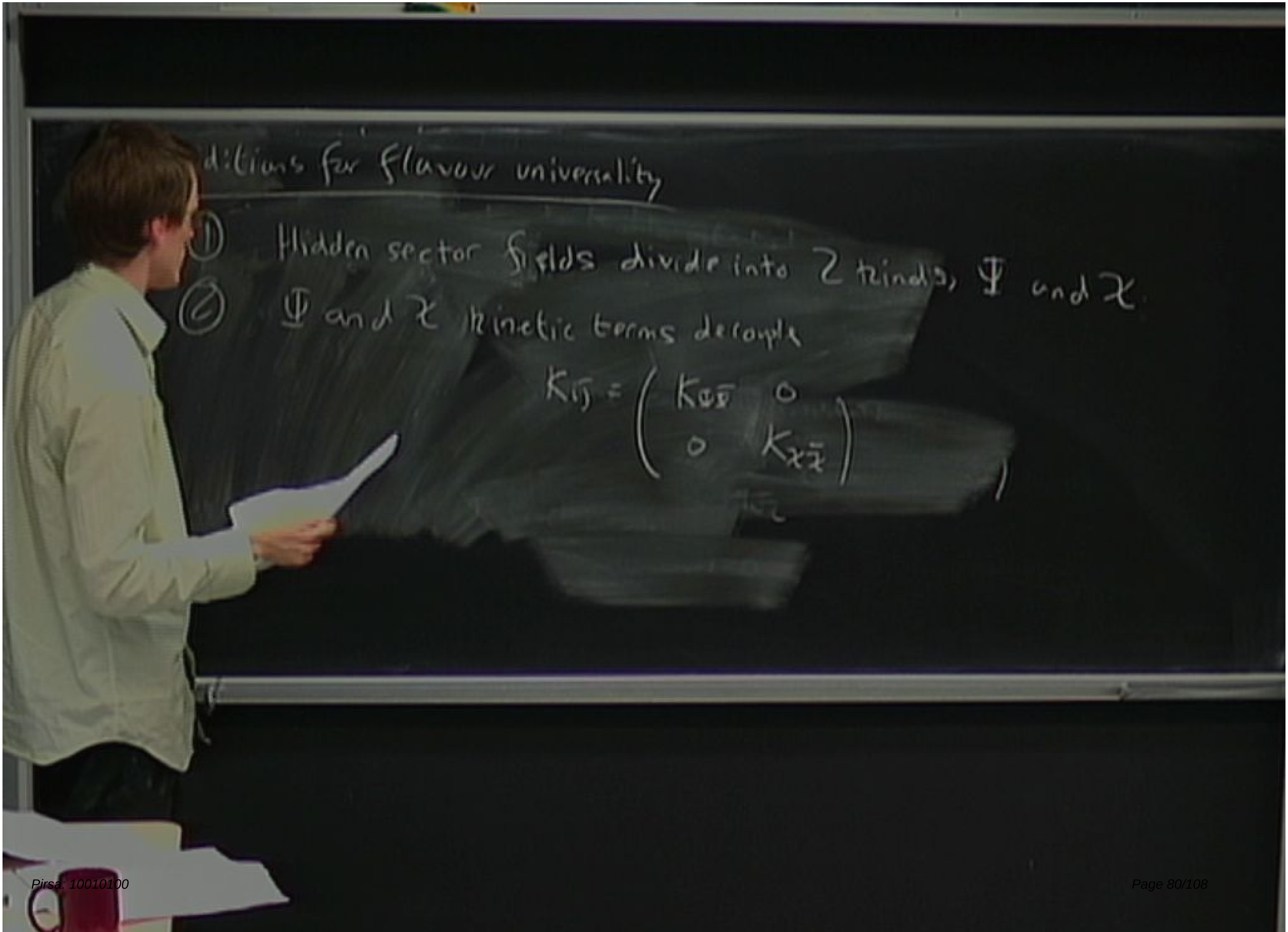
$\downarrow$

BAD

* Statements about M_{pl} suppressed couplings should be studied in string theory.


Conditions for flavour universality
1


Conditions for flavour universality
① Hidden sector fields divide into 2 kinds, Ψ and χ
② Ψ and χ kinetic terms decouple
$K_{i\bar{j}} =$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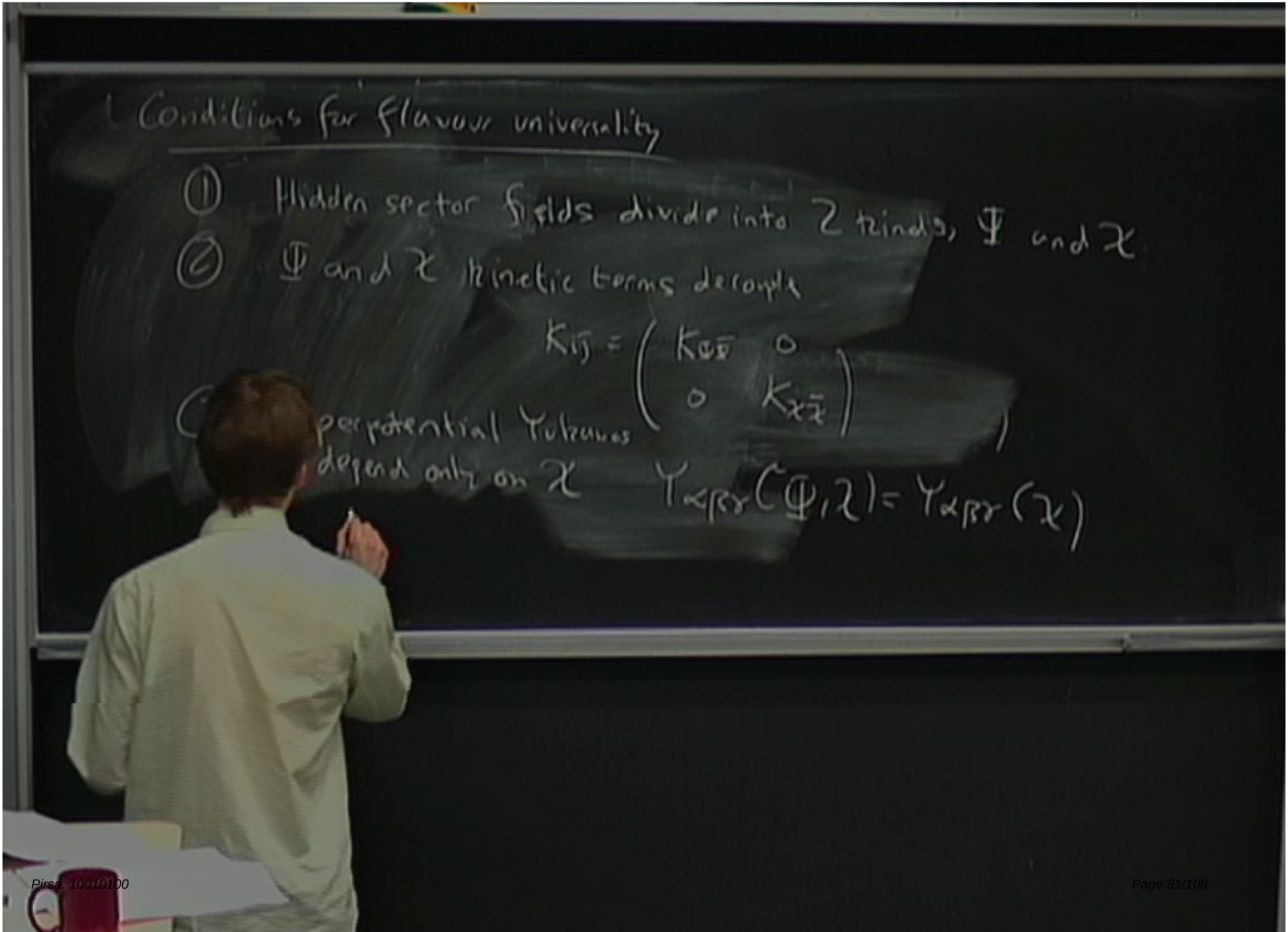
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Kij̄ = (KΦΦ̄ 0 / 0 Kχχ̄)
perpotential Yukawas
depend only on χ
Yαβγ(Φ,χ) = Yαβγ(χ)

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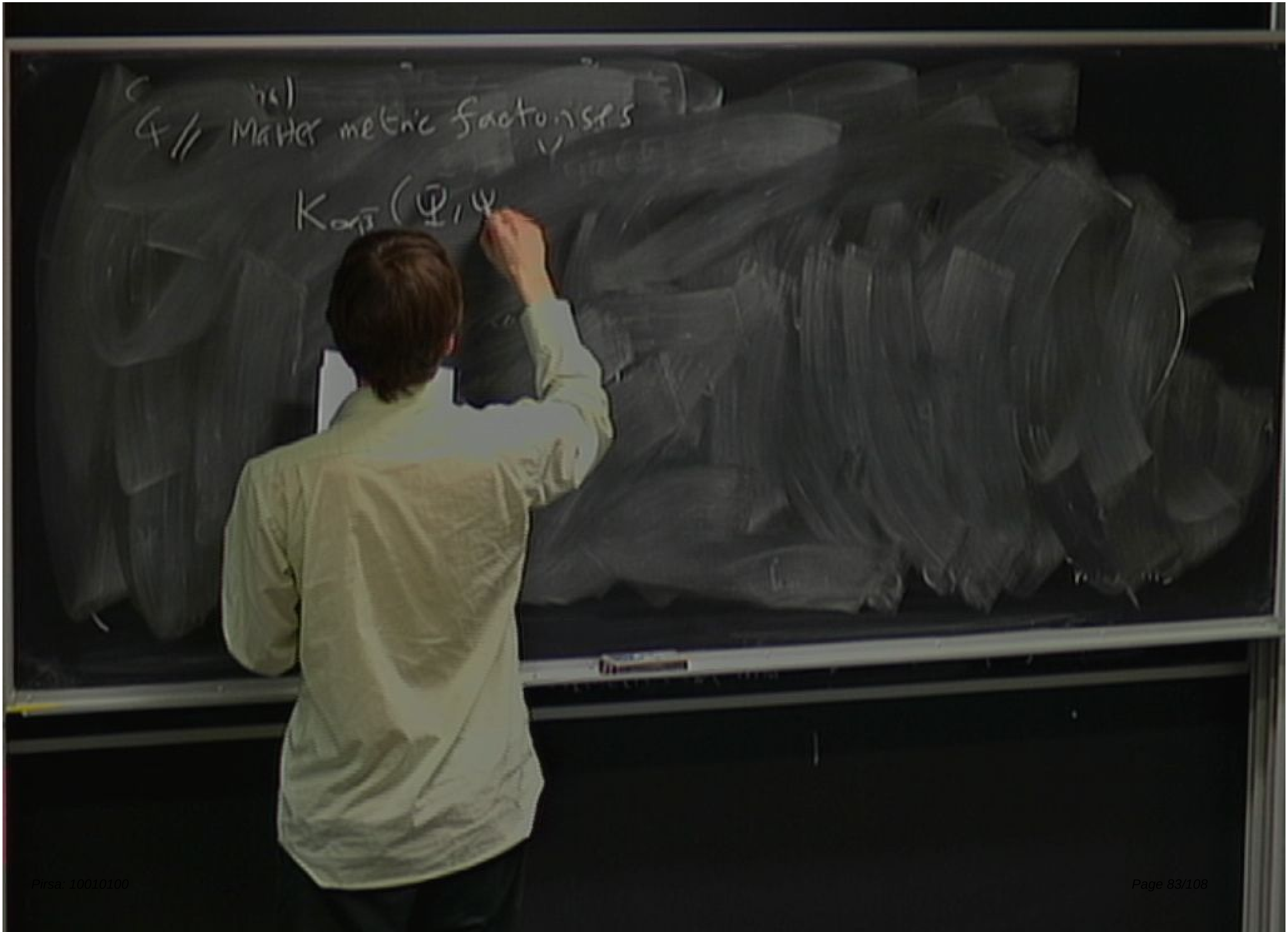
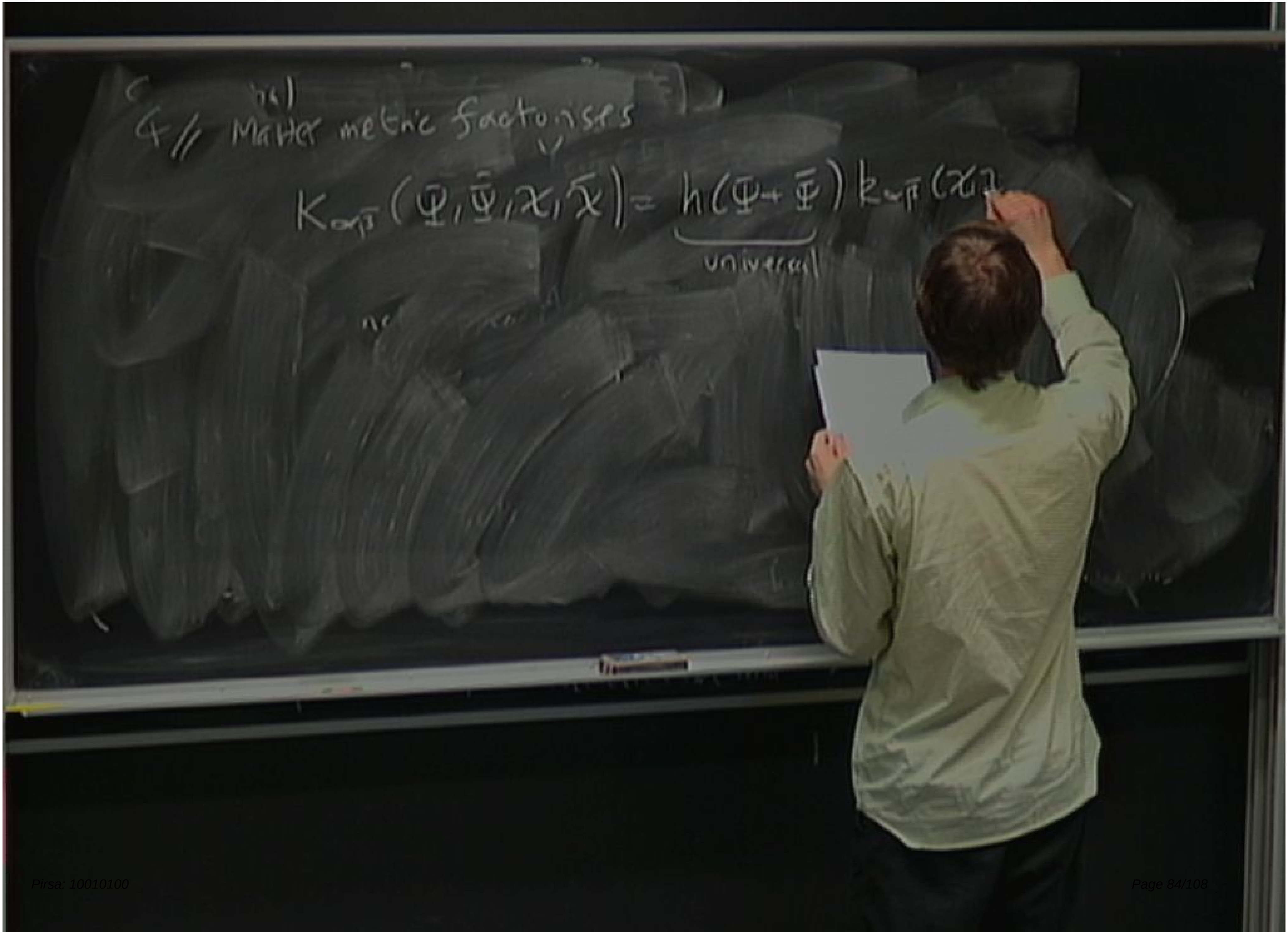

4// Matter metric factorises


4// Matter metric factorises
K_αβ̄(Ψ, Ψ̄, χ, χ̄) = h(Ψ + Ψ̄) k_αβ̄(χ, χ̄)
universal

4// Matter metric factorises

$$K_{\alpha\bar{\beta}}(\Psi,\bar{\Psi},\chi,\bar{\chi}) = \underbrace{h(\Psi+\bar{\Psi})}_{\text{universal}}\,\underbrace{k_{\alpha\bar{\beta}}(\chi,\bar{\chi})}_{\text{arbitrary}}$$

5// Ψ breaks susy and χ preserves it

$$F^{\Psi} \neq 0, \quad F^{\chi} = 0.$$

Susy broken : Yes, $F^i \neq 0$ No Yes, $F^i \neq 0$

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$\Psi \to$ Kähler moduli

$\chi \to$ complex structure moduli

* But Y_{ijk} cannot depend on T and cannot depend on χ_{α}

$$Y'_{ijk} = e^{K/2} \frac{Y_{ijk}}{\sqrt{Z_i Z_j Z_k}}$$

* In principle could have family dependence of Z_i

problems: (1) need kinetic terms that $\to \infty$ in weak coupling limit

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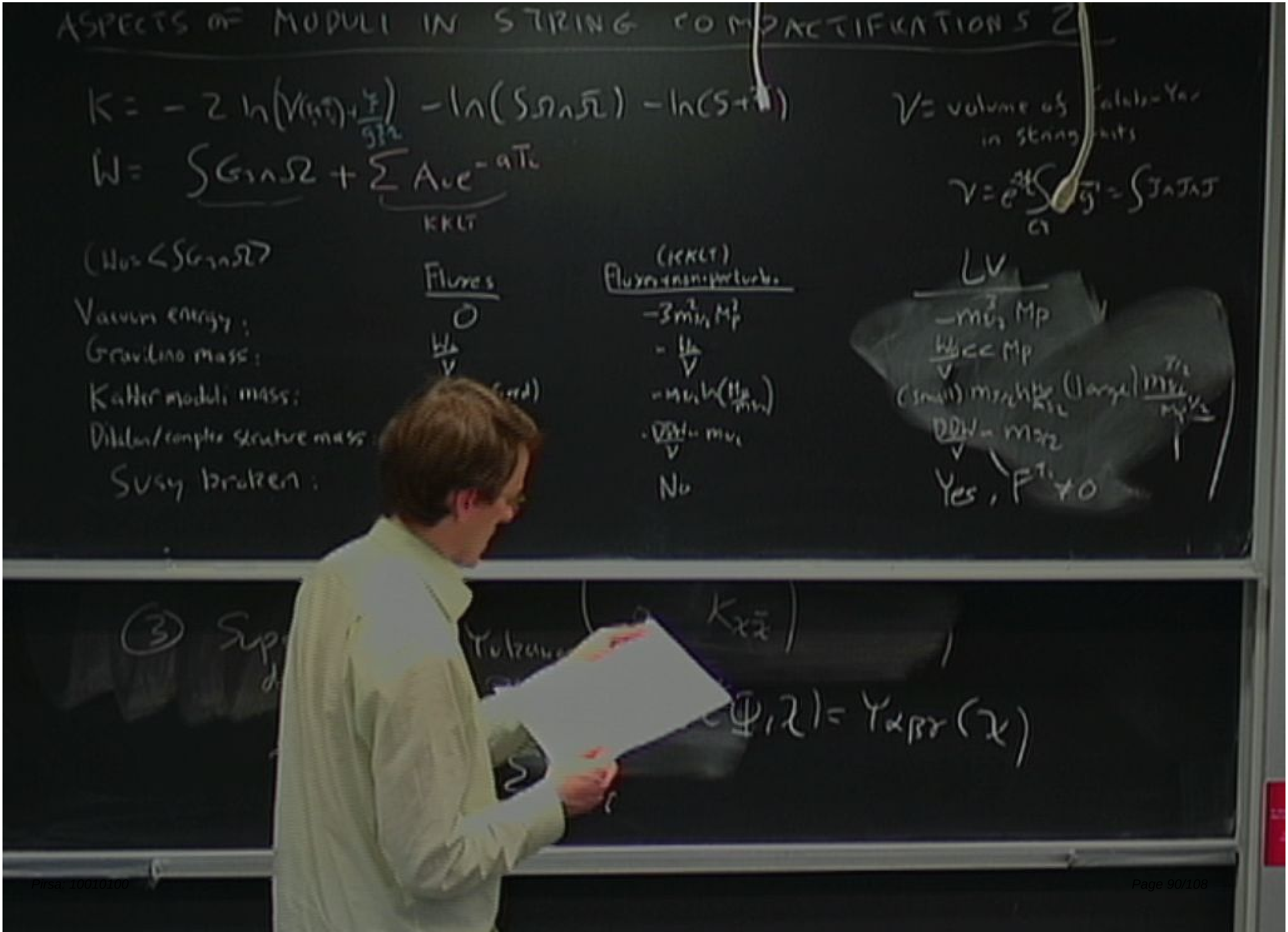
ASPECTS OF MODULI IN STRING COMPACTIFICATIONS 2
$K = -2\ln\left(\mathcal{V} + \frac{\xi}{g_s^{3/2}}\right) - \ln\left(\int \Omega \wedge \bar{\Omega}\right) - \ln(S+\bar{S})$
$\mathcal{V}$ = volume of Calabi-Yau in string units
$W = \int G_3 \wedge \Omega + \sum A_i e^{-a T_i}$
KKLT
$\mathcal{V} = \int J \wedge J \wedge J$
$(W_0 = \langle \int G_3 \wedge \Omega \rangle)$
Fluxes
(KKLT)
Fluxes+nonpert.
LV
Vacuum energy: 0 $-3 m_{3/2}^2 M_P^2$ $-m_{3/2}^3 M_P$
Gravitino mass: $\frac{W_0}{\mathcal{V}}$ $\frac{W_0}{\mathcal{V}}$ $\frac{W_0}{\mathcal{V}} \ll M_P$
Kähler moduli mass:
Dilaton/complex structure mass:
Susy broken: No Yes, $F^{T_i} \neq 0$
Yukawa
$Y_{\alpha\beta\gamma}(\chi)$

* Factorised kinetic terms inherited from $N=2$

hypermultiplets + vector multiplets

have no cross-terms in their kinetic mixing.

	Fluxes	(KKLT) Fluxes+nonperturb.	LV
Vacuum energy:	0	$-3m_{3/2}^2 M_P^2$	$-m_{3/2}^2 M_P$
Gravitino mass:	$\frac{W_0}{V}$	$\sim \frac{W_0}{V}$	$\frac{W_0}{V} \ll M_P$
Kahler moduli mass:	0 (unfixed)	$\sim m_{3/2} \ln\left(\frac{M_P}{m_{3/2}}\right)$	(small) $m_{3/2}$ (large) $\frac{m_{3/2}^{3/2}}{M_P^{1/2}}$
Dilaton/complex structure mass:	$\sim \frac{DDW}{V} \sim m_{3/2}$	$\sim \frac{DDW}{V} \sim m_{3/2}$	$\frac{DDW}{V} \sim m_{3/2}$
Susy broken:	Yes, $F^T \neq 0$	No	Yes, $F^{T_b} \neq 0$

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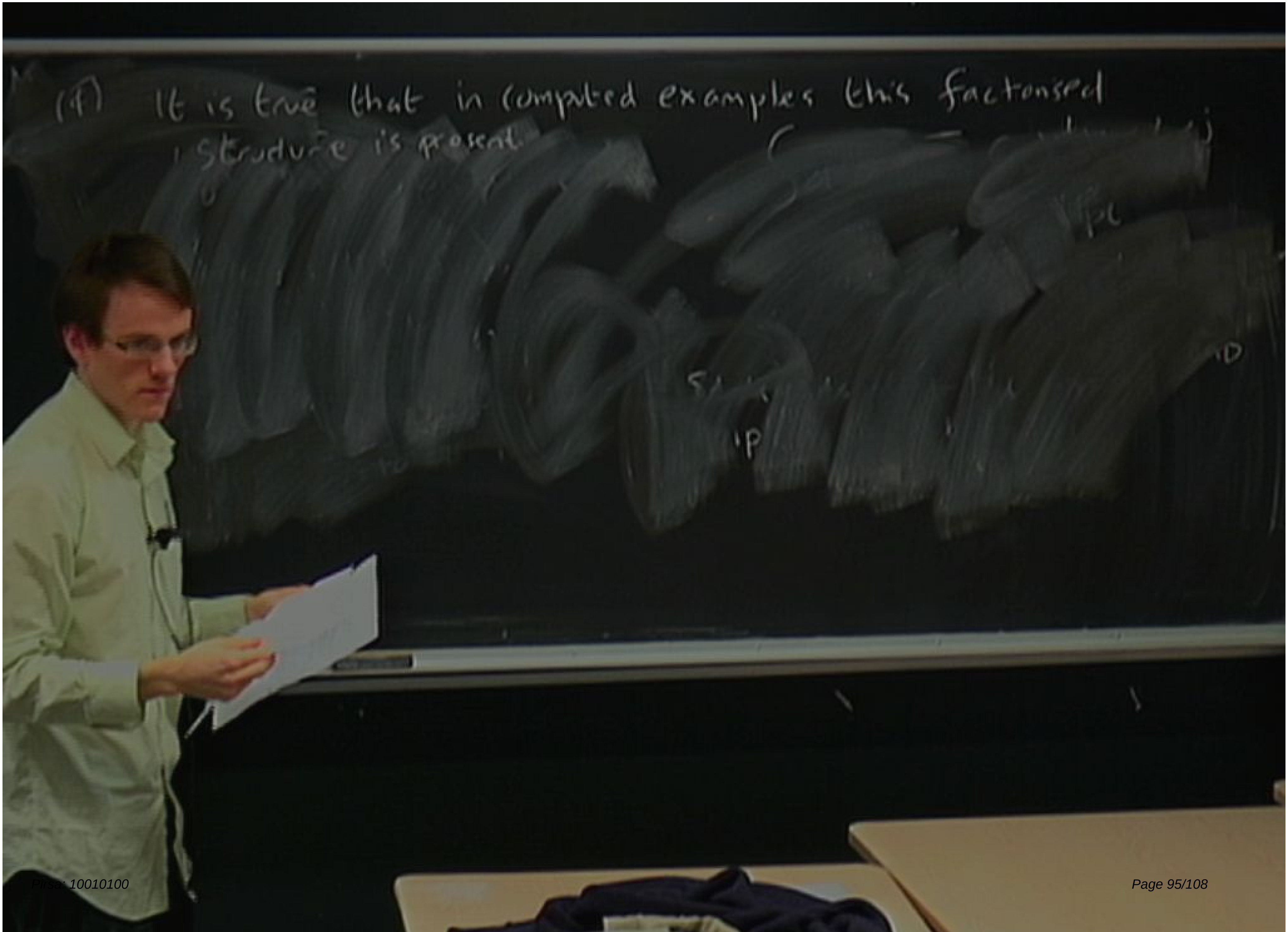
* (5): property of flux compactifications $F^T \neq 0, F^U \approx 0$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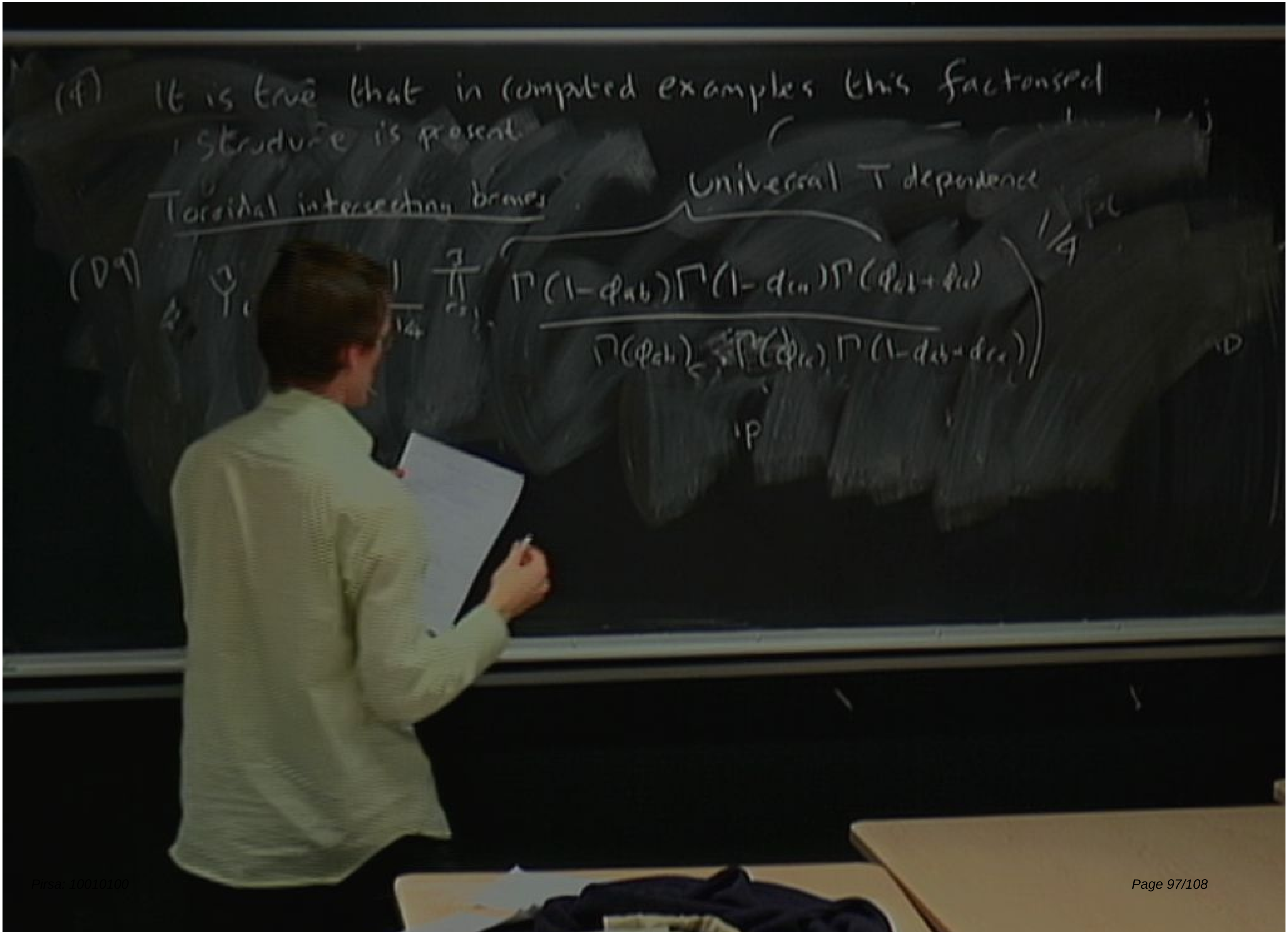
Toroidal intersecting branes

Y_{ijk}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Universal T dependence

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Toroidal intersecting branes

$$(D9)\quad Y_{ijk} = \left(\frac{1}{\gamma^{1/4}} \prod_{r=1}^{3} \overbrace{\left(\frac{\Gamma(1-\phi_{ab})\Gamma(1-\phi_{ca})\Gamma(\phi_{ab}+\phi_{ca})}{\Gamma(\phi_{ab})\Gamma(\phi_{ca})\Gamma(1-\phi_{ab}-\phi_{ca})} \right)^{1/4}}^{\text{Universal } T \text{ dependence}} \underbrace{(U_r)^{1/4}\, \Theta\begin{bmatrix} \delta_{ijk} \\ 0 \end{bmatrix}(\phi^r, U I_{ab} I_{bc} I_{ca})}_{U\text{-dependence}} \right)$$

ASPECTS OF MODULI IN STRING COMPACTIFICATIONS 2

In IIB setups, flavour comes from wave function overlap.
(Yukawas)

$\int \sqrt{g}\, \psi_i^\dagger \psi_j \phi_k$

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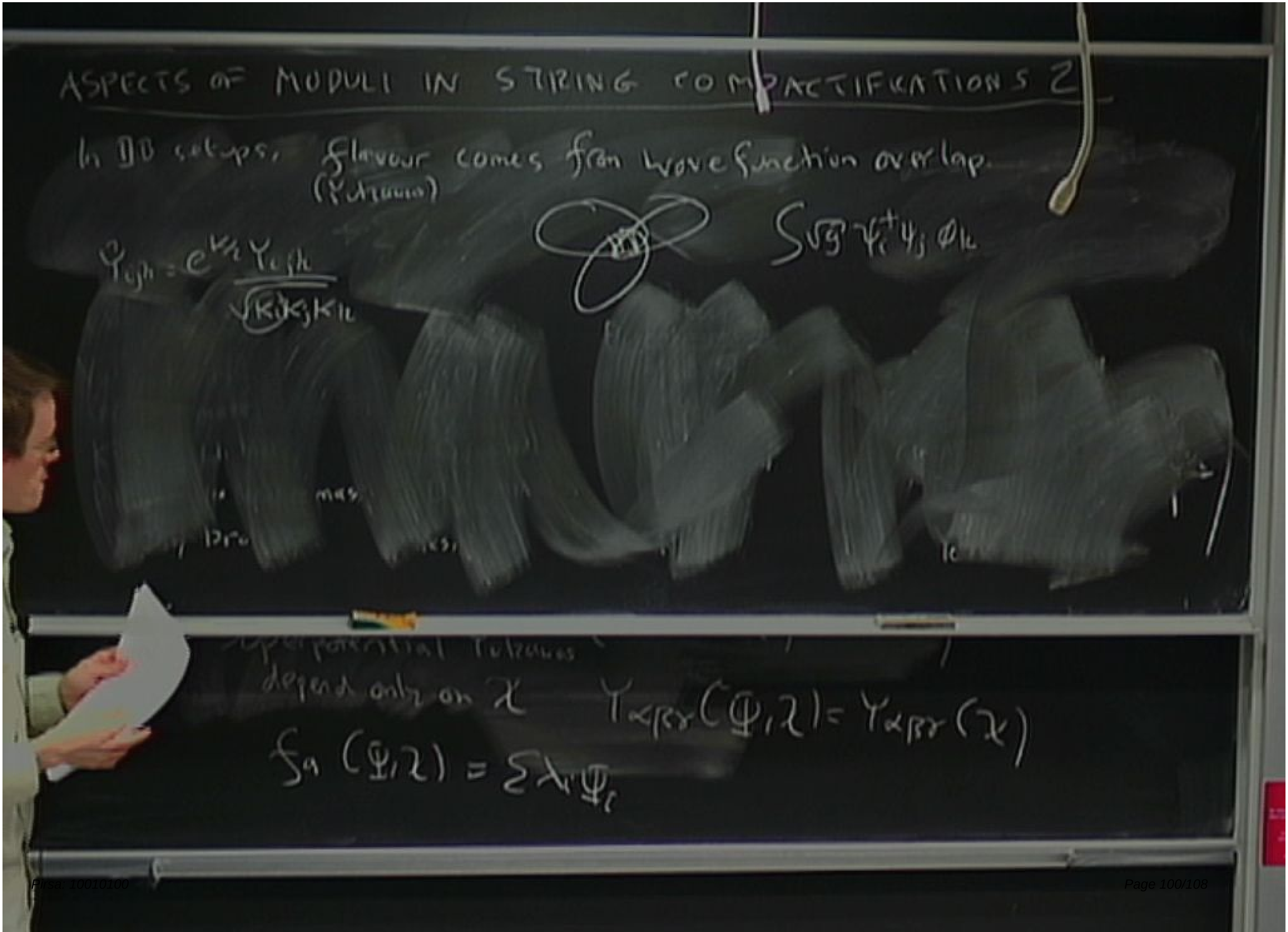

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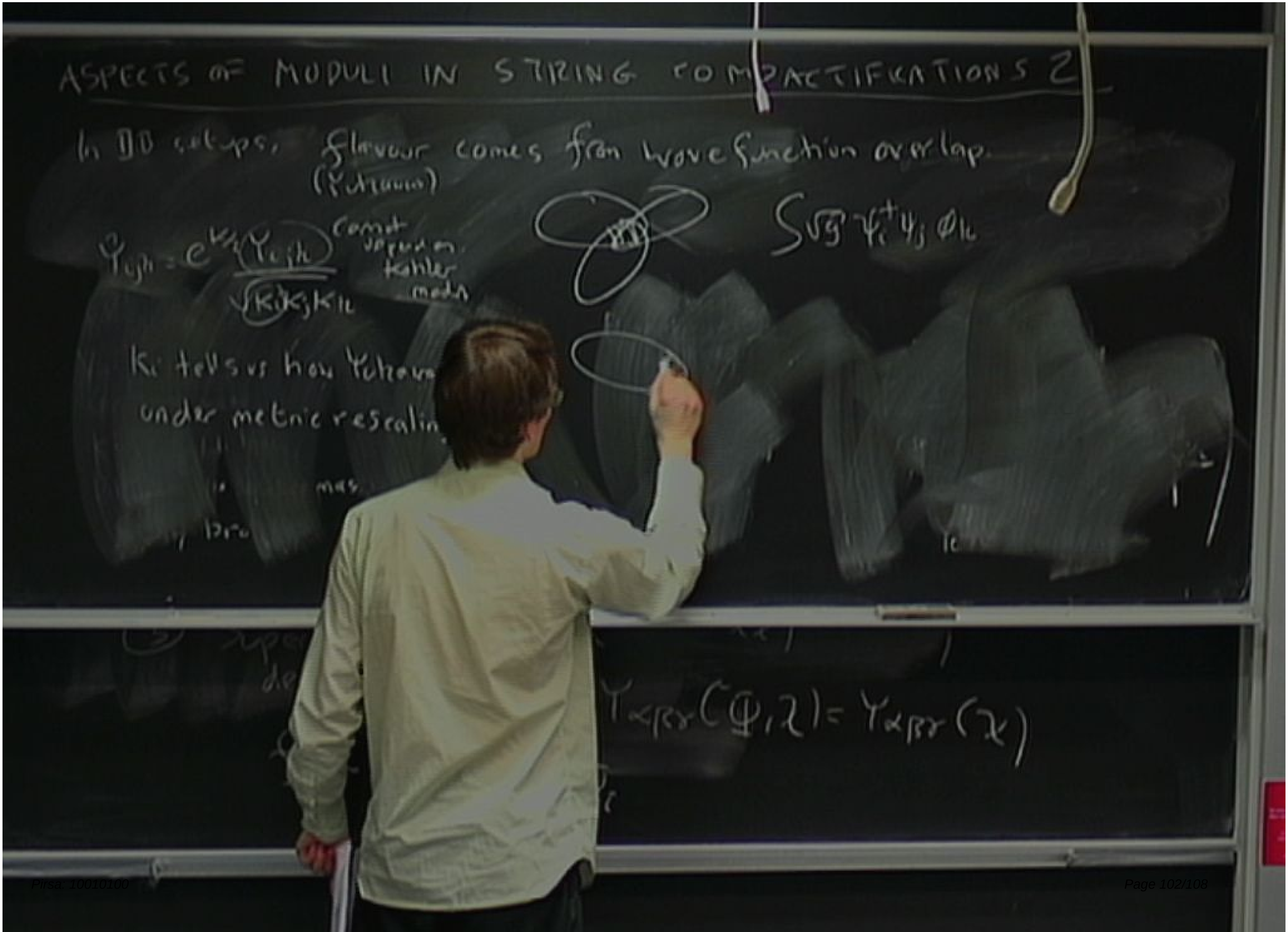
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K_i ... how Yukawas scale

... metric rescalings

... mas...

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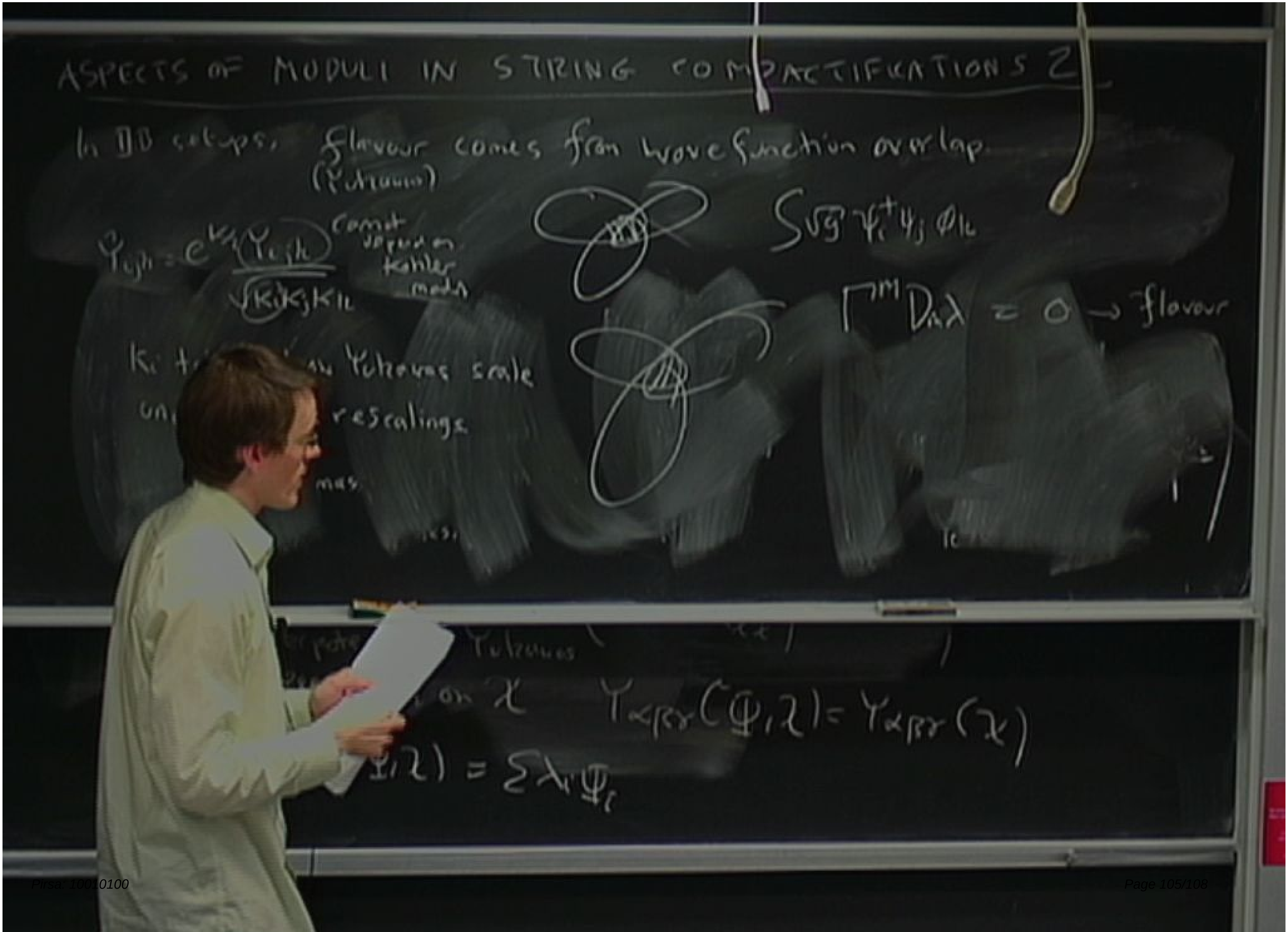
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rescalings
$\Gamma^m D_m \lambda = 0 \rightarrow$ flavour
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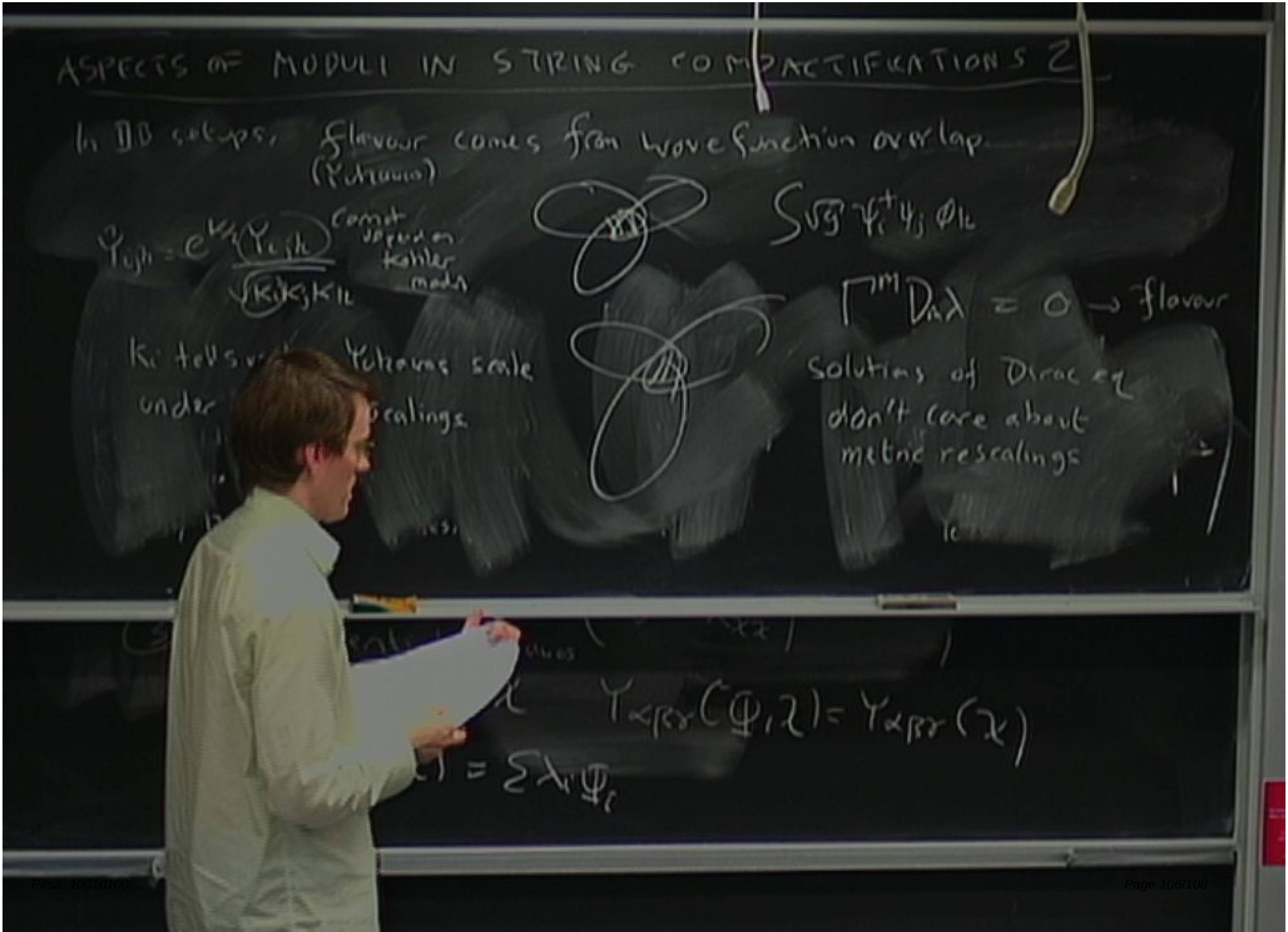
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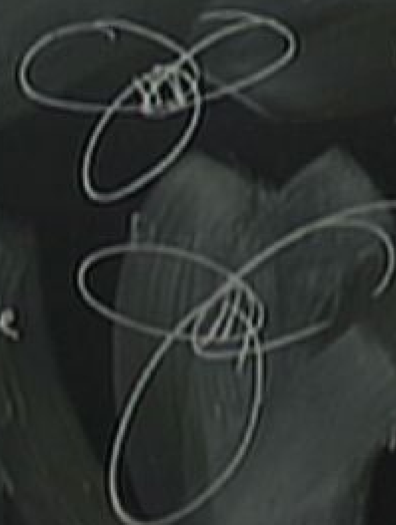

$$\int \sqrt{g}\,\psi_i^\dagger \psi_j \phi_k \qquad \int \sqrt{g}\,\psi^\dagger\psi = 1$$

$$\Gamma^m D_m \lambda = 0 \to \text{flavour}$$

K_i t... how Yukawas scale ... metric rescalings

Solutions of Dirac eq don't care about metric rescalings

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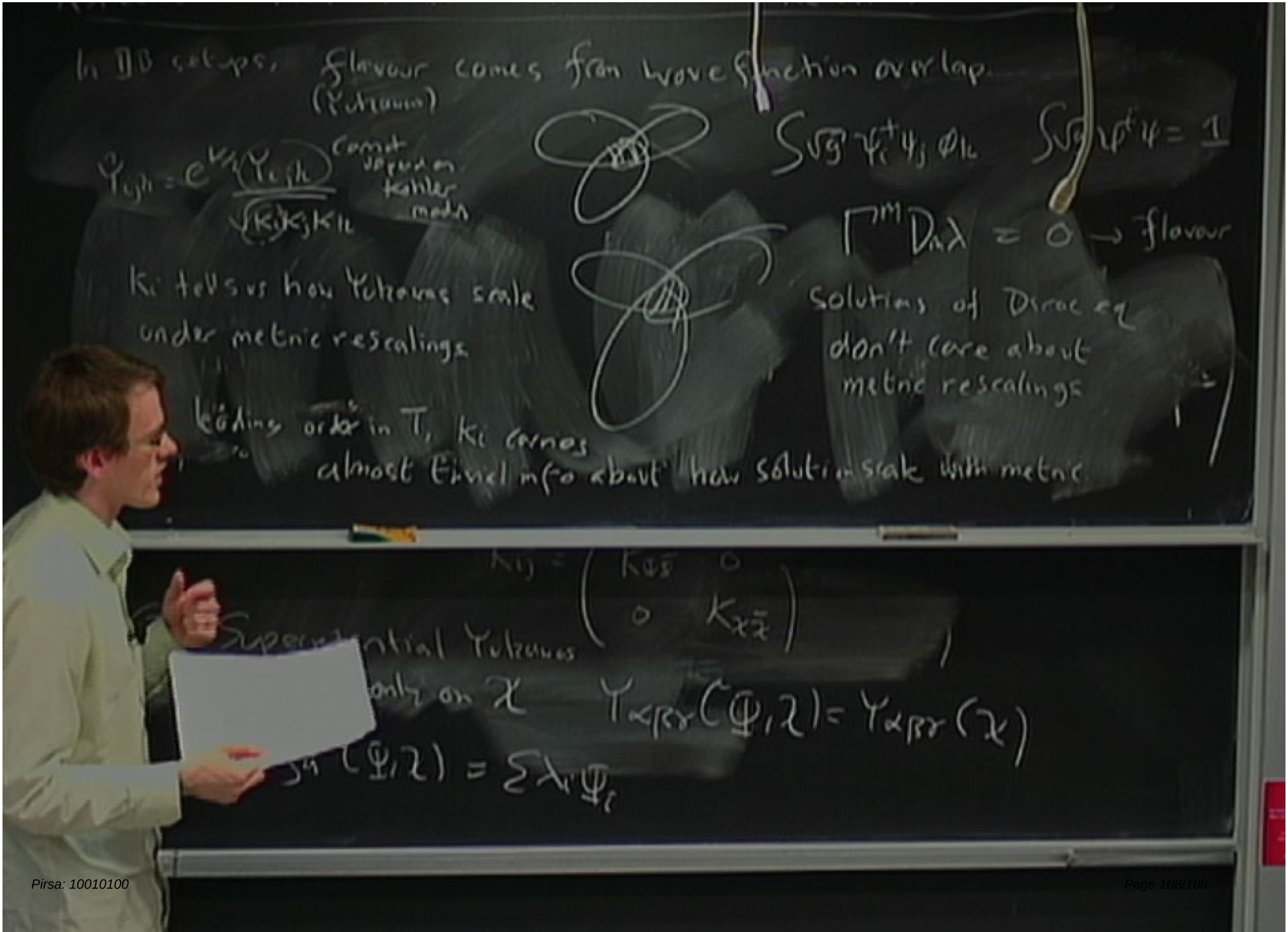
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