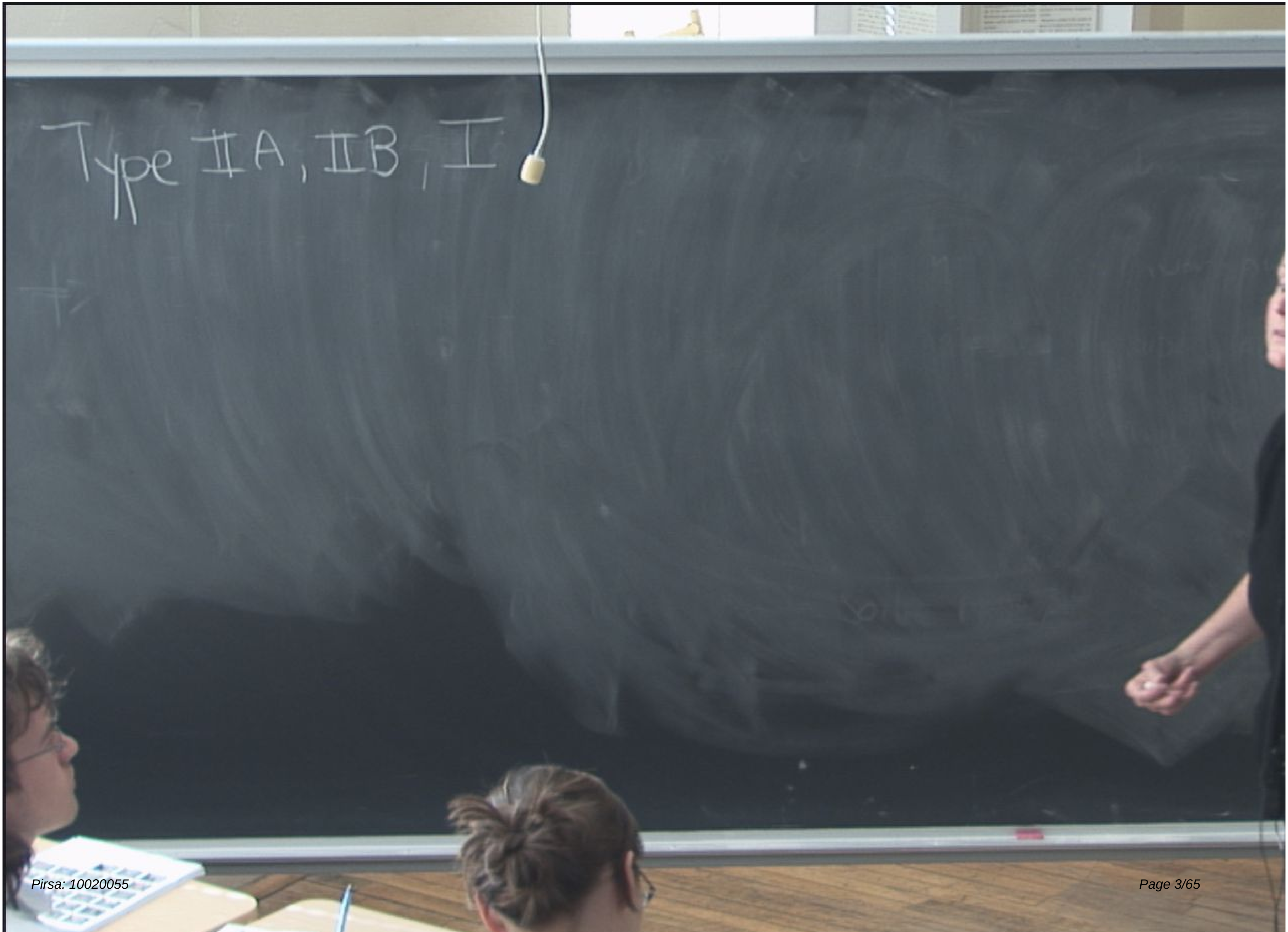
Title: String Theory - Review (PHYS 623) - Lecture 11

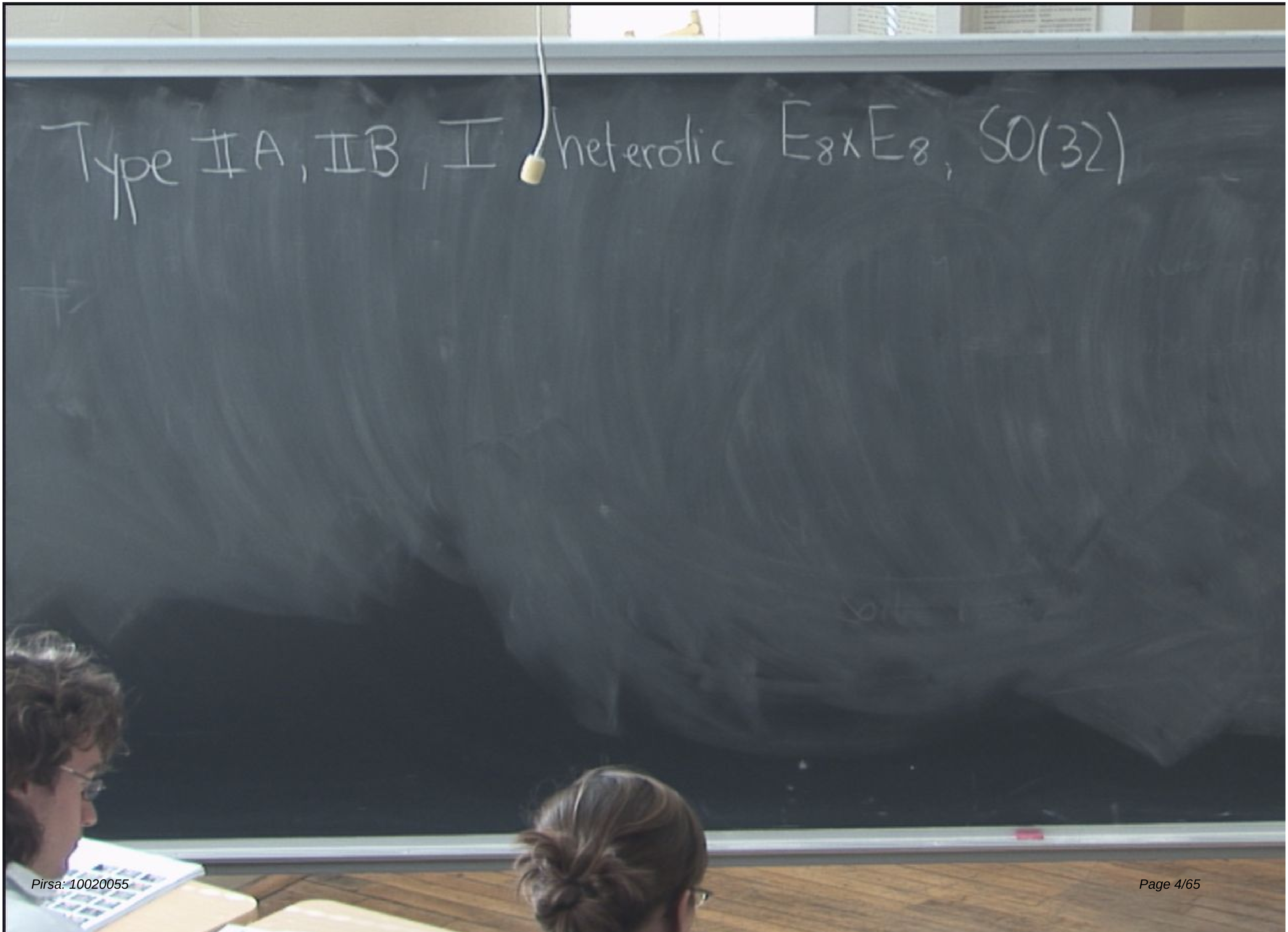
Date: Feb 08, 2010 11:20 AM

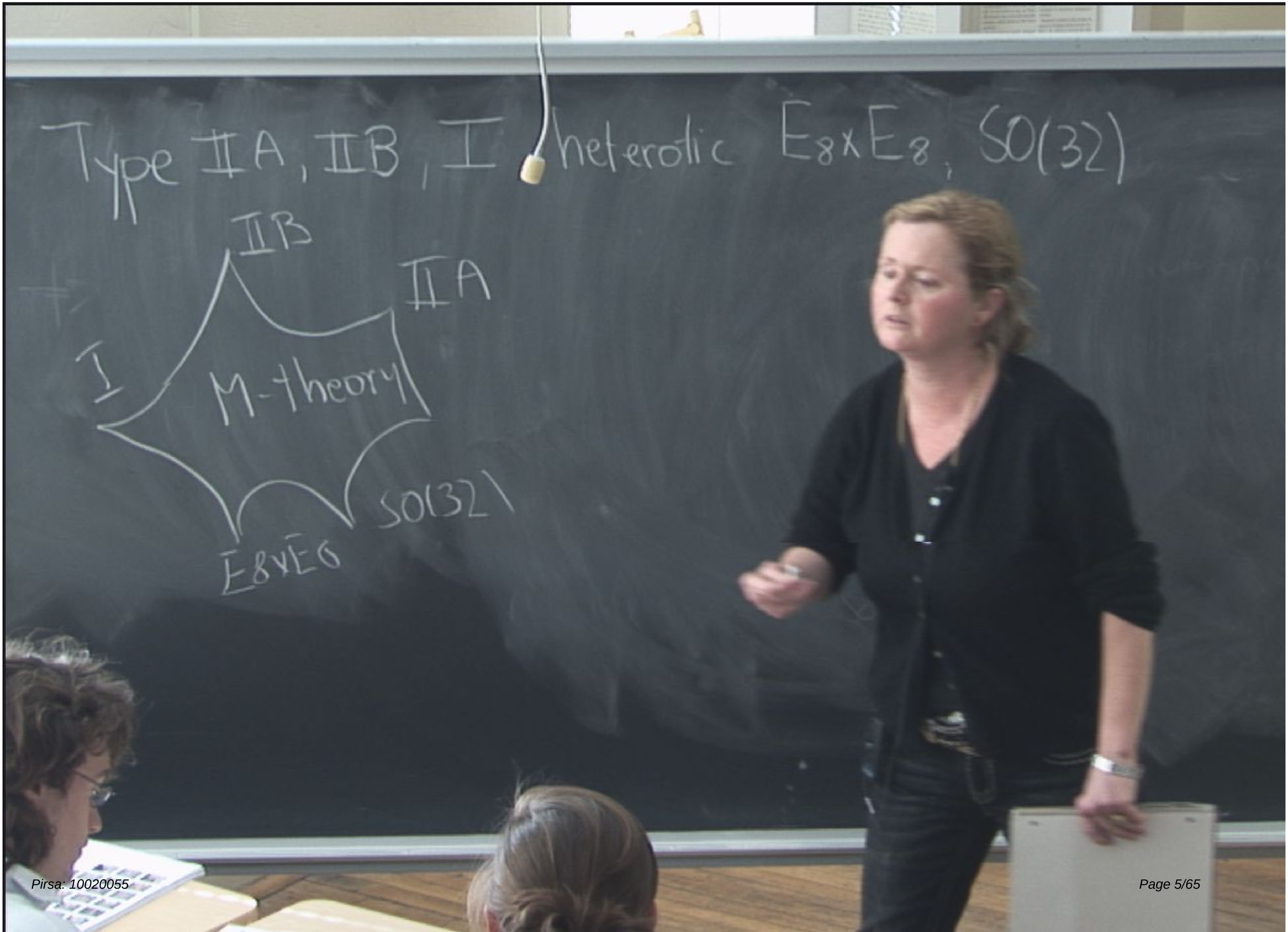
URL: http://pirsa.org/10020055

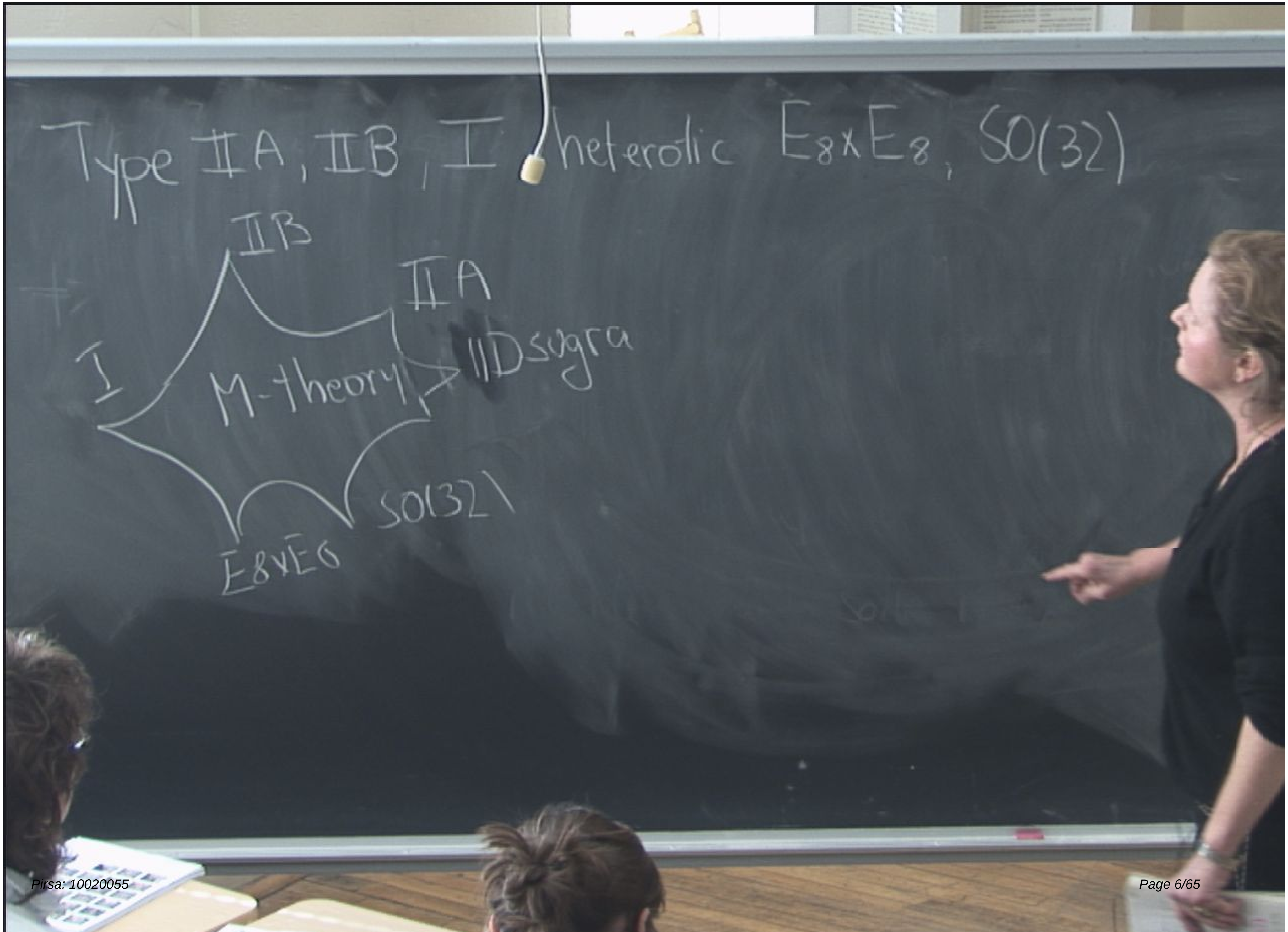
Abstract:

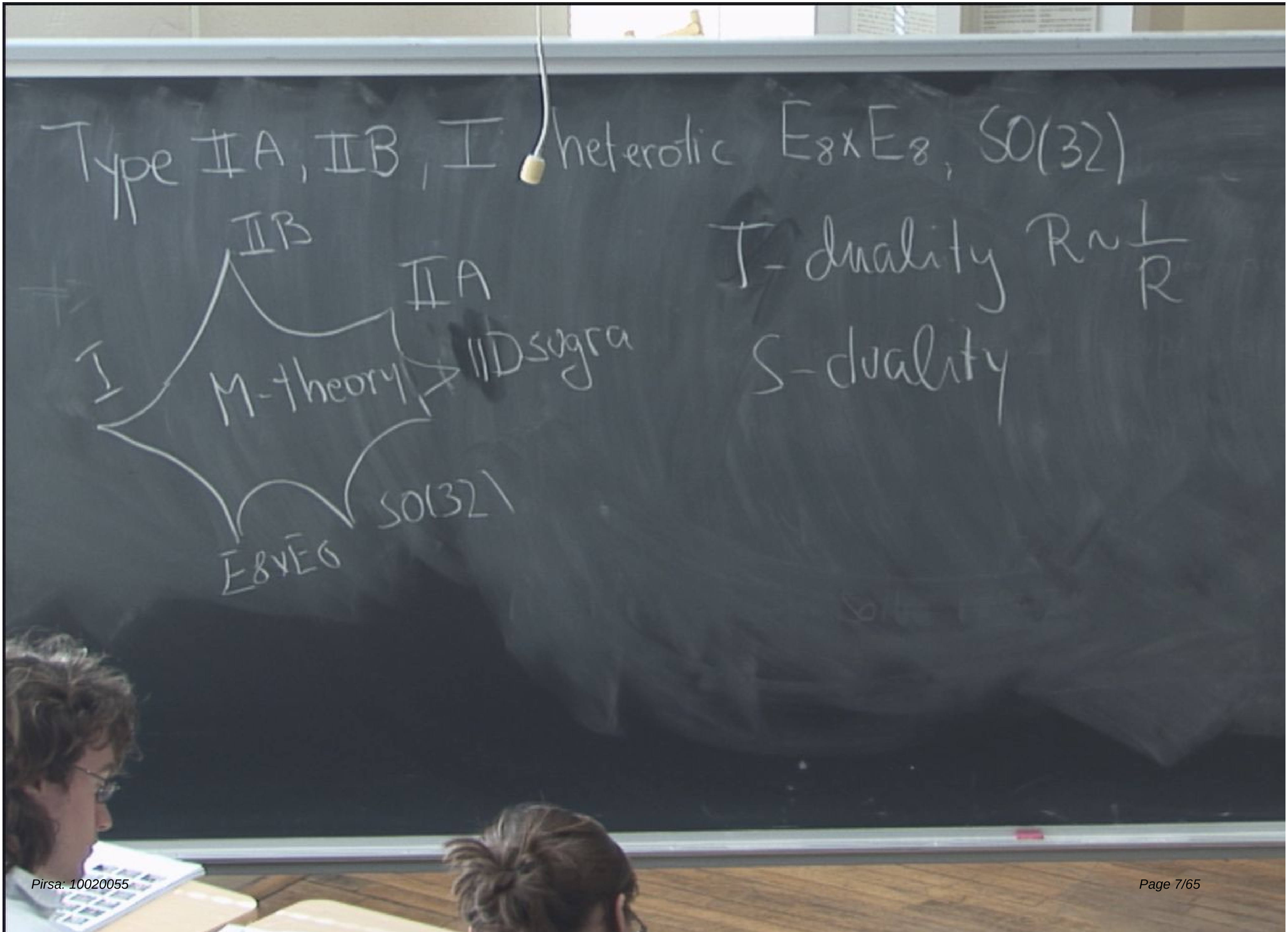
perimeter scholars
international

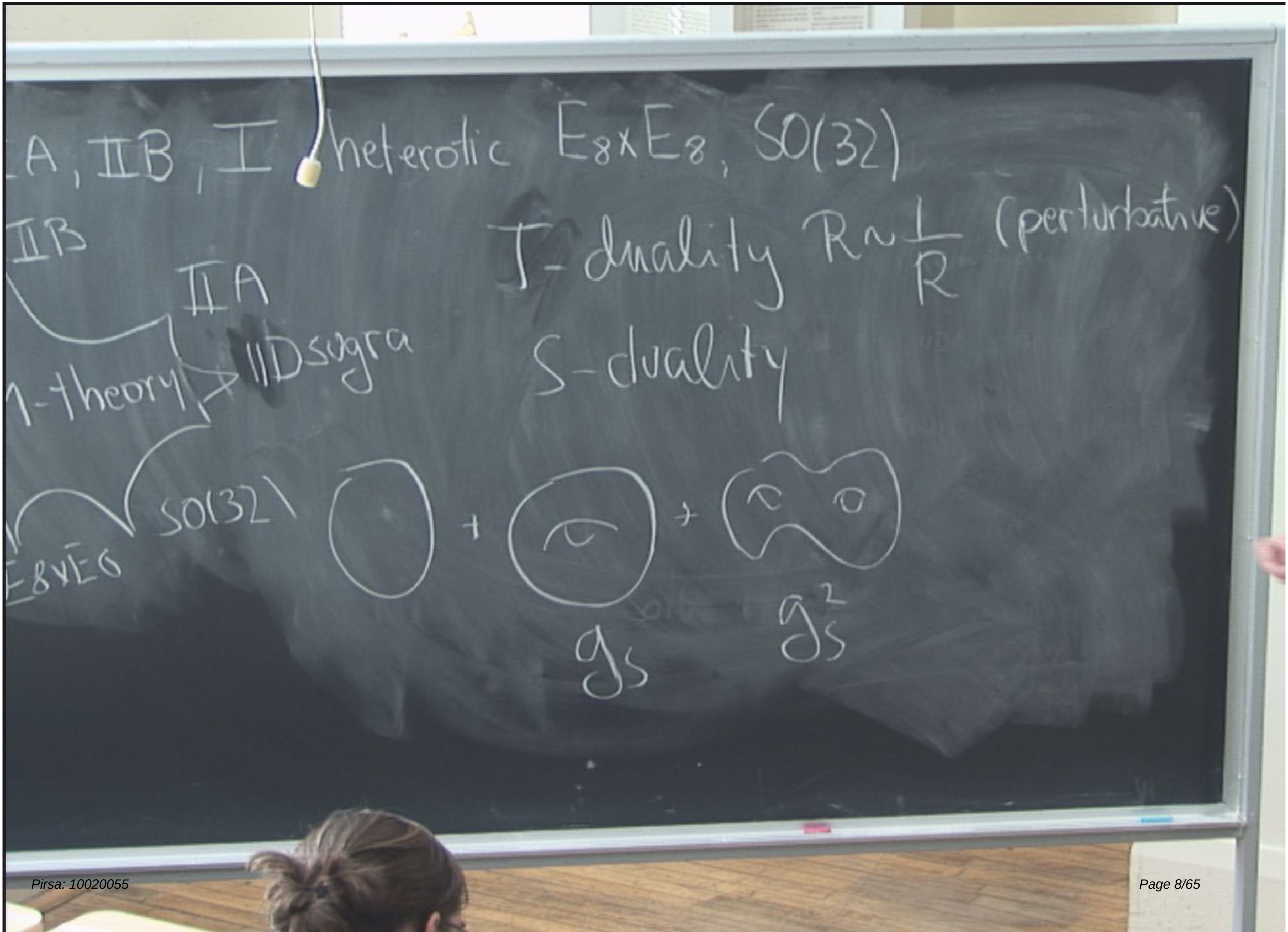

Type IIA, IIB, I


Type IIA, IIB, I, heterotic $E_8 \times E_8$, SO(32)


Type IIA, IIB, I, heterotic E8xE8, SO(32)
IIB
IIA
I
M-theory
SO(32)
E8xE8


Type IIA, IIB, I heterotic E8xE8, SO(32)
IIB
IIA
11D sugra
I
M-theory
SO(32)
E8xE8


Type IIA, IIB, I, heterotic E8xE8, SO(32)
IIB
IIA
I
M-theory
11D sugra
SO(32)
E8xE8
T-duality R~1/R
S-duality


A, IIB, I heterotic E8xE8, SO(32)
IIB
IIA
T-duality R~1/R (perturbative)
IID sugra
S-duality
M-theory
SO(32)
E8xE8
gs
gs^2

String Duality

(1) Low-energy effective actions.

$\alpha' \to 0$ (massless dof).

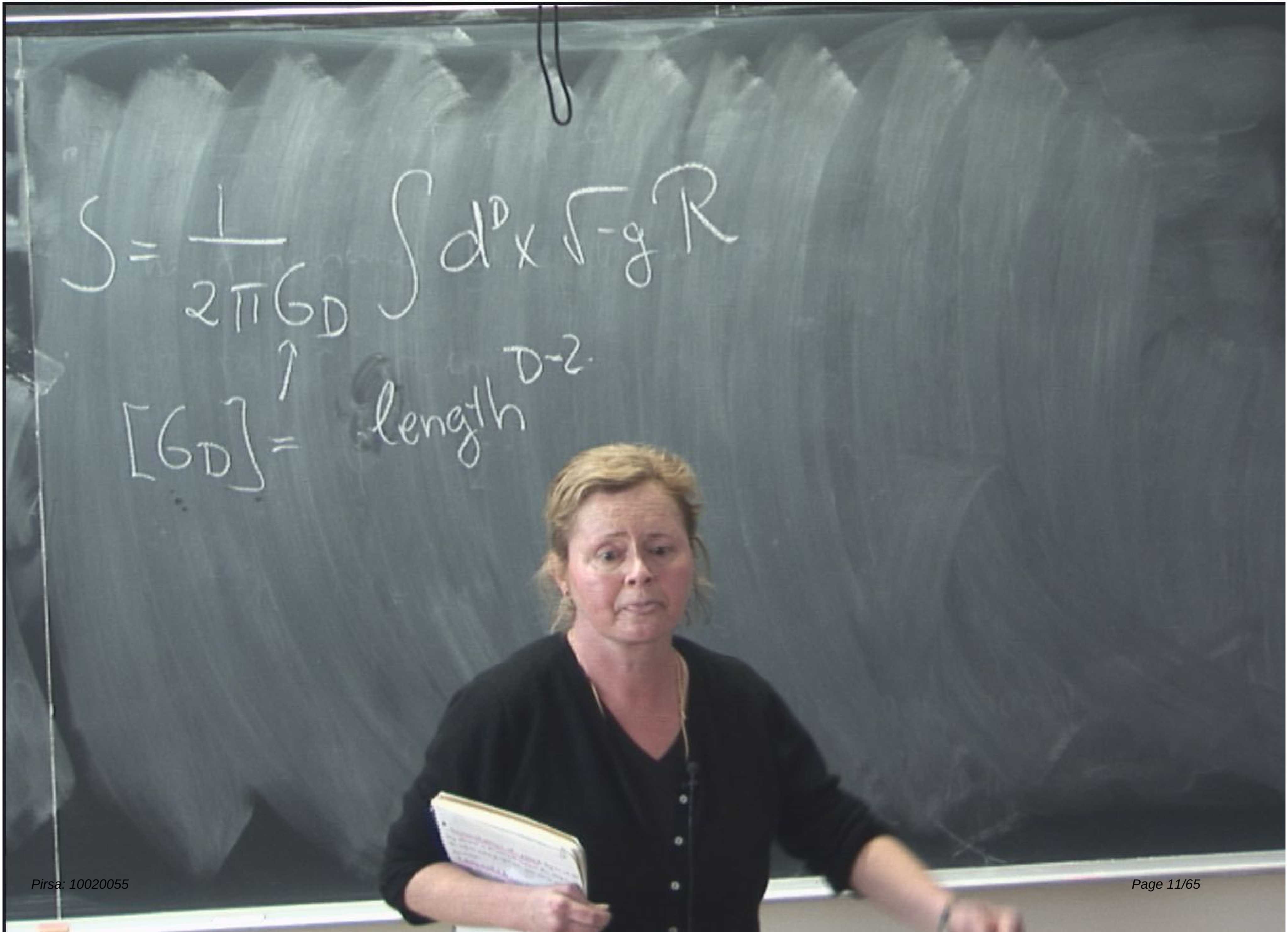
String Duality

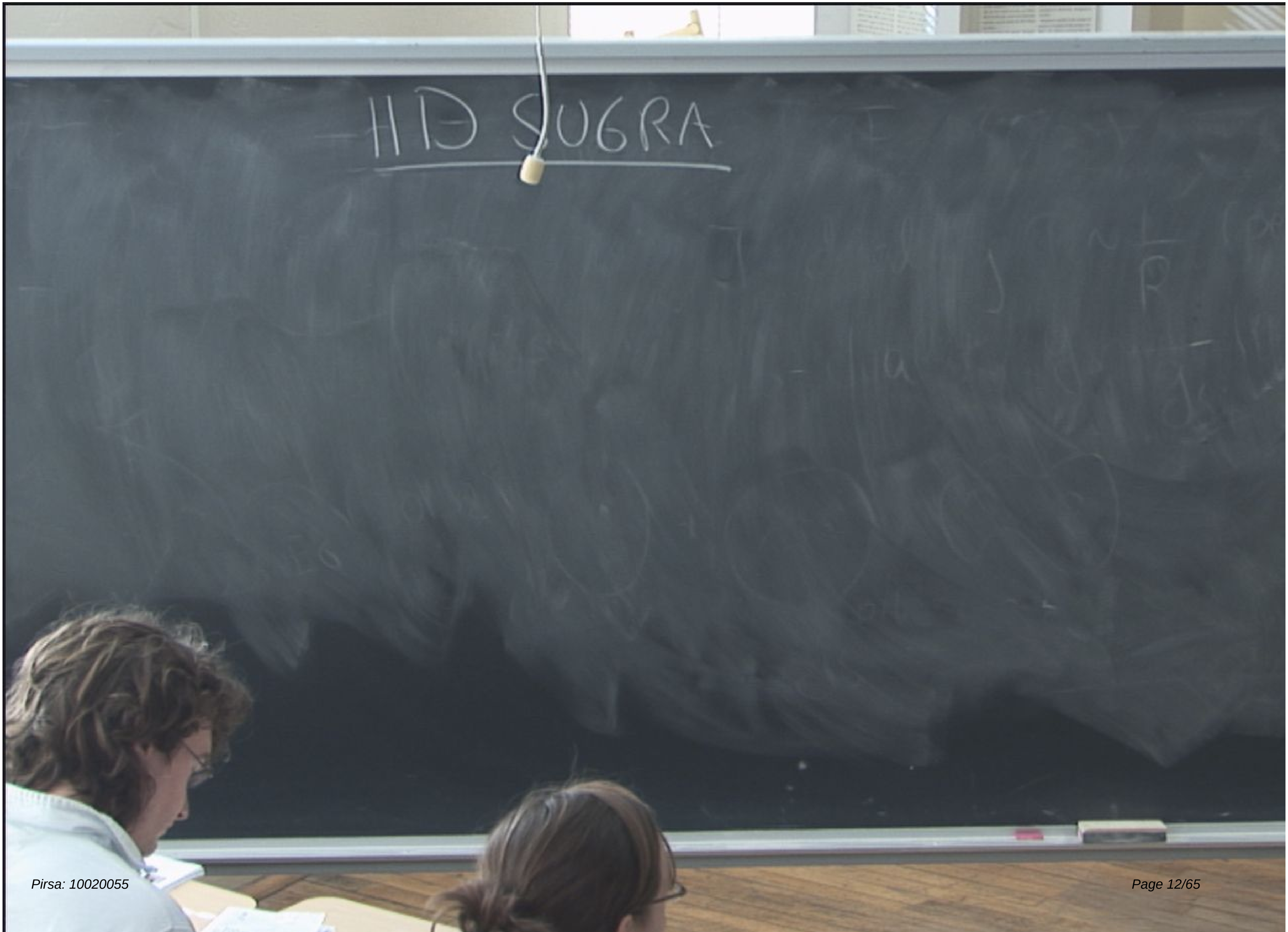
① Low-energy effective actions

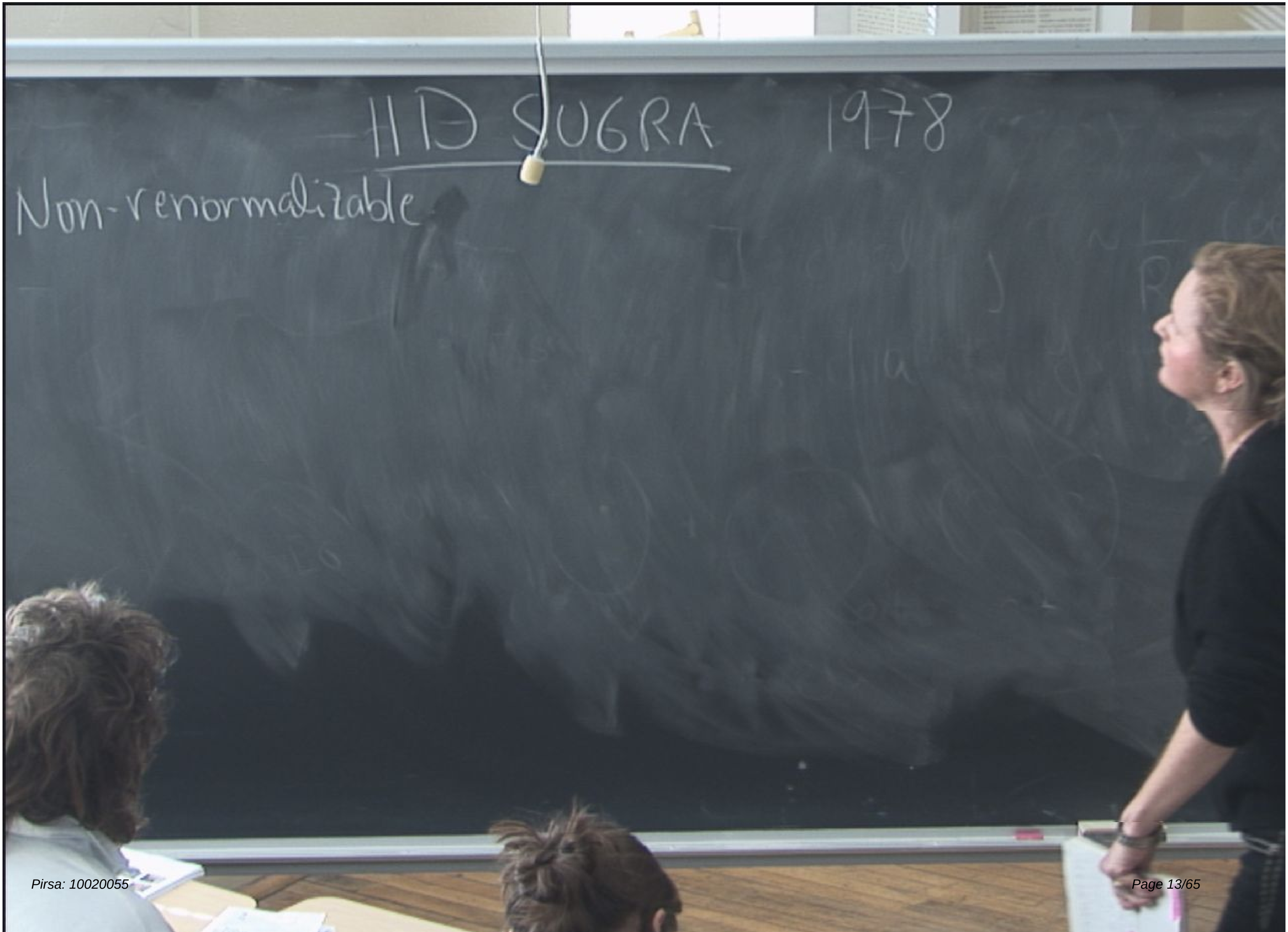
$\alpha' \to 0$ (massless dof).

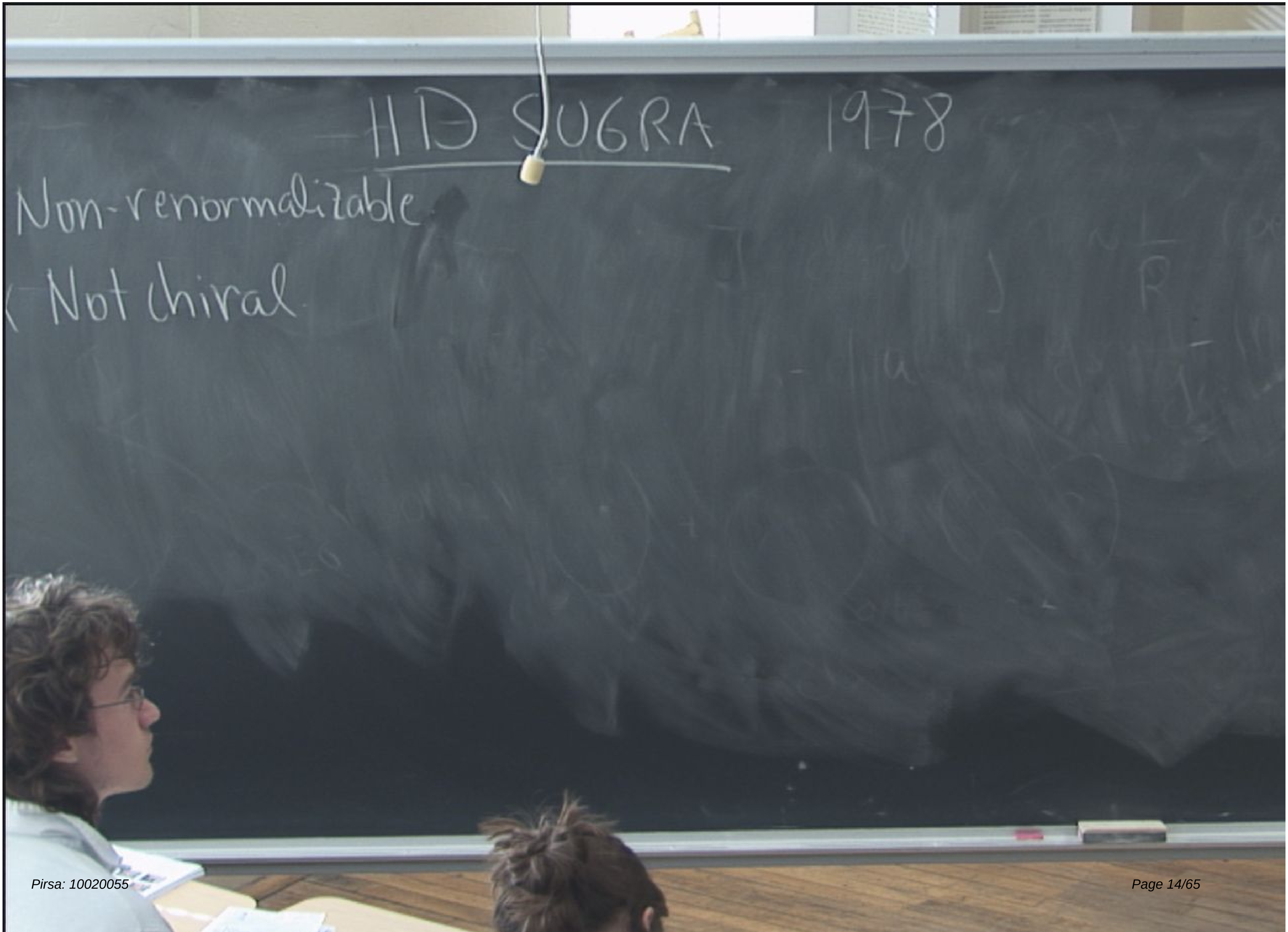
Enough susy $\Rightarrow$ Entire string

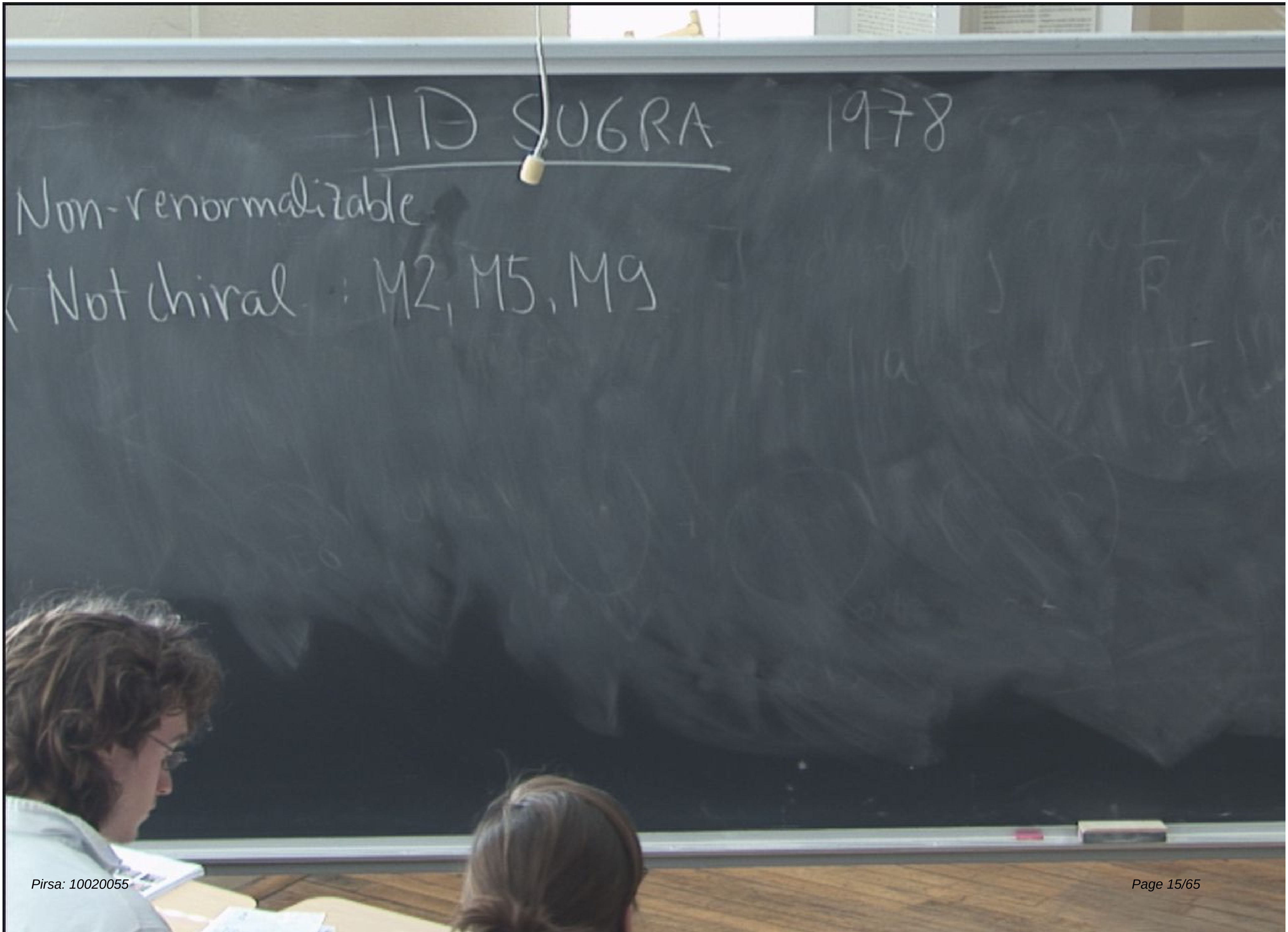
② BPS states (Compare branes)

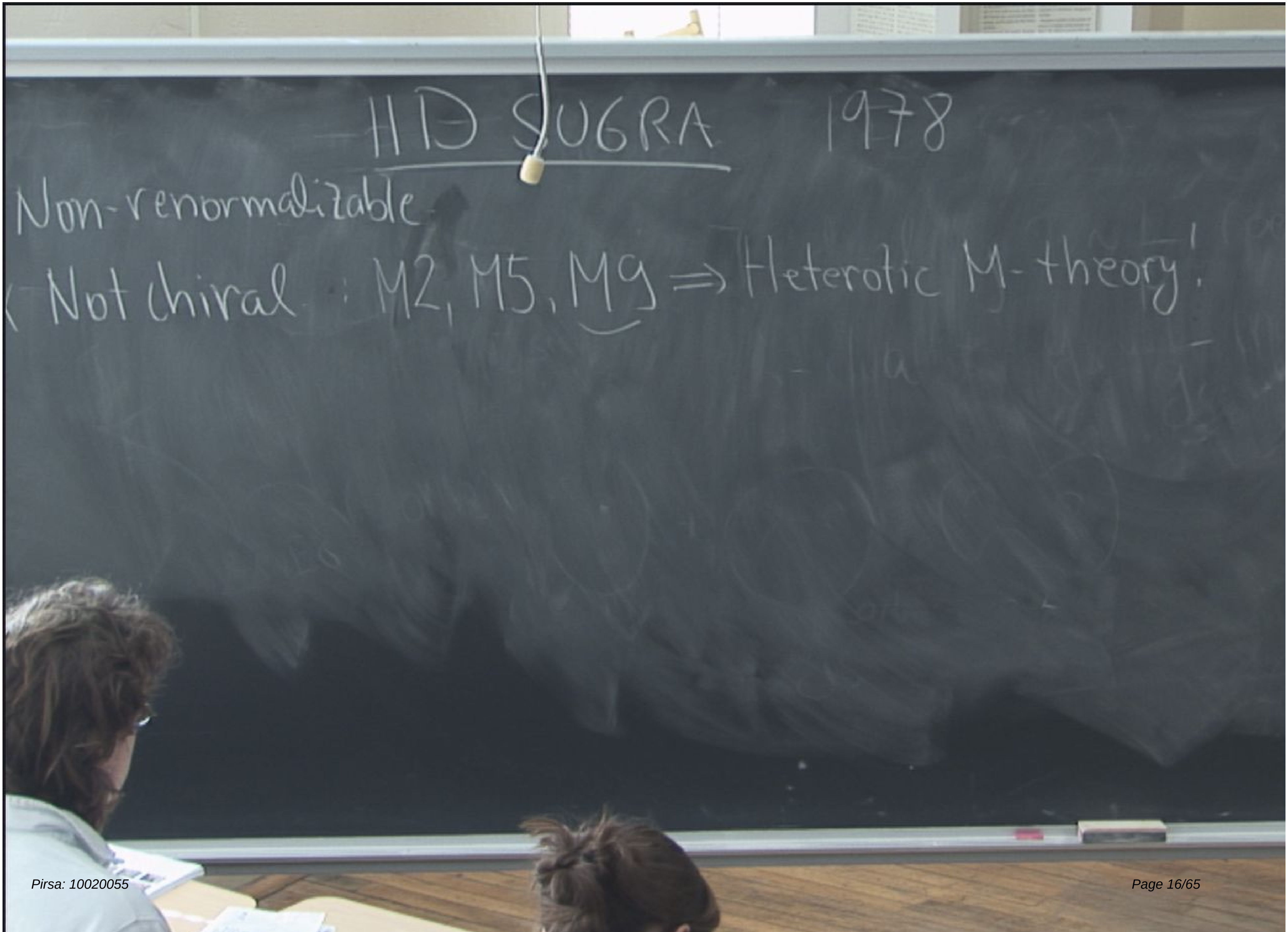

$S = \frac{1}{2\pi G_D} \int d^D x \sqrt{-g}\, R$
$[G_D] = \text{length}^{D-2}$

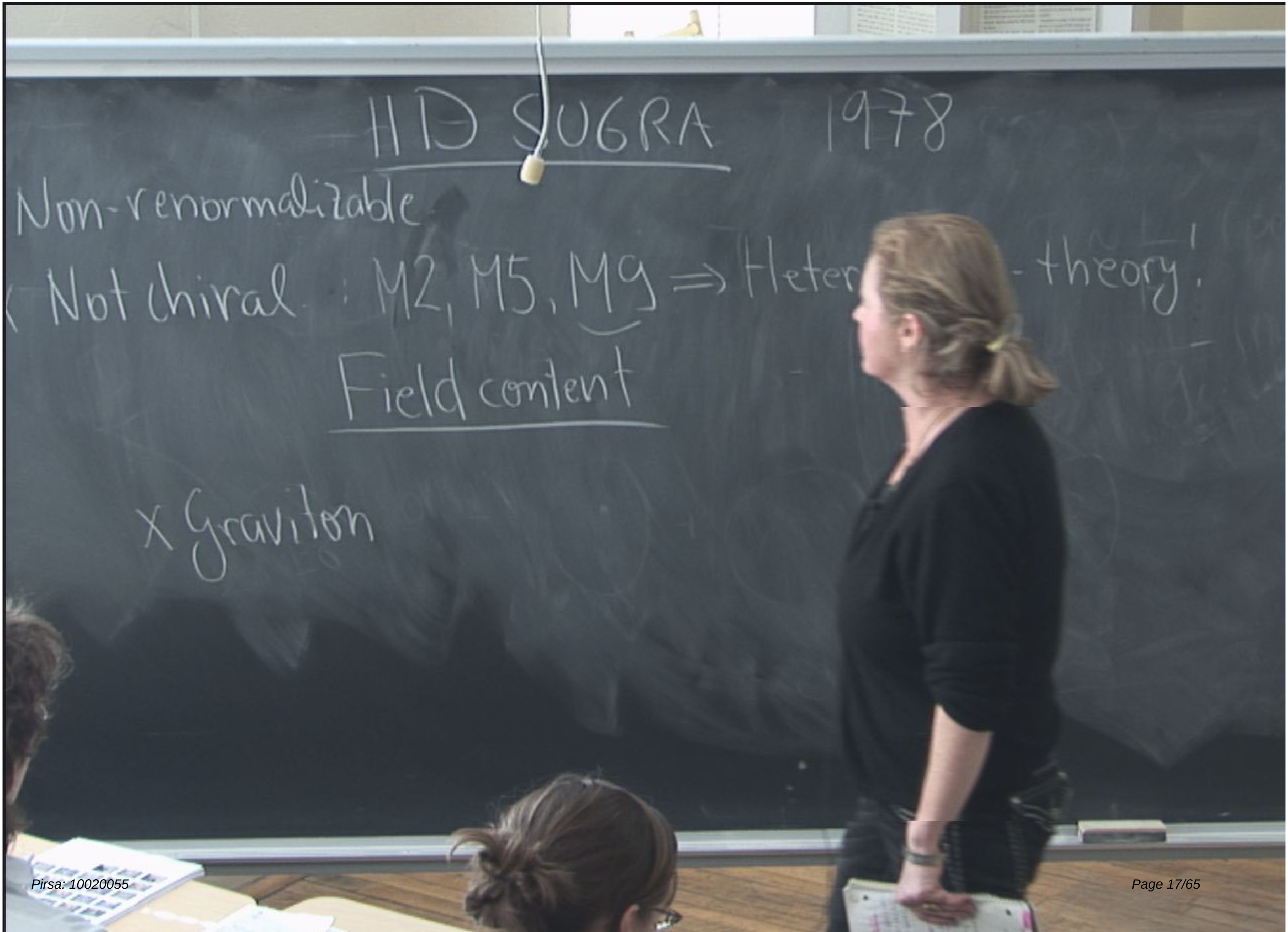

11D SUGRA


11D SUGRA 1978
Non-renormalizable


11D SUGRA 1978
Non-renormalizable
Not chiral


11D SUGRA 1978
Non-renormalizable
Not chiral : M2, M5, M9


11D SUGRA 1978
Non-renormalizable
Not chiral : M2, M5, M9 ⇒ Heterotic M-theory!


11D SUGRA 1978
Non-renormalizable
Not chiral : M2, M5, M9 ⇒
theory!
Field content
x Graviton

11D SUGRA 1978

Non-renormalizable

× Not chiral : M2, M5, M9 ⇒ Heterotic M-theory!

Field content

× Graviton $(D-2)(D-2)$ Matrix

$$\frac{1}{2}(D-1)(D-2) = 44 \text{ bosonic}$$

② Antisymmetric tensor A_3 $F_4 = dA_3$.

(2) Antisymmetric tensor A_3 $\quad F_4 = dA_3$.

$$A_{MNP} = 84 \text{ bosonic dof.}$$

$$\frac{9 \cdot 8 \cdot 7}{2}$$

② Antisymmetric tensor A_3 $F_4 = dA_3$.

$A_{MNP} = 84$ bosonic dof.

$$\frac{9 \cdot 8 \cdot 7}{2}$$

$\Rightarrow$ 128 bosonic dof

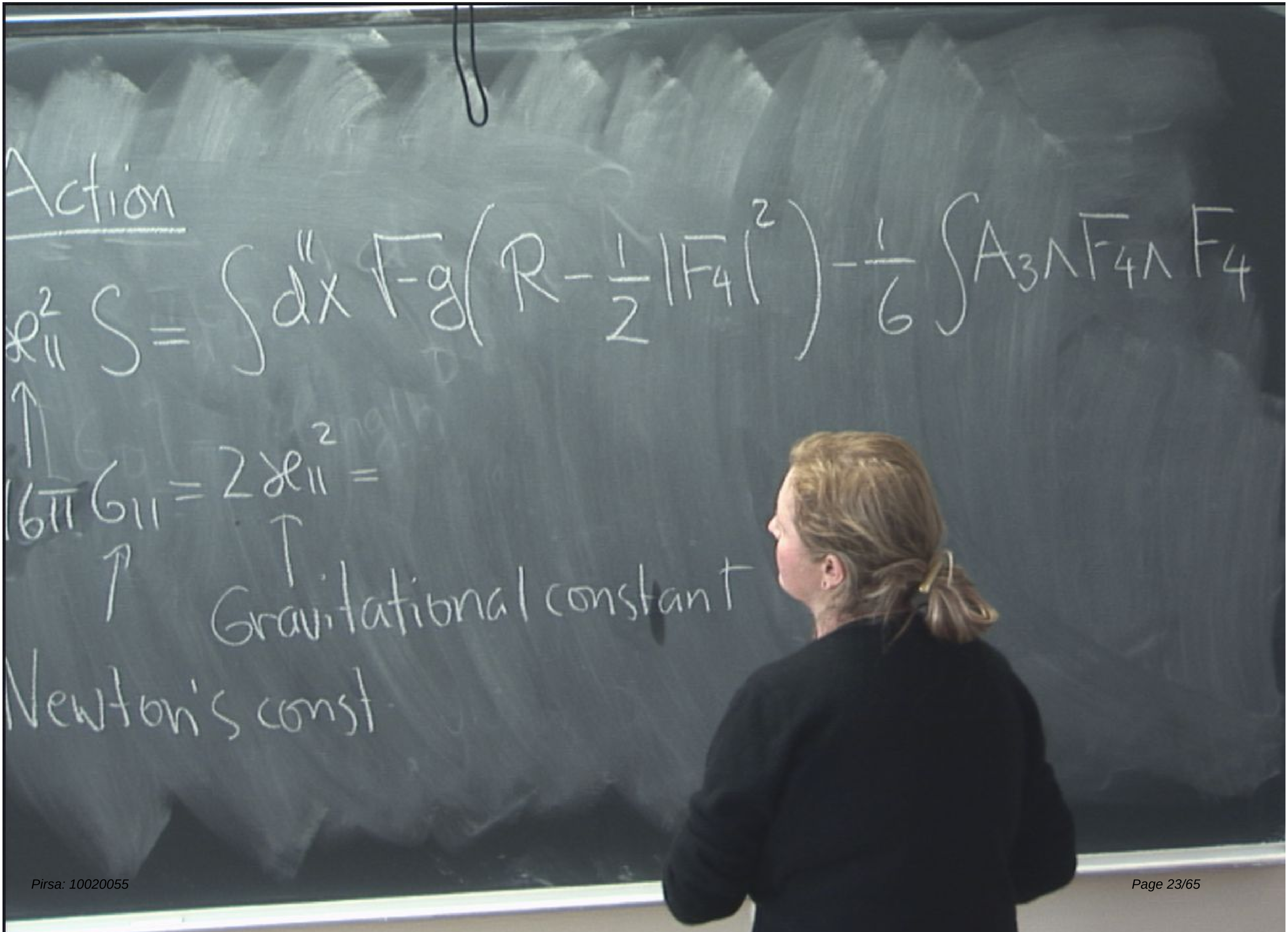
③ Gravitino ψ^{μ}_{M} $\mu \leftarrow$ vector index, $M \leftarrow$ Spinor index

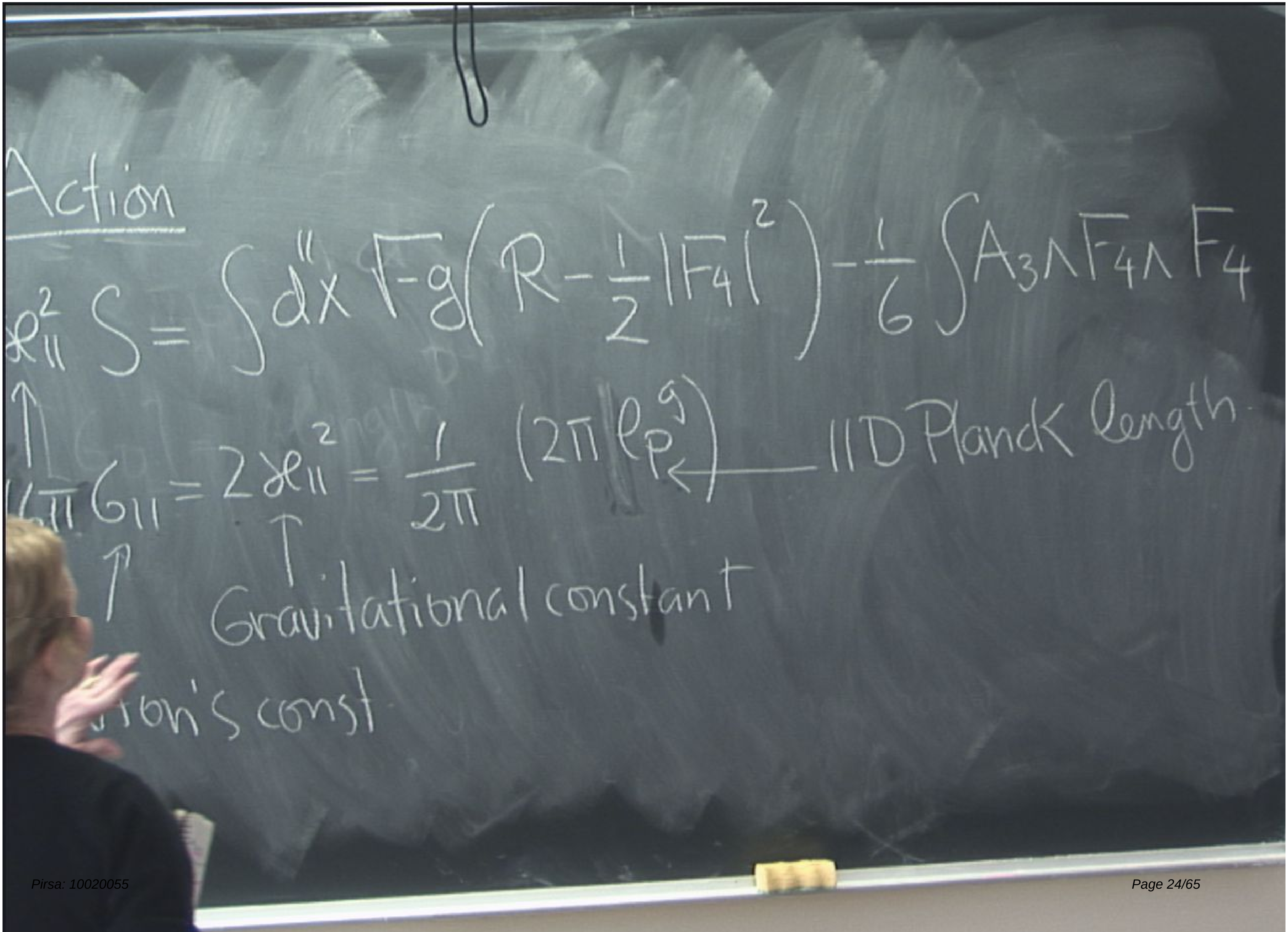
32-component Majorana

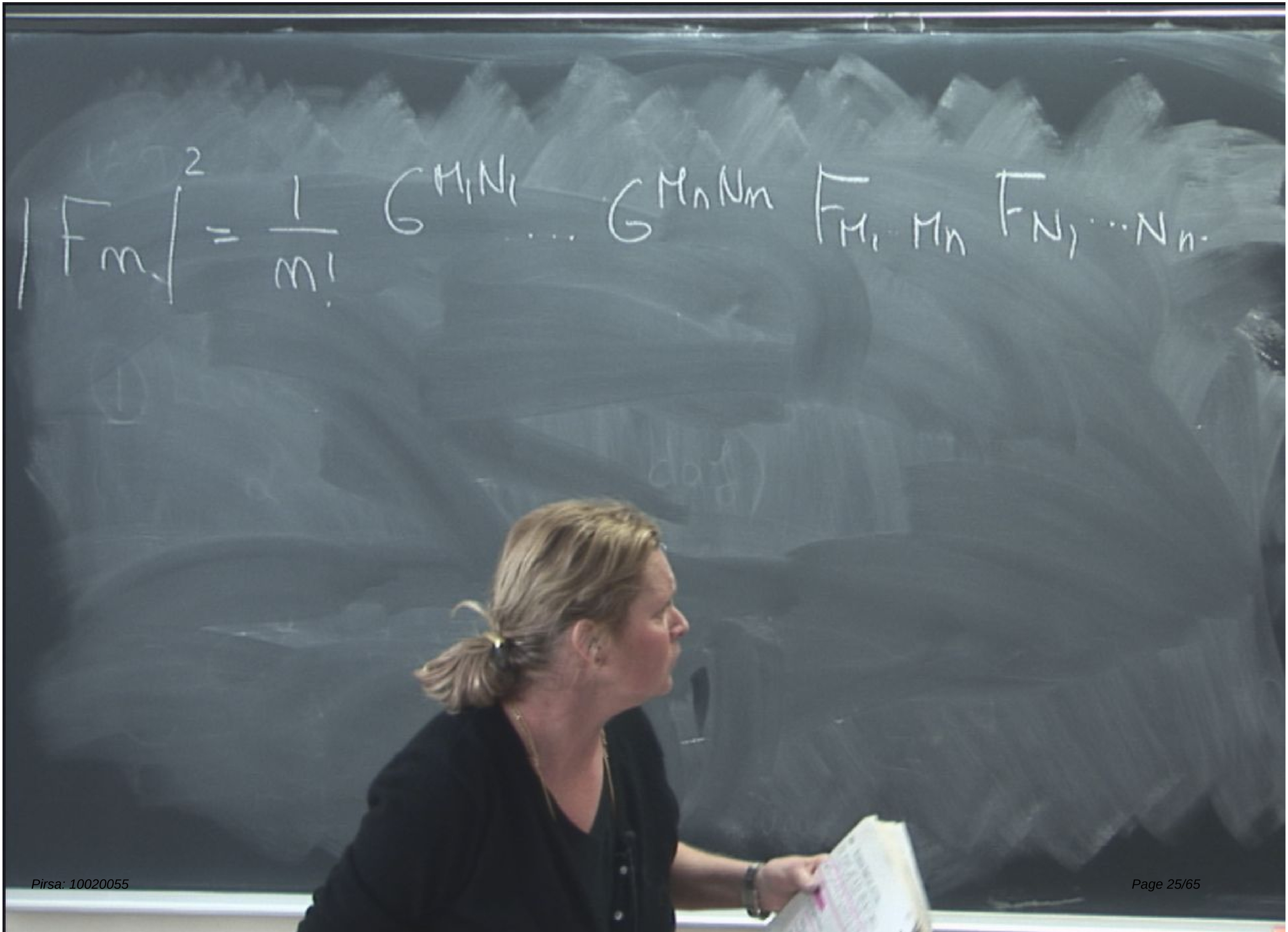
128 dof

Action

$$\kappa_{11}^2 S = \int d^{11}x \sqrt{-g}\left(R - \frac{1}{2}|F_4|^2\right) - \frac{1}{6}\int A_3 \wedge F_4 \wedge F_4$$


Action
$\kappa_{11}^2 S = \int d^{11}x \sqrt{-g}\left(R - \frac{1}{2}|F_4|^2\right) - \frac{1}{6}\int A_3 \wedge F_4 \wedge F_4$
$16\pi G_{11} = 2\kappa_{11}^2 =$
Gravitational constant
Newton's const


Action
$\varkappa_{11}^2 S = \int d^{11}x \sqrt{-g}\left(R - \frac{1}{2}|F_4|^2\right) - \frac{1}{6}\int A_3 \wedge F_4 \wedge F_4$
$16\pi G_{11} = 2\varkappa_{11}^2 = \frac{1}{2\pi}(2\pi \ell_P)^9$
11D Planck length
Gravitational constant
ton's const


$|F_m|^2 = \frac{1}{m!} G^{M_1N_1} \cdots G^{M_nN_m} F_{M_1 \cdots M_n} F_{N_1 \cdots N_n}$

Action

$$\varkappa_{11}^2 S = \int d^{11}x \sqrt{-g}\left(R - \frac{1}{2}|F_4|^2\right) - \frac{1}{6}\int A_3 \wedge F_4 \wedge F_4$$

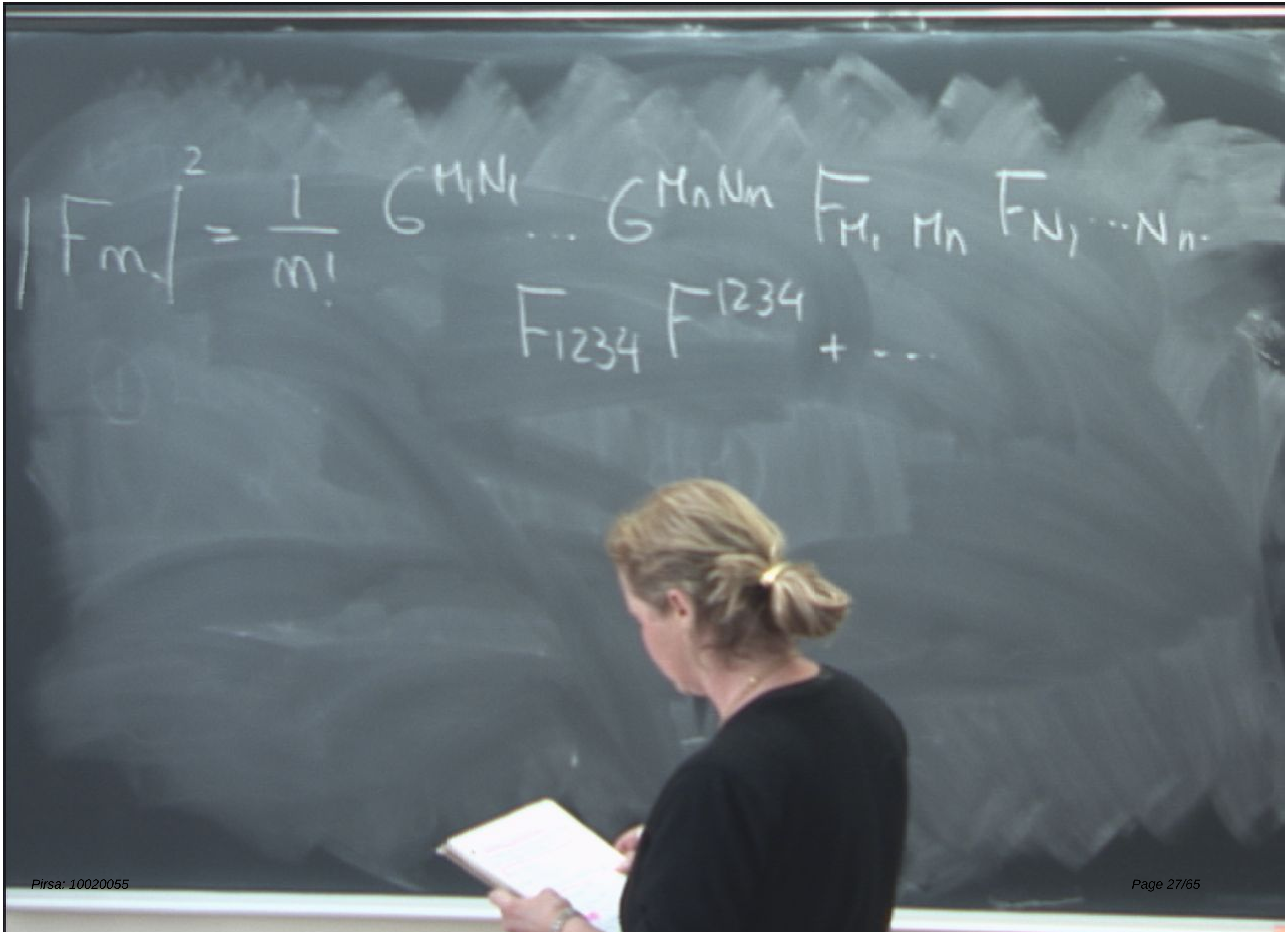
$$16\pi G_{11} = 2\varkappa_{11}^2 = \frac{1}{2\pi}(2\pi \ell_P)^9$$

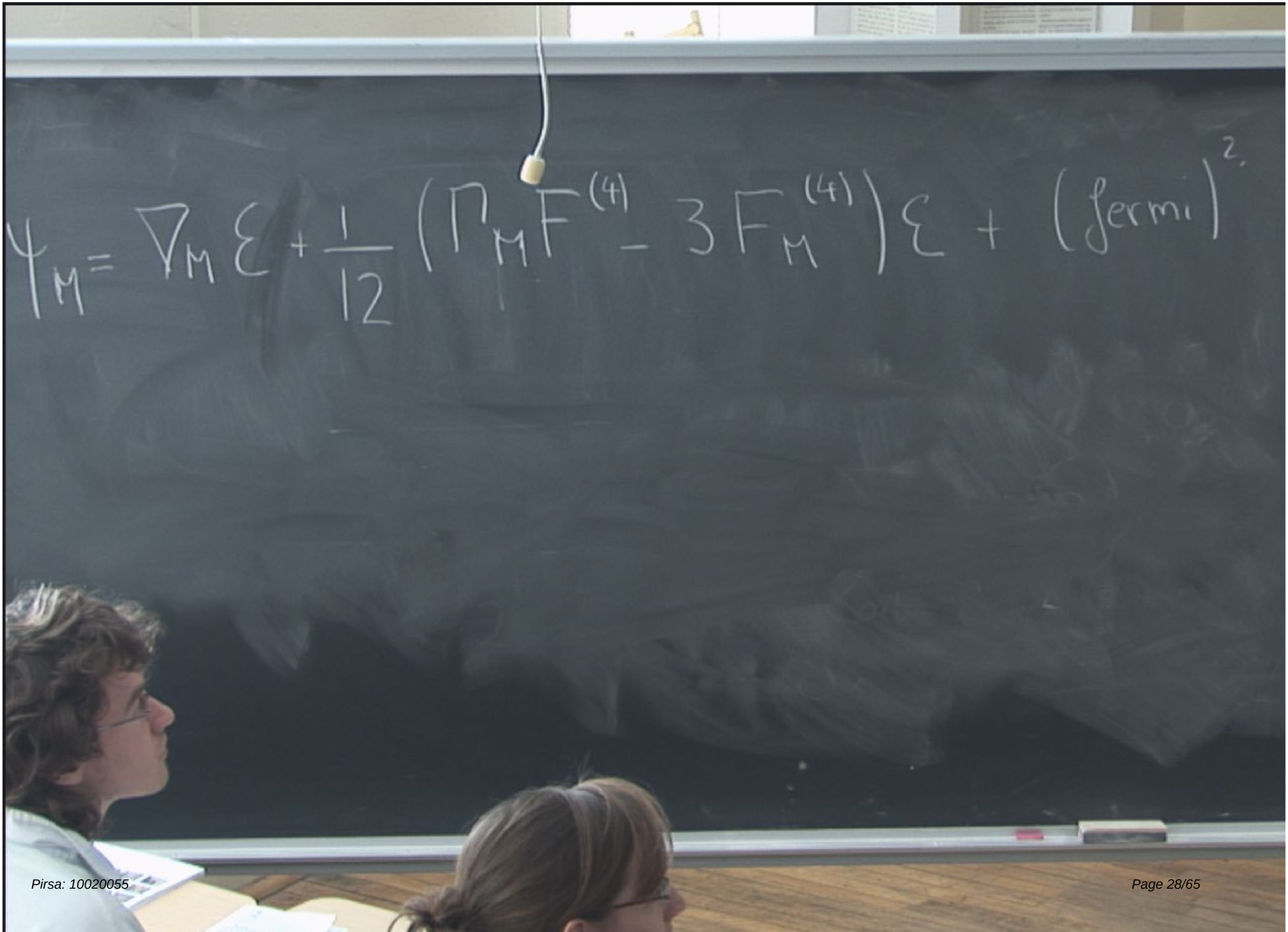
11D Planck length

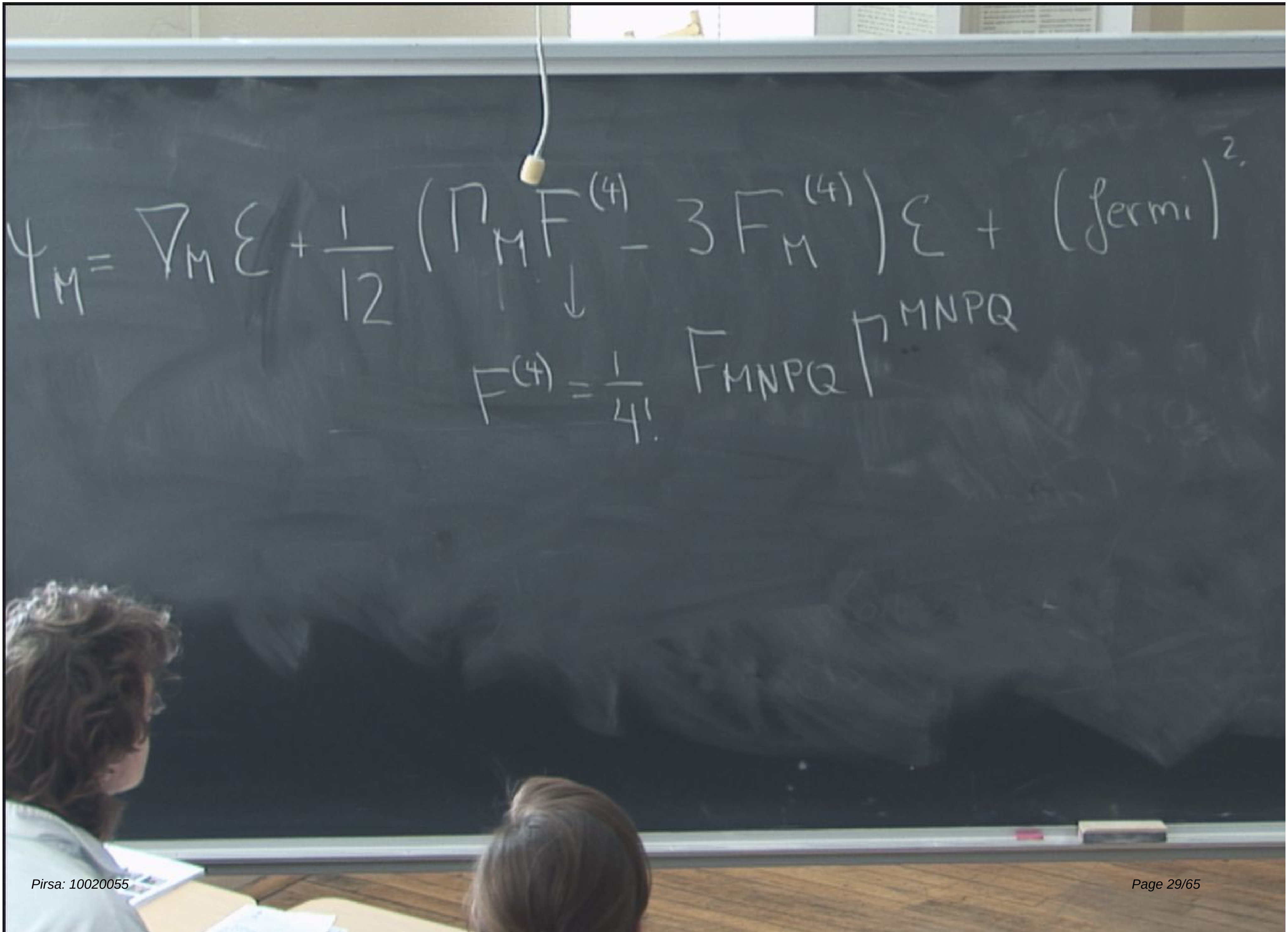
Gravitational constant

Chern-Simons term

Newton's const


$|F_m|^2 = \frac{1}{m!} G^{M_1N_1} \cdots G^{M_nN_m} F_{M_1 \, M_n} F_{N_1 \cdots N_n}$
$F_{1234} F^{1234} + \ldots$


$\psi_M = \nabla_M \varepsilon + \frac{1}{12}\left(\Gamma_M F^{(4)} - 3 F_M^{(4)}\right)\varepsilon + (\text{fermi})^2.$



$\psi_M = \nabla_M \varepsilon + \frac{1}{12}\left(\Gamma_M F^{(4)} - 3 F_M^{(4)}\right)\varepsilon + (\text{fermi})^2.$
$F^{(4)} = \frac{1}{4!} F_{MNPQ} \Gamma^{MNPQ}$

$$+\frac{1}{12}\left(\Gamma_M F^{(4)} - 3F_M^{(4)}\right)\varepsilon + (\text{fermi})^2 \quad)$$

$$F^{(4)} = \frac{1}{4!} F_{MNPQ}\Gamma^{MNPQ} \qquad \Gamma^1\Gamma^2\Gamma^3\Gamma^4 + \dots \text{antisymm}$$

$$F_M^{(4)} = \frac{1}{3!} F_{MNPQ}\Gamma^{NPQ}$$

$$\Psi_M = \nabla_M \varepsilon + \frac{1}{12}\left(\Gamma_M F^{(4)} - 3 F_M^{(4)}\right)\varepsilon + (\text{fermi})^2.$$

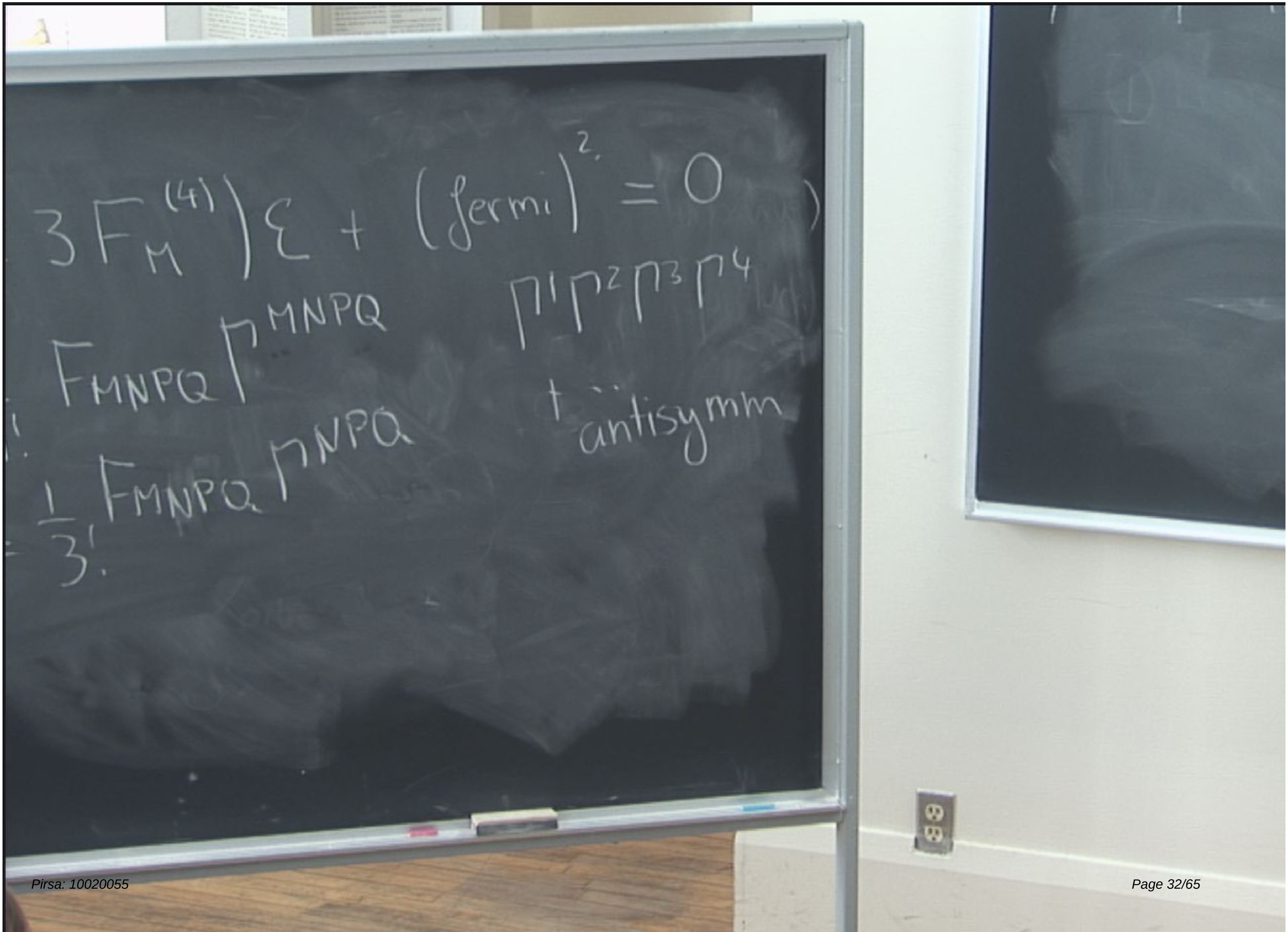
Check!

$$F^{(4)} = \frac{1}{4!} F_{MNPQ}\,\Gamma^{MNPQ}$$

$$F_M^{(4)} = \frac{1}{3!} F_{MNPQ}\,\Gamma^{NPQ}$$

$\Gamma^1\Gamma^2\Gamma$

$+ \ldots$ anti


3 F_M^(4)) ε + (fermi)^2 = 0
Γ^1 Γ^2 Γ^3 Γ^4
F_MNPQ Γ^MNPQ
+ ... antisymm
1/3! F_MNPQ Γ^NPQ
3!

$$+\frac{1}{12}\left(\Gamma_M F^{(4)} - 3F_M^{(4)}\right)\varepsilon + (\text{fermi})^2 = 0 \quad)$$

OK!

$$F^{(4)} = \frac{1}{4!} F_{MNPQ}\Gamma^{MNPQ} \qquad \Gamma^1\Gamma^2\Gamma^3\Gamma^4 + \ldots \text{ antisymm}$$

$$F_M^{(4)} = \frac{1}{3!} F_{MNPQ}\Gamma^{NPQ}$$

$\Rightarrow$ Classical susy solutions M2, M5 branes

A_3: $\int d^3\sigma \; A_3.$

$\uparrow$ 3D extended object.

$F_4 : A_3 : \quad \int d^3\sigma \, A_3 . \quad$ M2-brane.

$\uparrow$ 3D extended object.

$* F_4 = F_7 \; ; \quad \int d^6\sigma \, C_6$

$F_7 = dC_6$

$F_4 : A_3 :$ $\int d^3\sigma \, A_3$. M2-brane

$\uparrow$ 3D extended object.

$*\bar{F}_4 = \bar{F}_7$; $\int d^6\sigma \, C_6$

$$\bar{F}_7 = dC_6$$

$F_4 : A_3 : \quad \int d^3\sigma \, A_3$. M2-brane.

$\uparrow$ 3D extended object.

$* F_4 = F_7 \; ; \quad \int d^6\sigma \, C_6$

$ \, \| $

$ dC_6$

$F_4 = dA_3$

$F_4 : A_3 : T_2 \int d^3\sigma \, A_3$ M2-brane

$\uparrow$ 3D extended object

$* F_4 = F_7 ; T_5 \int d^6\sigma \, C_6$ M5-brane

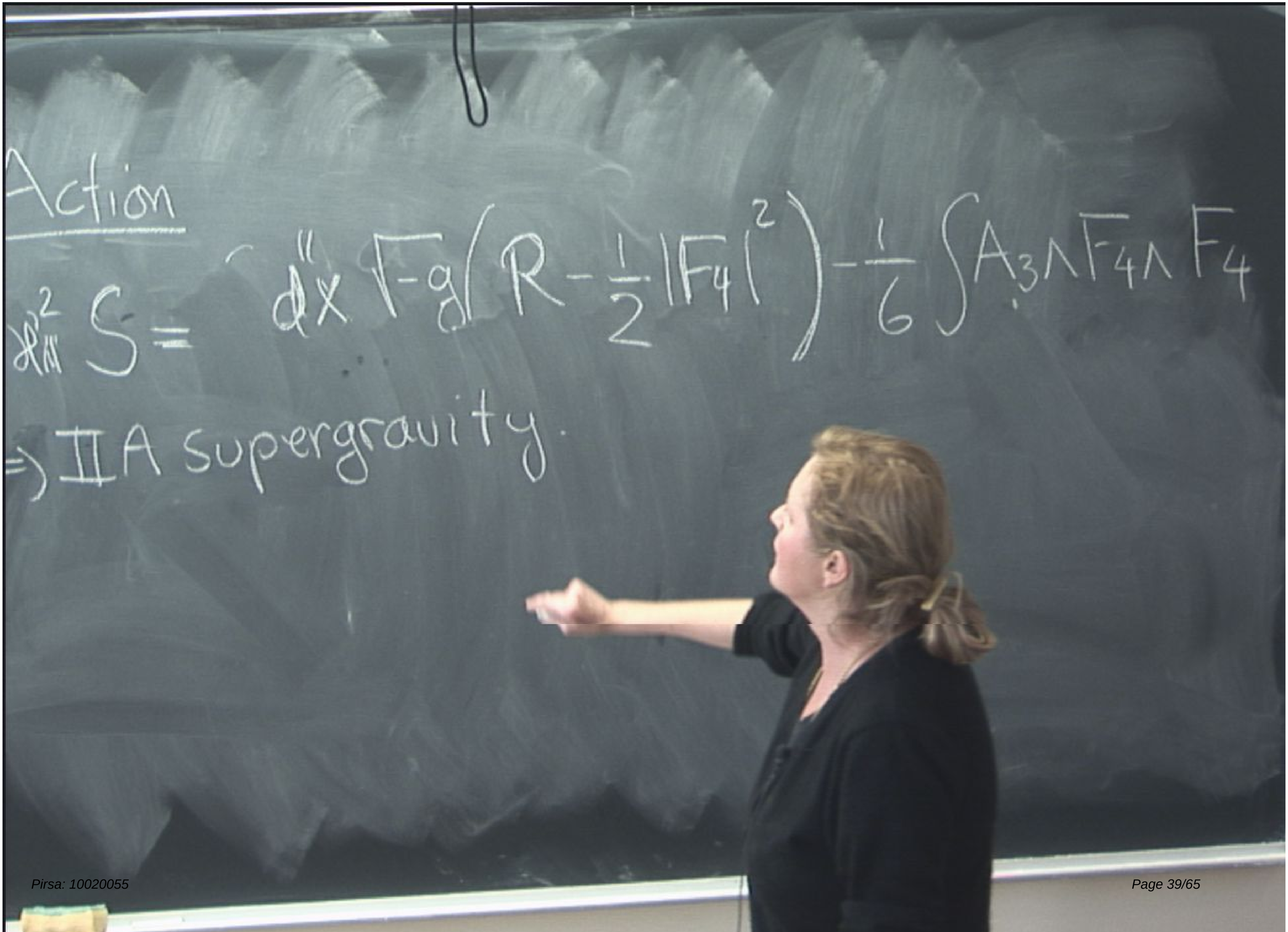
$ \parallel$

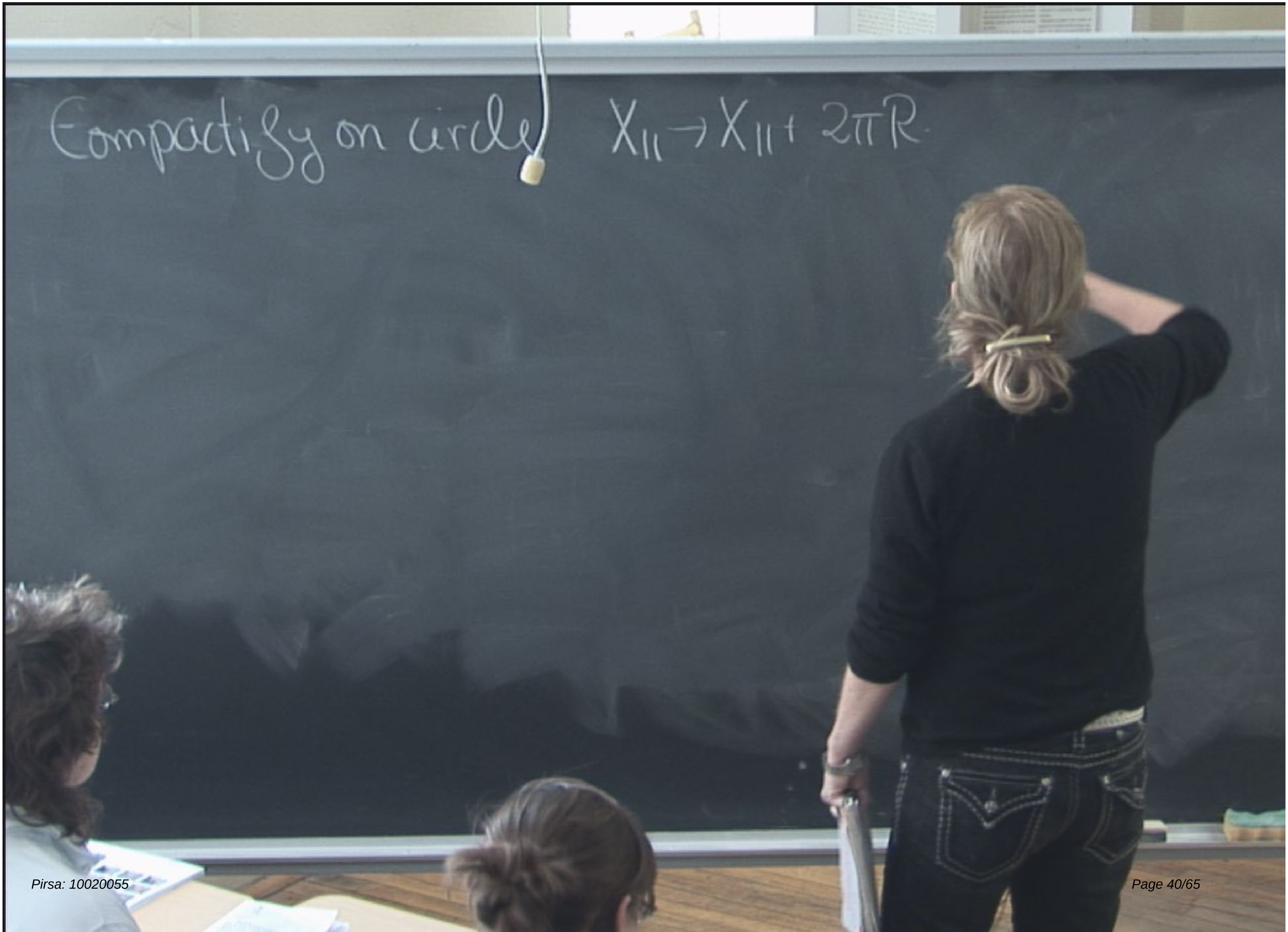
$ dC_6$

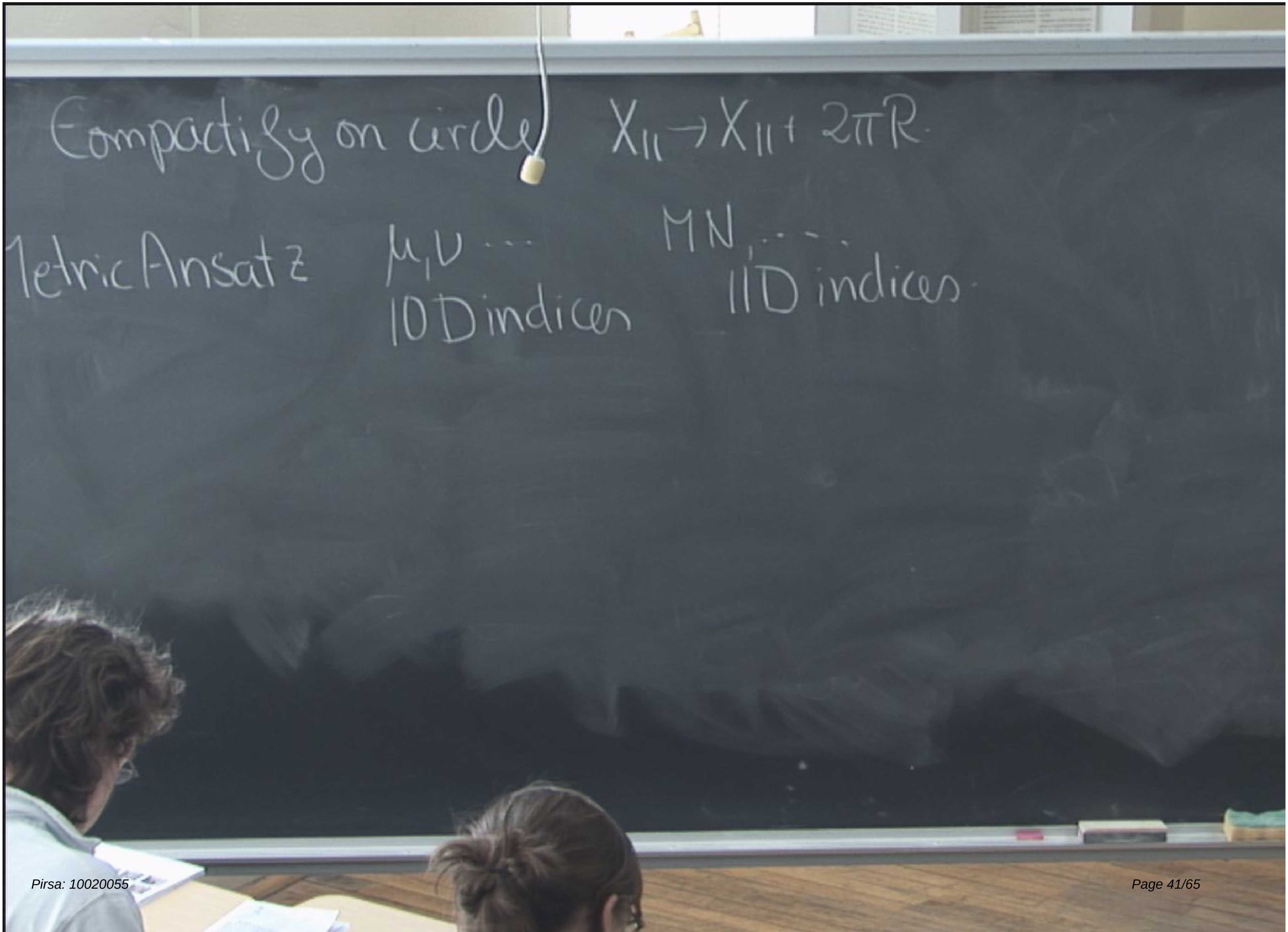
$F_4 = dA_3$

$T_2 = 2\pi (2\pi \ell_p)^{-3}$

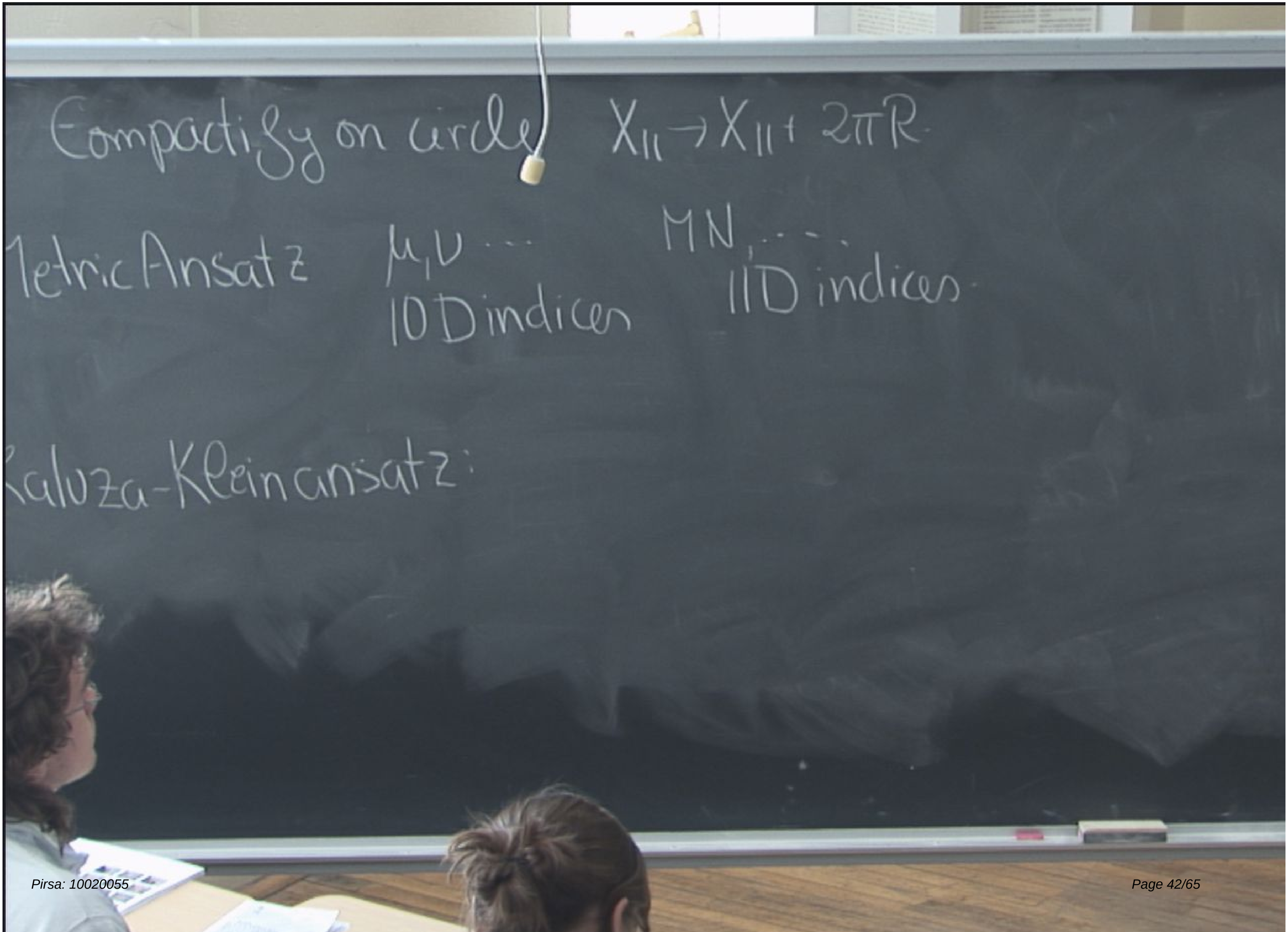
$T_5 = 2\pi (2\pi \ell_p)^{-6}$


Action
$\kappa_{11}^2 S = \int d^{11}x \sqrt{-g}\left(R - \frac{1}{2}|F_4|^2\right) - \frac{1}{6}\int A_3 \wedge F_4 \wedge F_4$
$\Rightarrow$ IIA supergravity.


Compactify on circle $X_{11} \to X_{11} + 2\pi R$



Compactify on circle
$X_{11} \to X_{11} + 2\pi R$.
Metric Ansatz
$\mu, \nu \ldots$
10D indices
$M N, \ldots$
11D indices.


Compactify on circle $X_{11} \to X_{11} + 2\pi R$.
Metric Ansatz $\mu, \nu \ldots$ 10D indices
$M N, \ldots$ 11D indices.
Kaluza-Klein ansatz:

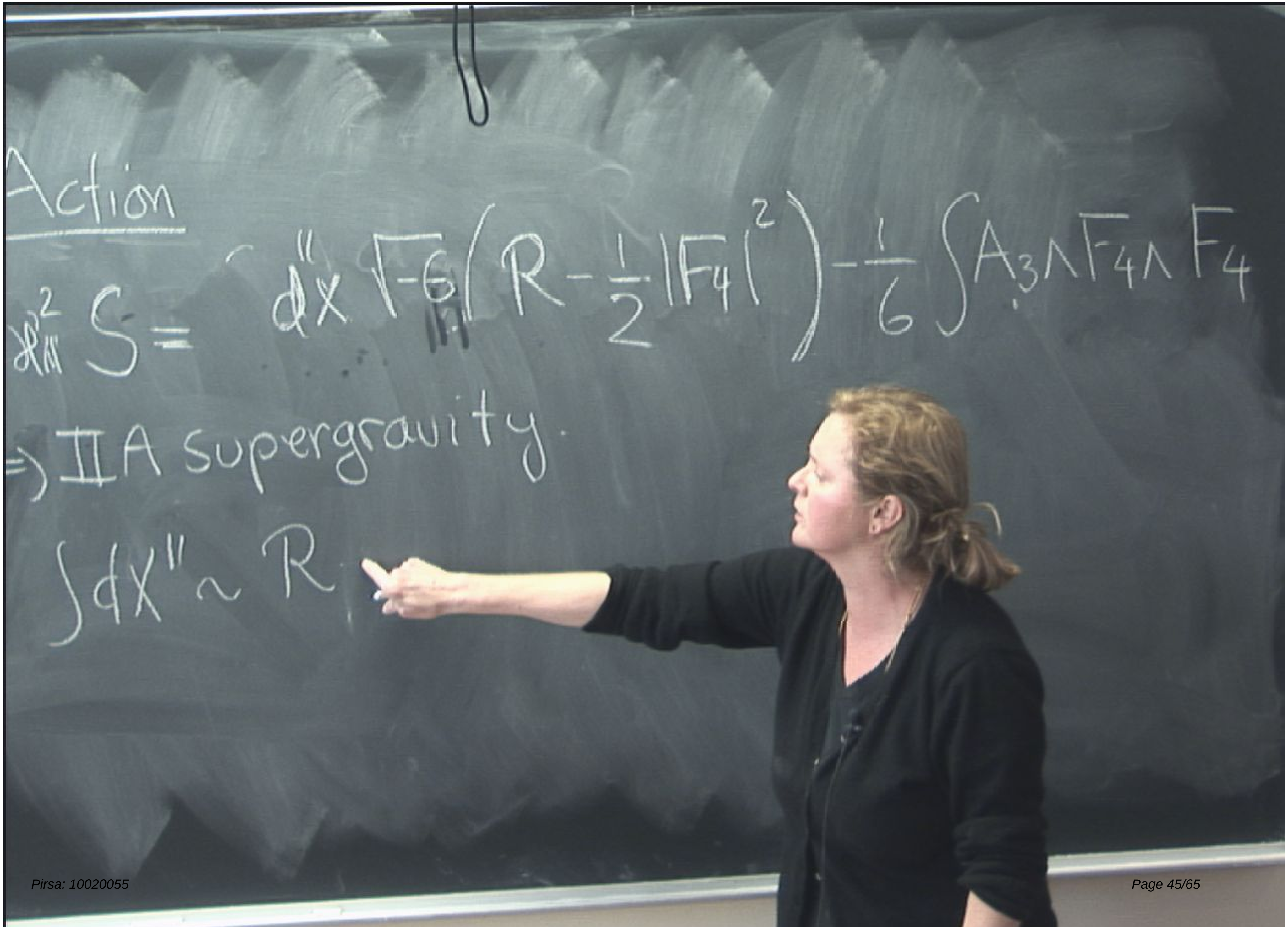
$$G_{MN} = e^{-2\phi/3} \begin{pmatrix} g_{\mu\nu} + e^{2\phi} A_\mu A_\nu & e^{2\phi} A_\mu \\ e^{2\phi} A_\nu & e^{2\phi} \end{pmatrix}$$

10D

$$G_{MN} = e^{-2\phi/3} \begin{pmatrix} g_{\mu\nu} + e^{2\phi} A_\mu A_\nu & e^{2\phi} A_\mu \\ e^{2\phi} A_\nu & e^{2\phi} \end{pmatrix}$$

10D dilaton

$A, \phi, g^{\mu\nu}$ don't depend on X^{1}


Action
$2\kappa_{11}^2 S = \int d^{11}x \sqrt{-G}\left(R - \frac{1}{2}|F_4|^2\right) - \frac{1}{6}\int A_3 \wedge F_4 \wedge F_4$
$\Rightarrow$ IIA supergravity.
$\int dx^{11} \sim R$

$$G_{MN} = e^{-2\phi/3} \begin{pmatrix} g_{\mu\nu} + e^{2\phi} A_\mu A_\nu & e^{2\phi} A_\mu \\ e^{2\phi} A_\nu & e^{2\phi} \end{pmatrix}$$

10D dilaton

$A^{(1)}, \phi, g^{\mu\nu}$ don't depend on X^{11}

① $G_{MN} = \underset{\substack{\text{10D} \\ \text{dilaton}}}{e^{-2\phi/3}} \begin{pmatrix} g_{\mu\nu} + e^{2\phi} A_\mu A_\nu & e^{2\phi} A_\mu \\ e^{2\phi} A_\nu & e^{2\phi} \end{pmatrix}$

$A^{(1)}, \phi, g^{\mu\nu}$ don't depend on X''

② F_{MNPQ}

① $G_{MN} = e^{-2\phi/3} \begin{pmatrix} g_{\mu\nu} + e^{2\phi} A_\mu A_\nu & e^{2\phi} A_\mu \\ e^{2\phi} A_\nu & e^{2\phi} \end{pmatrix}$

10D dilaton

$A^{(1)}, \phi, g^{\mu\nu}$ don't depend on X^{11}

② F_{MNPQ}

$F_{mnp11} = H_{mnp}$ $\quad H_3 = dB_2$

① $G_{MN} = e^{-2\phi/3} \begin{pmatrix} g_{\mu\nu} + e^{2\phi} A_\mu A_\nu & e^{2\phi} A_\mu \\ e^{2\phi} A_\nu & e^{2\phi} \end{pmatrix}$

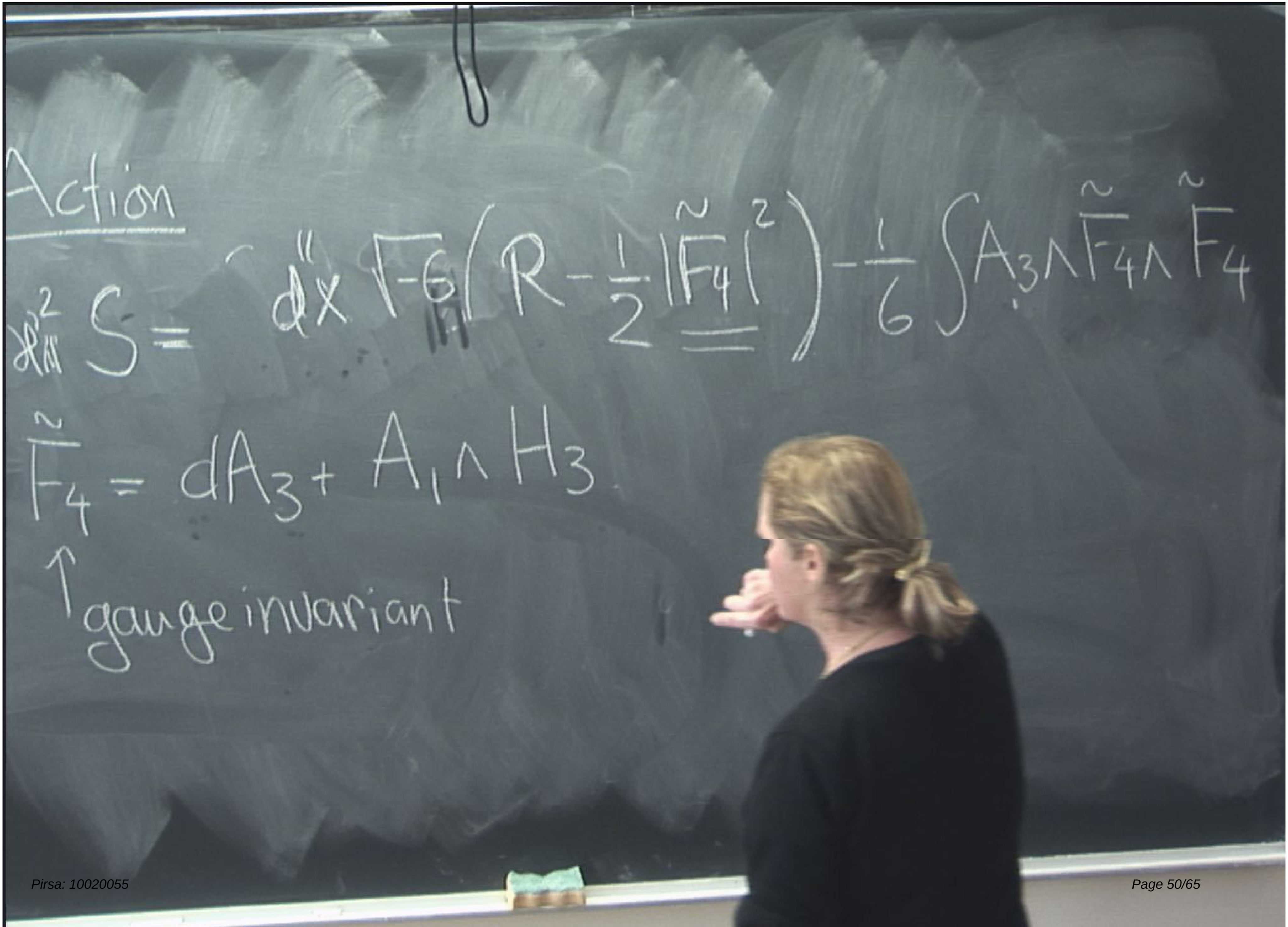
10D dilaton

$A^{(1)}, \phi, g^{\mu\nu}$ don't depend on x^{11}

② F_{MNPQ}

$F_{mnp11} = H_{mnp} \quad H_3 = dB_2$

$F_{mnpq} \Rightarrow F_4 = dC_3$


Action
$2\kappa_{11}^2 S = \int d^{11}x \sqrt{-G}\left(R - \frac{1}{2}|\tilde{F}_4|^2\right) - \frac{1}{6}\int A_3 \wedge \tilde{F}_4 \wedge \tilde{F}_4$
$\tilde{F}_4 = dA_3 + A_1 \wedge H_3$
gauge invariant

Action

$$2\kappa_{11}^2 S = \int d^{11}x \sqrt{-G}\left(R - \frac{1}{2}|\tilde{F}_4|^2\right) - \frac{1}{6}\int A_3 \wedge \tilde{F}_4 \wedge \tilde{F}_4$$

$$\tilde{F}_4 = dA_3 + A_1 \wedge H_3$$

↑ gauge invariant

Gauge transformations.

$$A_3 \to A_3 + d\Lambda_2$$

Action

$$2\kappa_{11}^2 S = \int d^{11}x \sqrt{-G}\left(R - \frac{1}{2}|\tilde{F}_4|^2\right) - \frac{1}{6}\int A_3 \wedge \tilde{F}_4 \wedge \tilde{F}_4$$

$$\tilde{F}_4 = dA_3 + A_1 \wedge H_3$$

Gauge transformations

$$\delta A_1 = d\Lambda$$

$$\delta A_3 = d\Lambda \wedge B_2$$

Action

$$\kappa_{11}^2 S = \int d^{11}x \sqrt{-G}\left(R - \frac{1}{2}|\tilde{F}_4|^2\right) - \frac{1}{6}\int A_3 \wedge \tilde{F}_4 \wedge \tilde{F}_4$$

$$\tilde{F}_4 = dA_3 + A_1 \wedge H_3$$

Gauge transformations

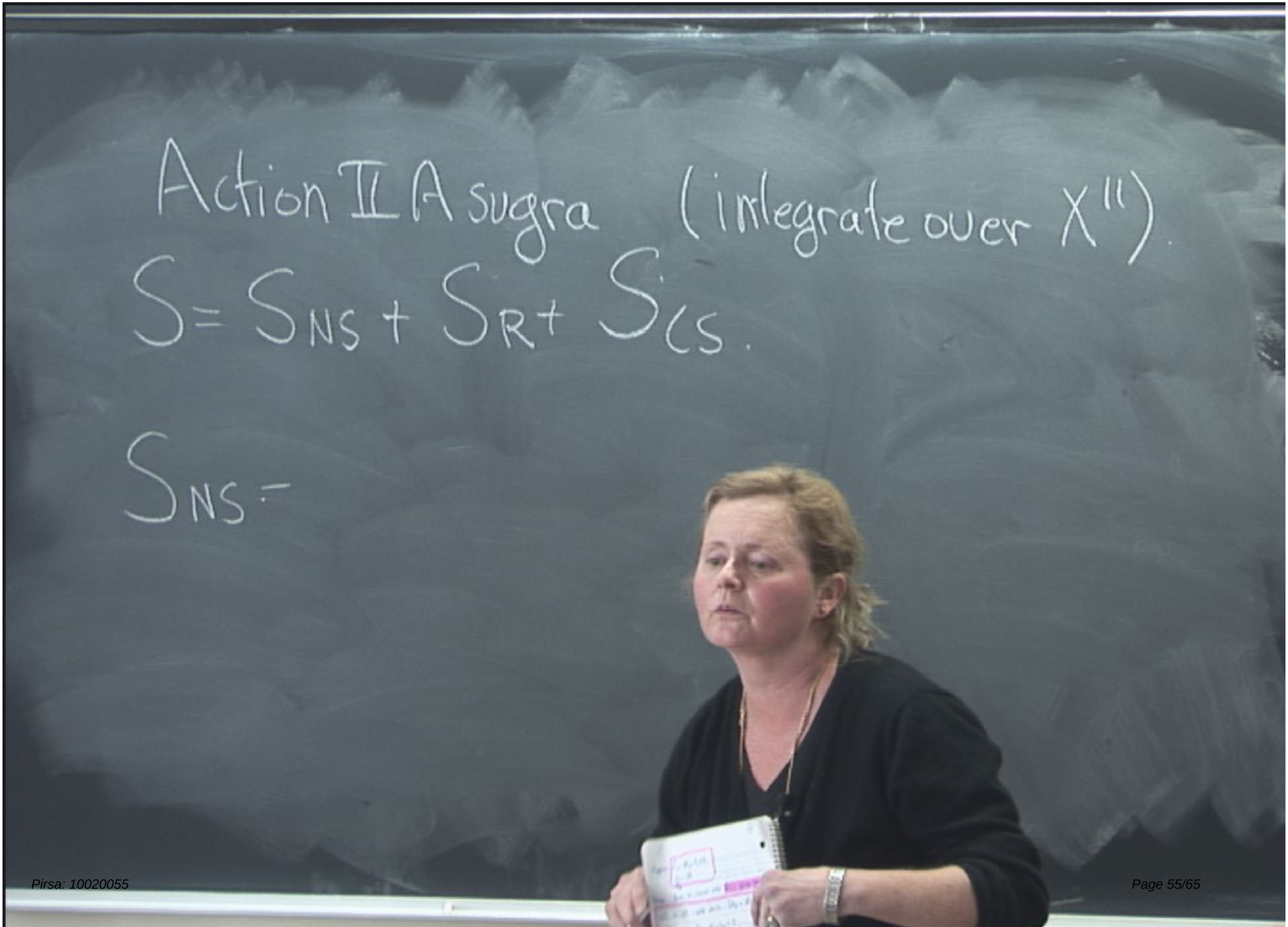
$$\delta A_1 = d\Lambda$$

$$\delta A_3 = d\Lambda \wedge B_2$$

$$\delta \tilde{F}_4 = d(d\Lambda \wedge B_2) + d\Lambda \wedge H_3 = 0$$

Action IIA sugra (integrate over X^{11}).

$$S = S_{NS} + S_{R} + S_{CS}.$$


Action IIA sugra (integrate over X^{11}).
$S = S_{NS} + S_{R} + S_{CS}$.
$S_{NS} =$

Action IIA sugra (integrate over X^{11}).

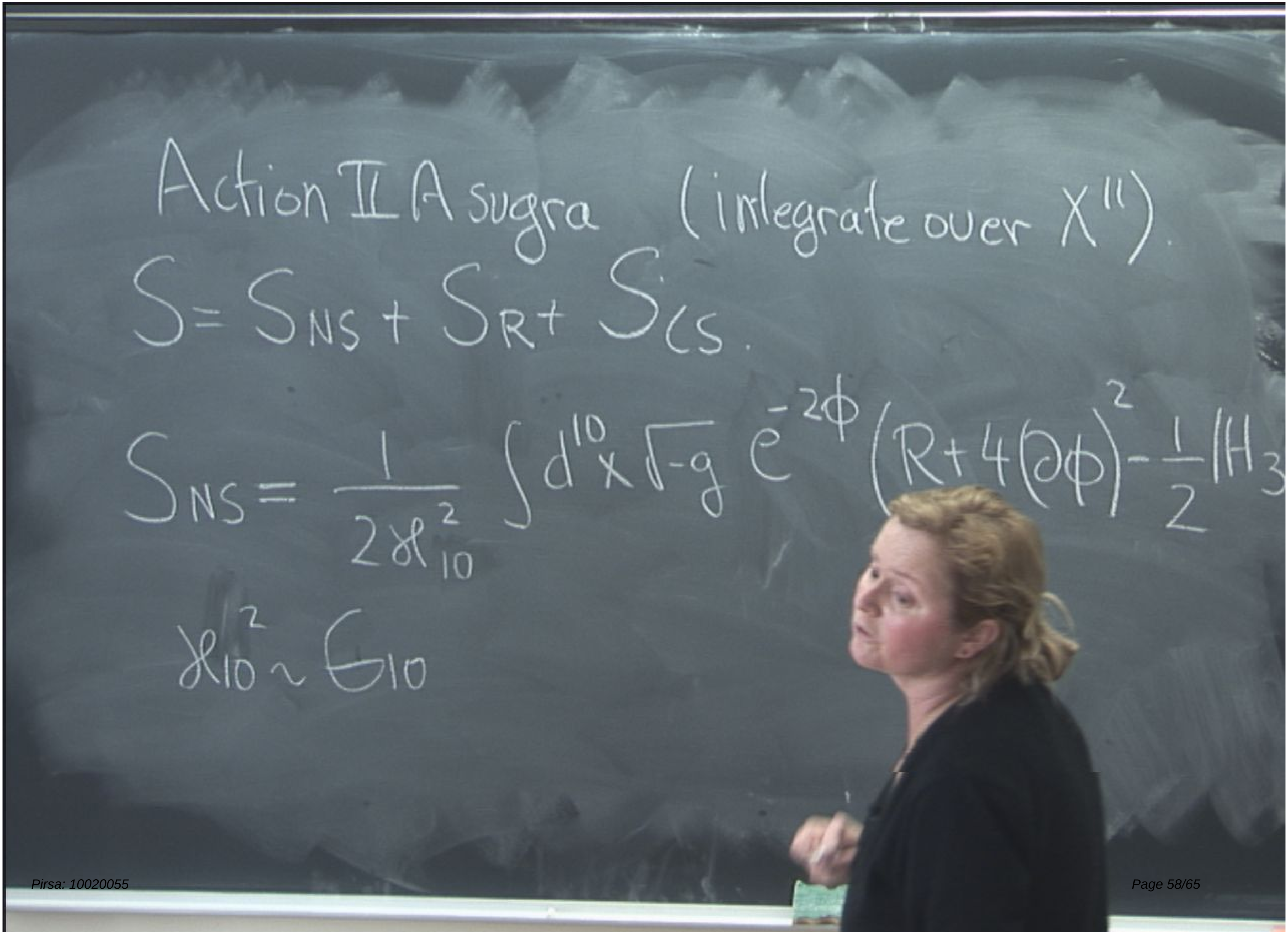
$$S = S_{NS} + S_{R} + S_{CS}.$$

$$S_{NS} = \frac{1}{2\kappa^2}\int d^{10}x\,\sqrt{-g}$$

Action IIA sugra (integrate over X^{11}).

$$S = S_{NS} + S_{R} + S_{CS}.$$

$$S_{NS} = \frac{1}{2\kappa^2}\int d^{10}x\sqrt{-g}\,e^{-2\phi}\left(R + 4(\partial\phi)^2 - \frac{1}{2}|H_3$$


Action IIA sugra (integrate over X^{11}).
$S = S_{NS} + S_{R} + S_{CS}$.
$S_{NS} = \frac{1}{2\kappa_{10}^2} \int d^{10}x \sqrt{-g}\, e^{-2\phi} \left(R + 4(\partial\phi)^2 - \frac{1}{2}|H_3$
$\kappa_{10}^2 \sim G_{10}$

Action IIA sugra (integrate over X^{11}).

$$S = S_{NS} + S_R + S_{CS}.$$

$$S_{NS} = \frac{1}{2\kappa_{10}^2} \int d^{10}x \sqrt{-g}\, e^{-2\phi} \left(R + 4(\partial\phi)^2 - \frac{1}{2}|H_3$$

$$\kappa_{10}^2 \sim G_{10} \Rightarrow G_{11} = 2\pi R \cdot G_{10}$$

Action IIA sugra (integrate over X^{11}).

$$S = S_{NS} + S_R + S_{CS}.$$

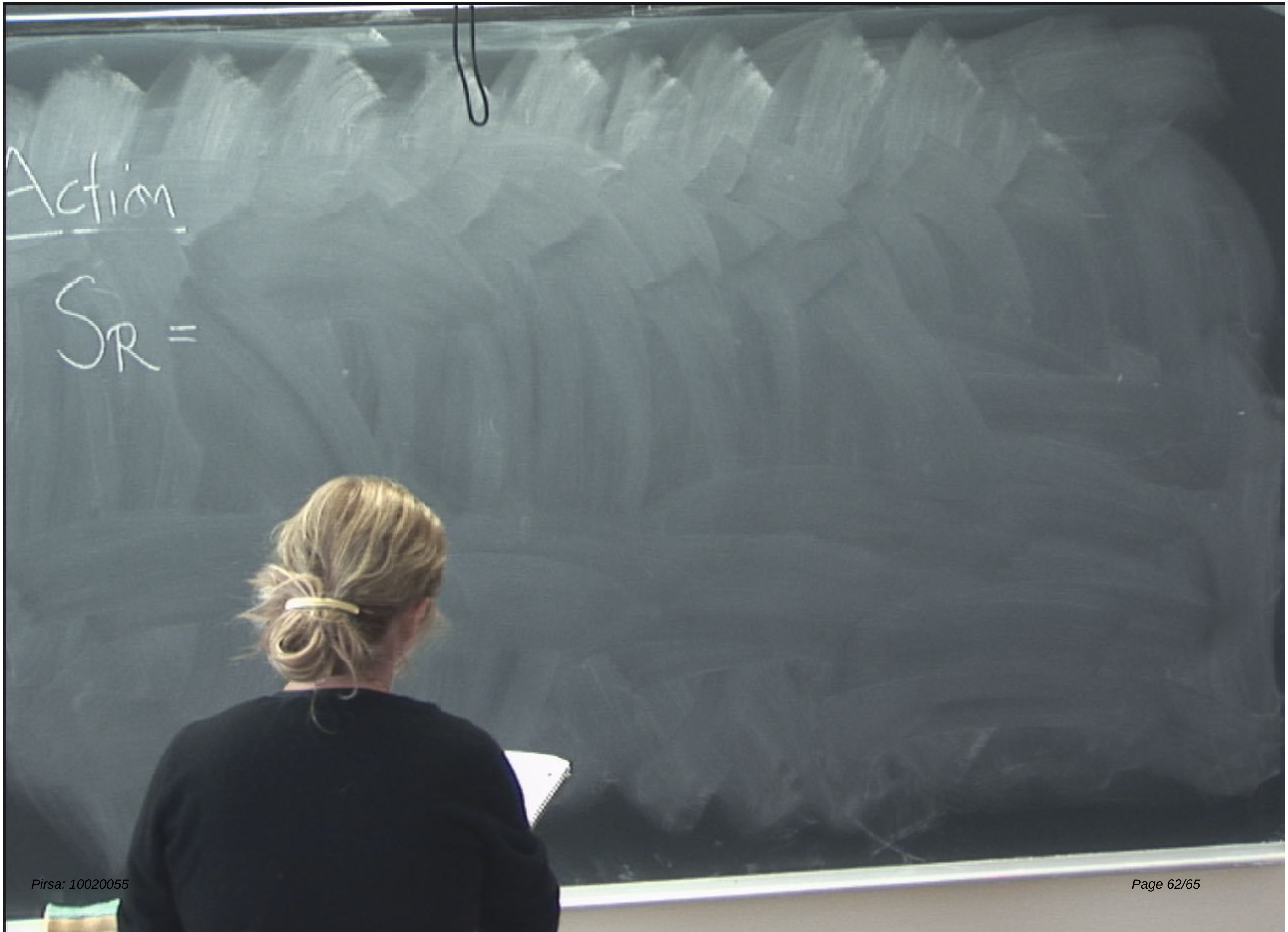
$$S_{NS} = \frac{1}{2\kappa_{10}^2} \int d^{10}x \sqrt{-g}\, e^{-2\phi} \left(R + 4(\partial\phi)^2 - \frac{1}{2}|H_3|^2 \right.$$

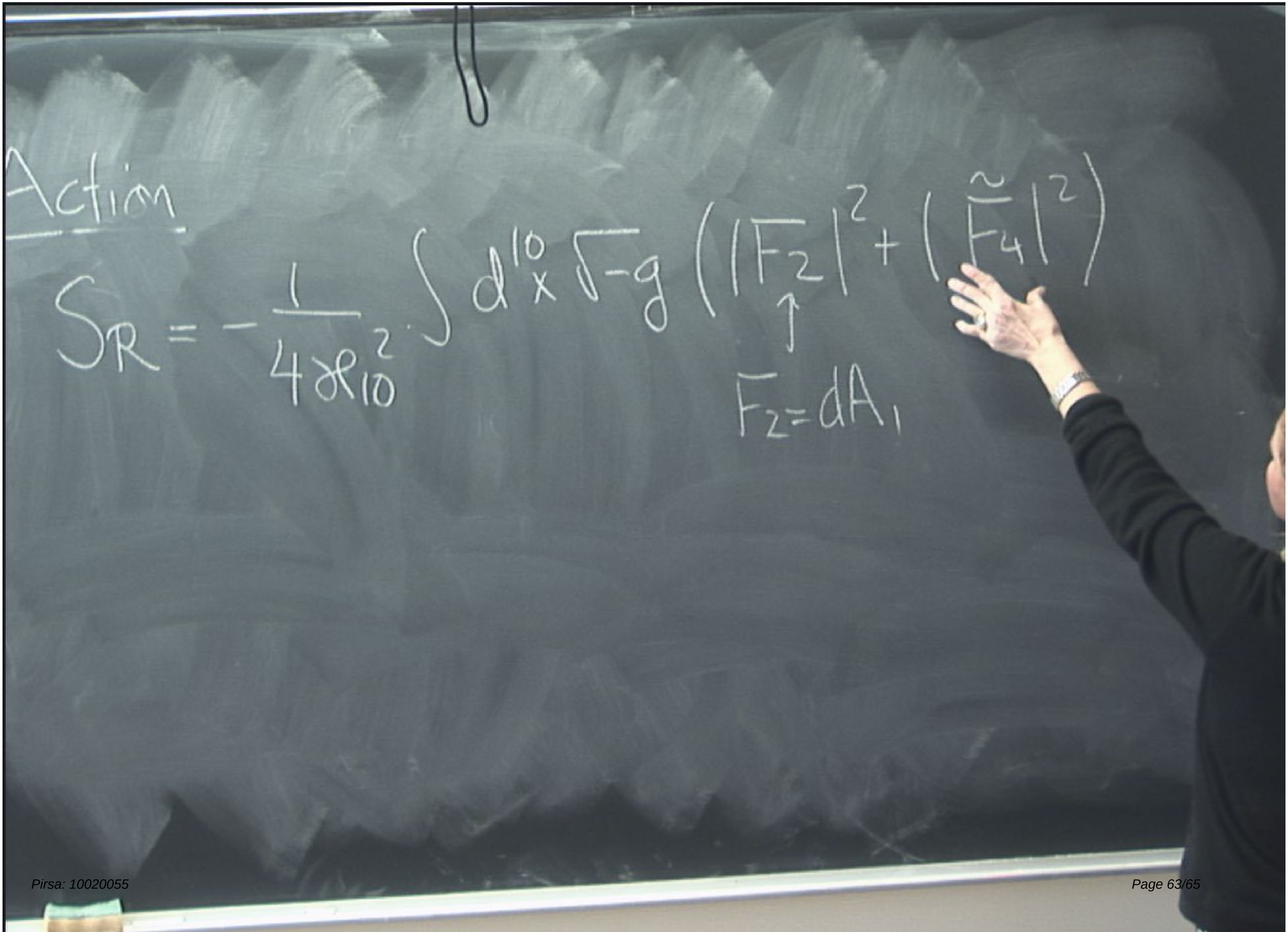
$$\kappa_{10}^2 \sim G_{10} \Rightarrow G_{11} = \underbrace{2\pi R}_{\int dx^{11}} \cdot G_{10}$$

Action

String frame action.

Einstein frame $\int d^{10}x \sqrt{-g}\, R$


Action
$S_R =$


Action
$S_R = -\frac{1}{4\kappa_{10}^2} \int d^{10}x \sqrt{-g} \left(|F_2|^2 + |\tilde{F}_4|^2 \right)$
$F_2 = dA_1$

Action

$$S_R = -\frac{1}{4\kappa_{10}^2}\int d^{10}x\,\sqrt{-g}\,\left(|F_2|^2 + |\tilde{F}_4|^2\right)$$

$$F_2 = dA_1$$

$$S_{CS} = -\frac{1}{4\kappa^2}\int B_2\wedge F_4\wedge F_4)$$

Action

$$S_R = -\frac{1}{4\kappa_{10}^2}\int d^{10}x\,\sqrt{-g}\,\left(|F_2|^2 + |\tilde{F}_4|^2\right)$$

$$F_2 = dA_1$$

$$S_{CS} = -\frac{1}{4\kappa^2}\int B_2 \wedge F_4 \wedge F_4$$

$$\Psi_M \to \psi_\mu + \lambda \to \text{dilatino}$$