Title: Strings and Particle Physics

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Abstract:

Thm: Intersecting D-brane models w/o O-planes contain SU(2) chiral exotics

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$U(N)$ $\qquad\qquad$ $SU(2) \subset U(2)$

$3 \times (3, 2)$ $\qquad\qquad$ 9 fund

$3 \times (1, \bar{2})$ $\qquad\qquad$ $\bar{2}$ $\quad$ 2

Thm: Intersecting D-brane models w/o O-planes contain SU(2) chiral exotics

U(N) SU(2) ⊂ U(2)

$3 \times (3, 2)$ 9 fund 6 SU(2) doublets

$3 \times (1, \bar{2})$

$\bar{2}$ 2

Thm: Intersecting D-brane models w/o O-planes contain SU(2) chiral exotics

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3 × (3, 2) 9 fund 6 SU(2) doublets

3 × (1, $\bar{2}$) $\bar{2}$ 2

U(2) Class Models

U(2) Class Models

In orientifold model

$(N, \bar{M})$, (N, M)

U(2) Class Models

In orientifold model

$(3, 2)$

$(N, \bar{M})$, (N, M)

U(2) Class Models

In orientifold model $(N, \bar{M})$, (N, M)

$$(3, \bar{2}) \oplus 2(3, 2)$$

U(2) Class Models

In orientifold model

$(N, \bar{M})$, (N, M)

$SU(3) \times SU(2)$

$(3, \bar{2}) \oplus 2\,(3, 2)$

3x fund.

U(2) Class Models

In orientifold model

$(N, \bar{M})$, (N, M)

$SU(3) \times SU(2)$

$(3, \bar{2}) \oplus 2\,(3, 2)$

$3 \times$ fund.

4 stacks of D-branes $U(3)_a \times U(2)_b \times U(1)_c \times U(1)_d$

$I_{ab} = 1$ $I_{ab'} = 2$ $I_{ac} = -3$ $I_{ac'} = -3$

$I_{bd} = 0$ $I_{bd'} = -3$ $I_{cd} = -3$ $I_{cd'} = 3$

<u>Exercise.</u>

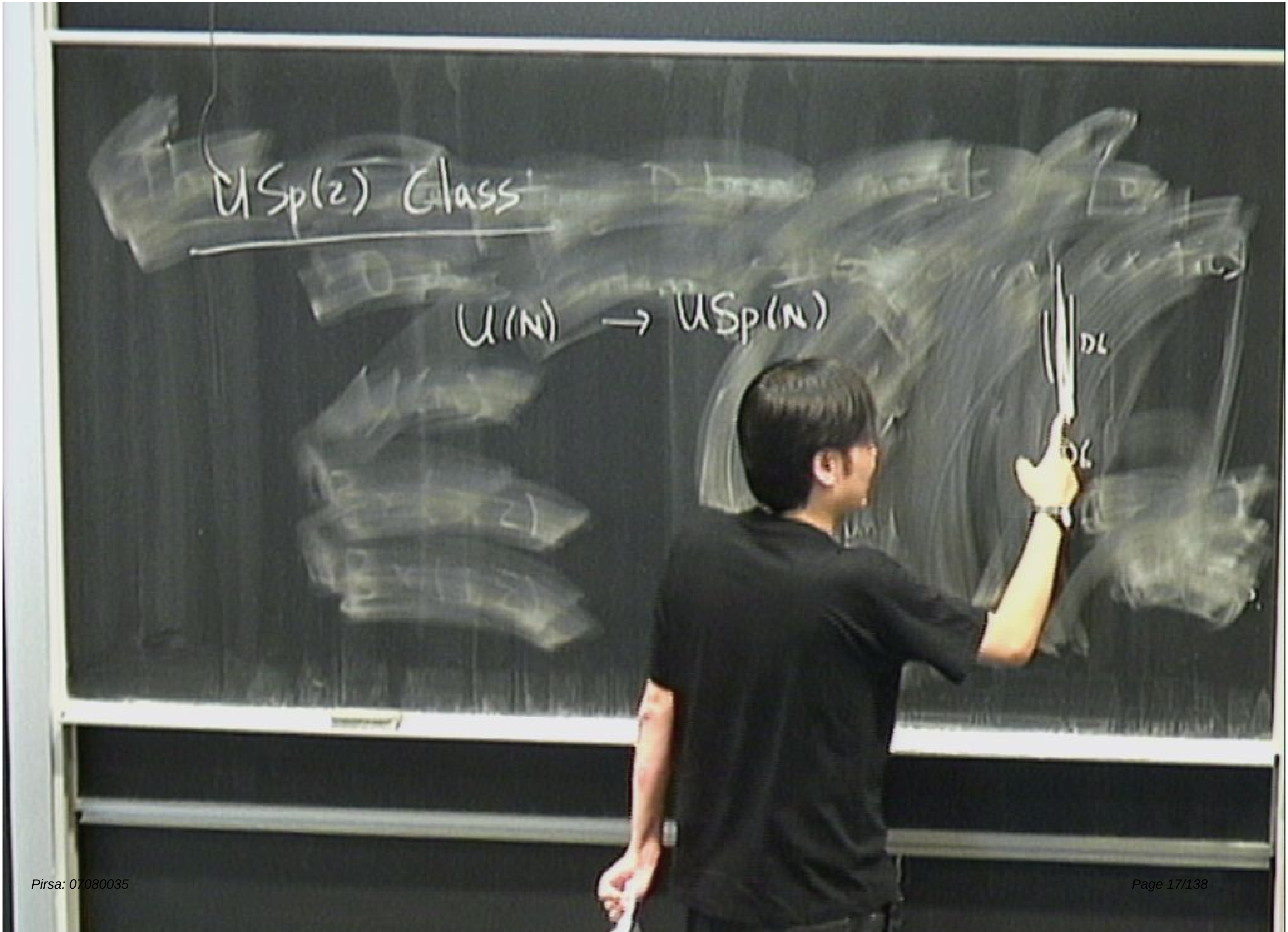
4 stacks of D-branes $U(3)_a \times U(2)_b \times U(1)_c \times U(1)_d$

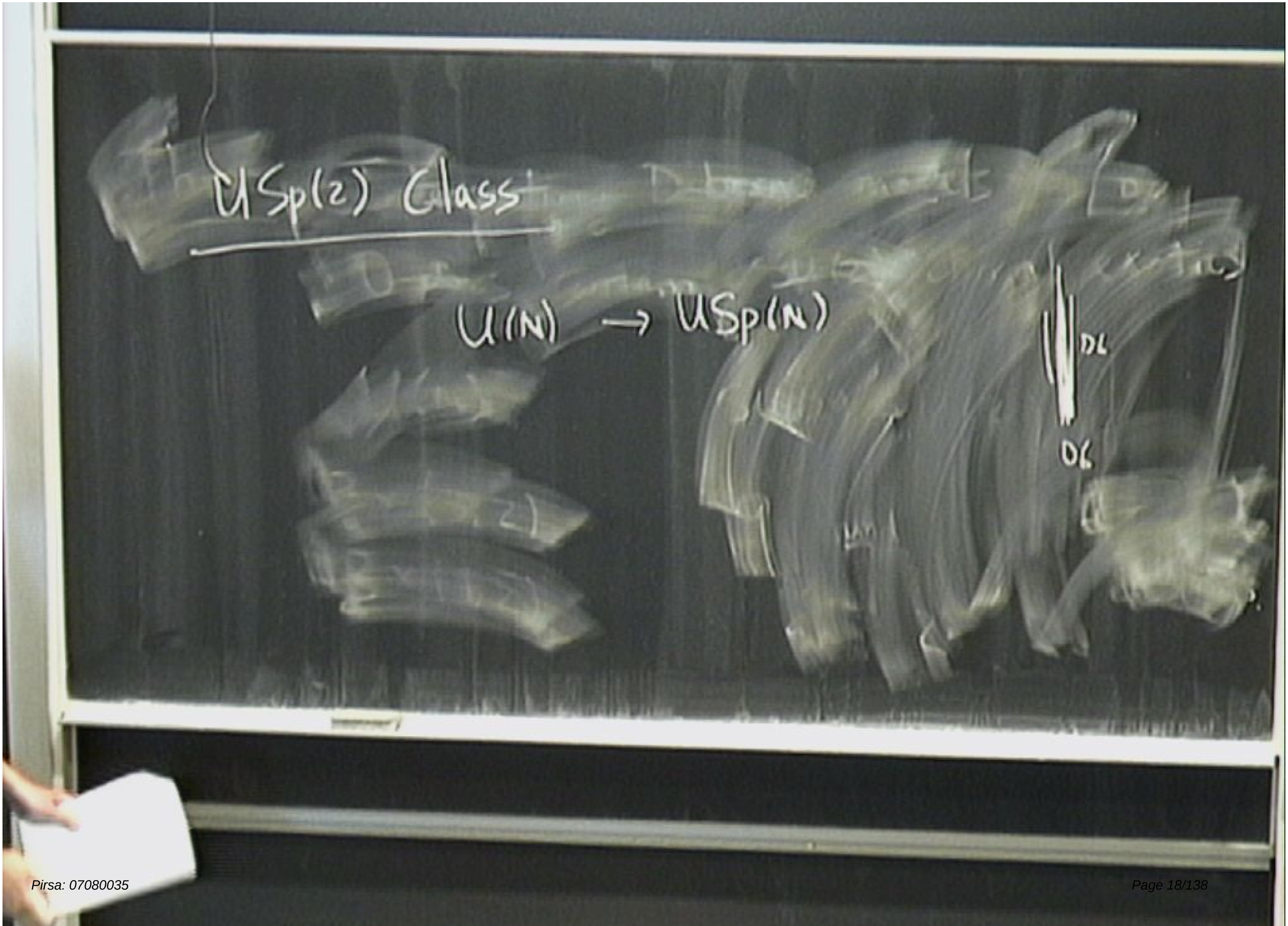
$I_{ab} = 1 \quad I_{ab'} = 2 \quad I_{ac} = -3 \quad I_{ac'} = -3$

$I_{bd} = 0 \quad I_{bd'} = -3 \quad I_{cd} = -3 \quad I_{cd'} = 3$

Exercise. SM spectrum + 3 RH neutrinos.

$$Q_Y = \frac{1}{6} Q_a - \frac{1}{2} Q_c + \frac{1}{2} Q_d.$$


USp(2) Class
U(N) → USp(N)


USp(2) Class
U(N) → USp(N)
D6
D6

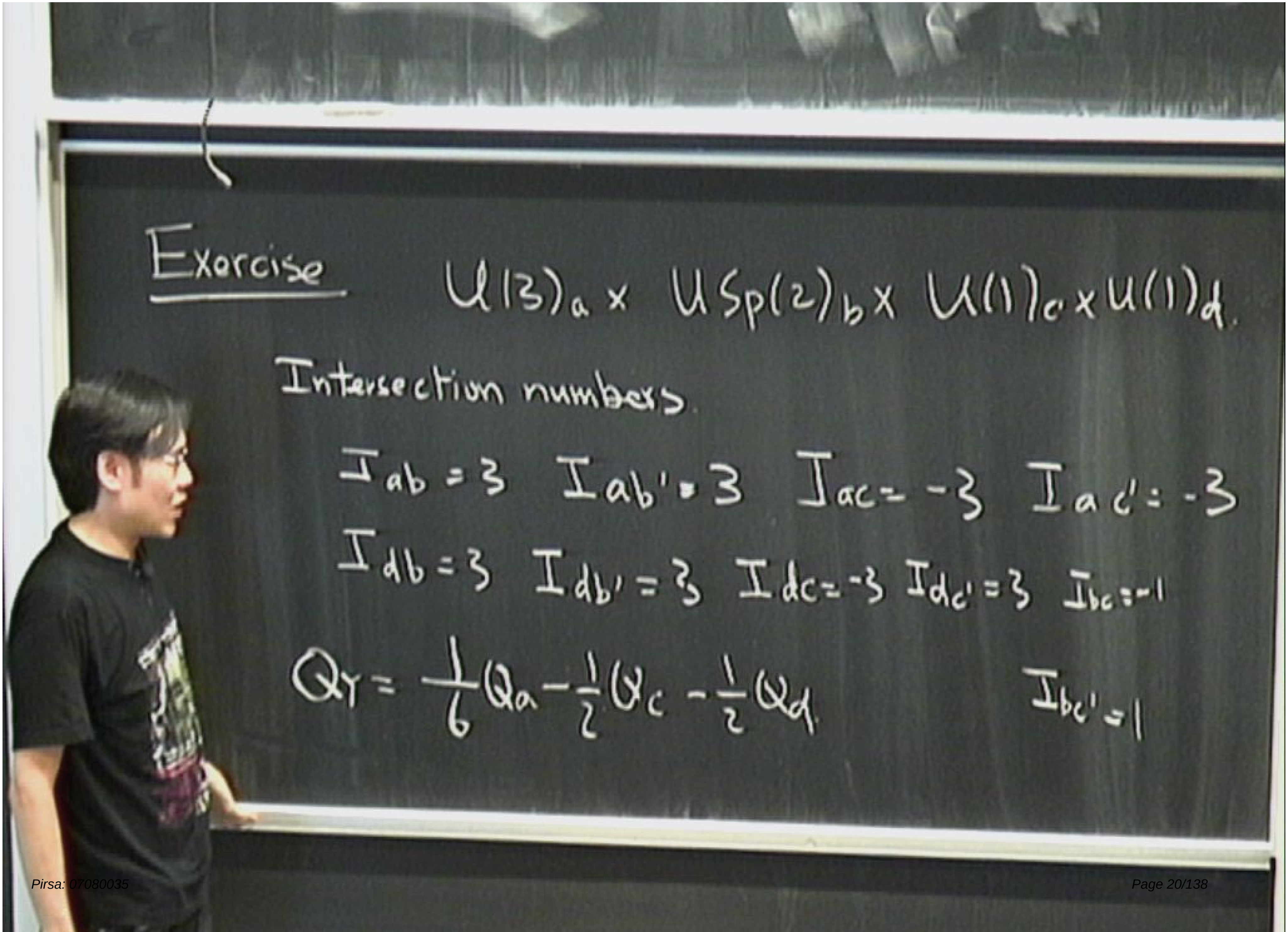
Exercise $U(3)_a \times USp(2)_b \times U(1)_c \times U(1)_d$.

Intersection numbers

$I_{ab} = 3 \quad I_{ab'} = 3 \quad I_{ac} = -3 \quad I_{ac'} = -3$

$I_{db} = 3 \quad I_{db'} = 3 \quad I_{dc} = -3 \quad I_{dc'} = 3 \quad I_{bc} = -1$

$I_{bc'} = 1$


Exercise
$U(3)_a \times USp(2)_b \times U(1)_c \times U(1)_d$.
Intersection numbers
$I_{ab} = 3$ $I_{ab'} = 3$ $I_{ac} = -3$ $I_{ac'} = -3$
$I_{db} = 3$ $I_{db'} = 3$ $I_{dc} = -3$ $I_{dc'} = 3$ $I_{bc} = -1$
$Q_Y = \frac{1}{6} Q_a - \frac{1}{2} Q_c - \frac{1}{2} Q_d$.
$I_{bc'} = 1$


Supersymmetric Compact Examples

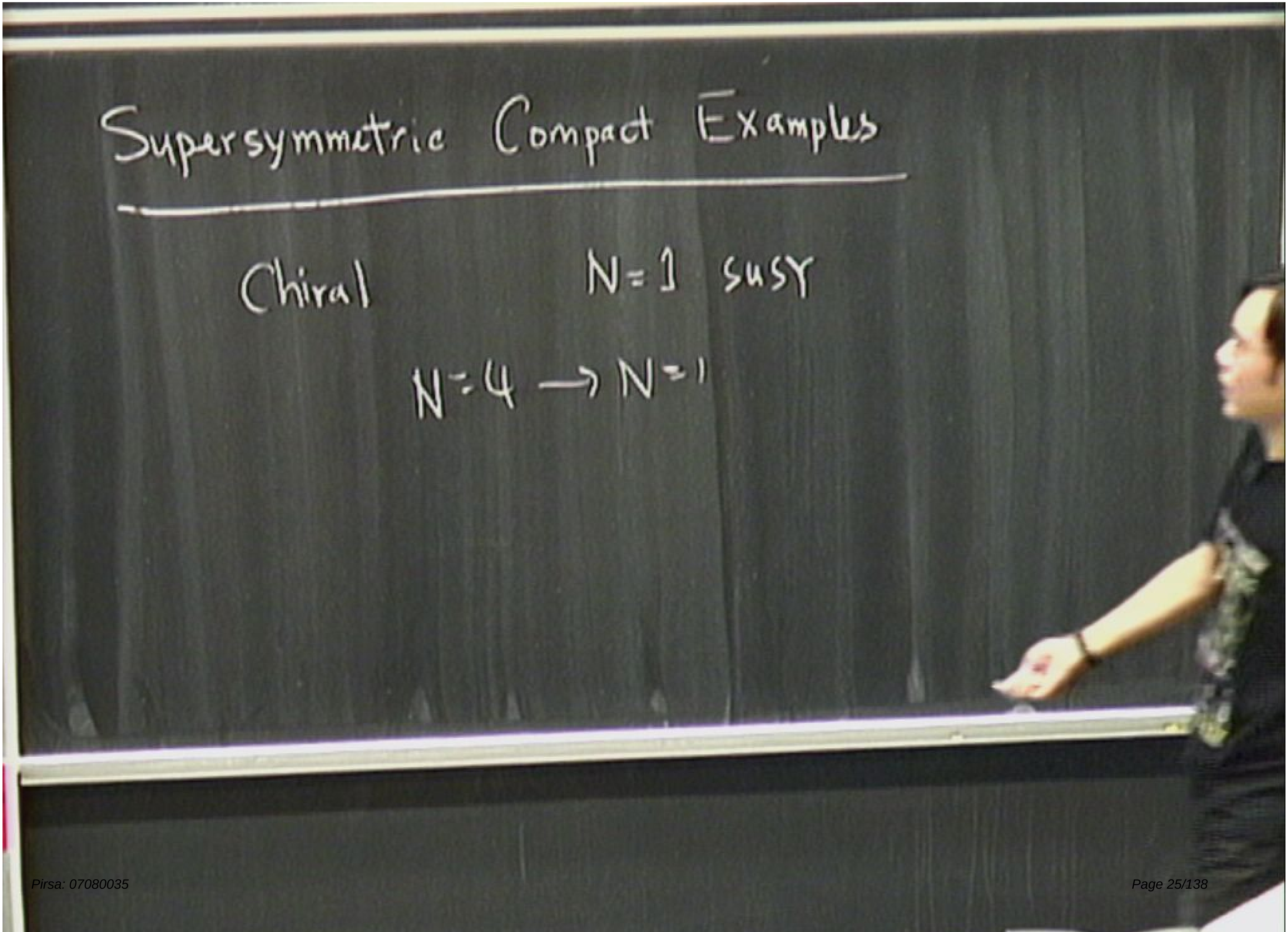
Supersymmetric Compact Examples

Supersymmetric Compact Examples

Chiral $\qquad$ $N=1$ susy

Supersymmetric Compact Examples

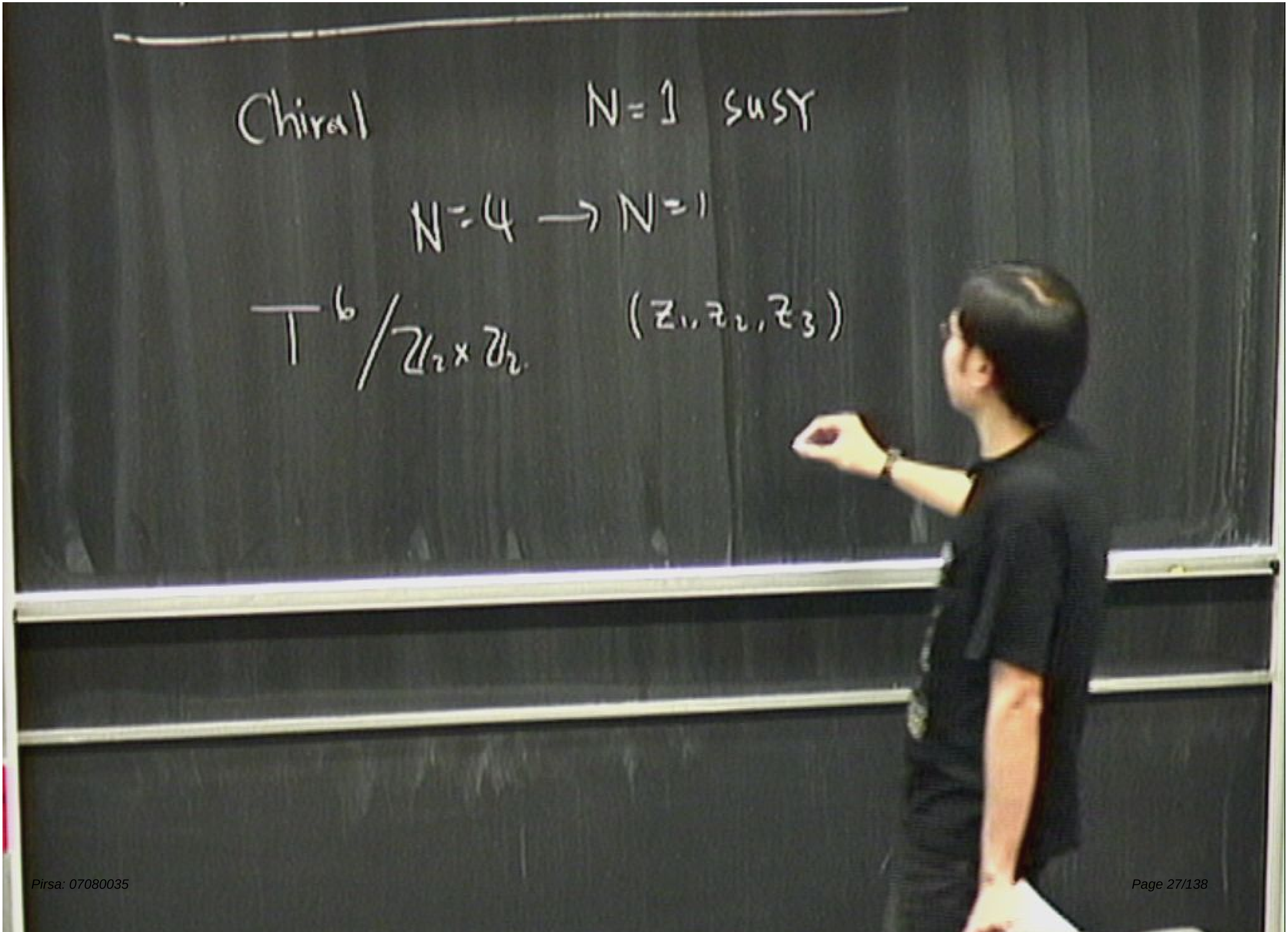
Chiral $\qquad$ $N=1$ SUSY


Supersymmetric Compact Examples
Chiral
N=1 susy
N=4 → N=1

Chiral $\qquad N=1$ susy

$N=4 \rightarrow N=1$

T^6


Chiral
N=1 susy
N=4 → N=1
T^6/Z_2 × Z_2
(z_1, z_2, z_3)

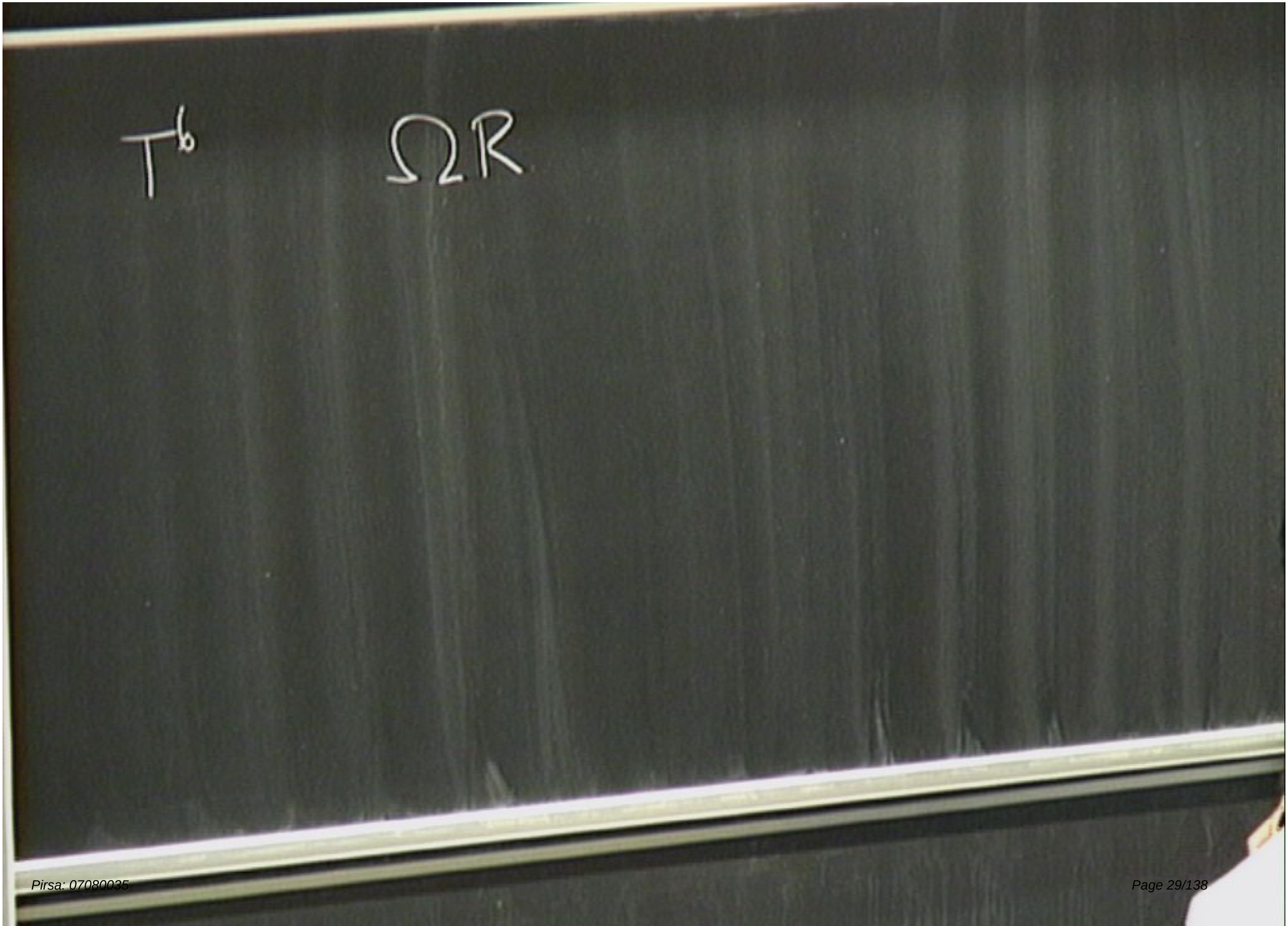
Chiral $\quad N=1$ susy

$$N=4 \longrightarrow N=1$$

$$T^6/\mathbb{Z}_2 \times \mathbb{Z}_2 \qquad (z_1, z_2, z_3)$$

$$\theta: (z_1, z_2, z_3) \rightarrow (-z_1, -z_2, z_3)$$

$$\omega: (z_1, z_2, z_3) \rightarrow (z_1, -z_2, -z_3)$$


T^6
ΩR

T^6 $\Omega R \to 06$

$T^{\flat}$

$\Omega R \to Ob$

$\Omega\bar{\bar{\sigma}}$

T^6 $\quad \Omega R \to O6$

$\Omega \bar{\bar{\sigma}}$

T^6

$\Omega R \to O6$

$\Omega \bar{\sigma}$

$\Omega R \theta$

$\Omega R w$

$\Omega R \theta w$

T^6

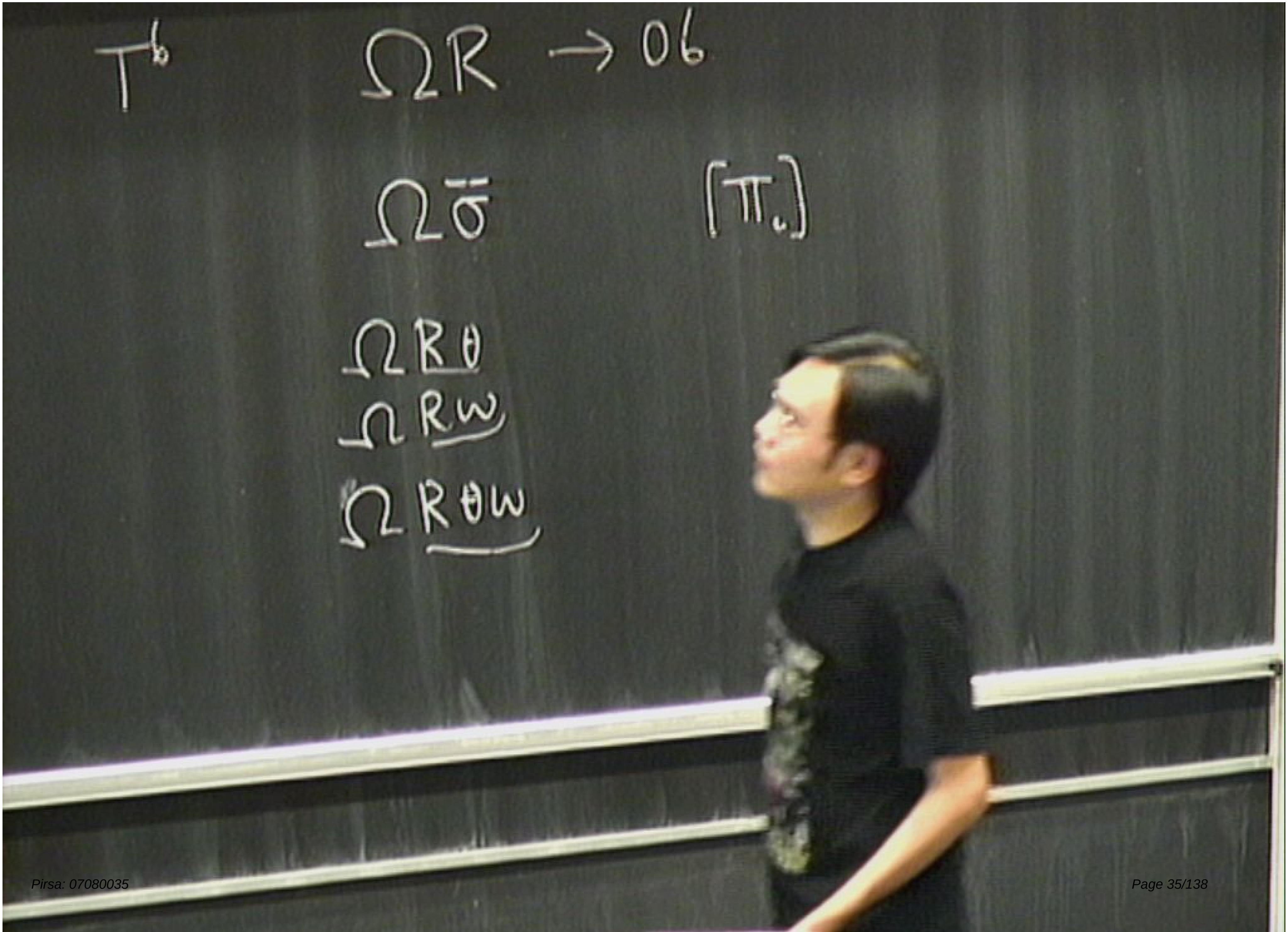
$\Omega R \to O6$

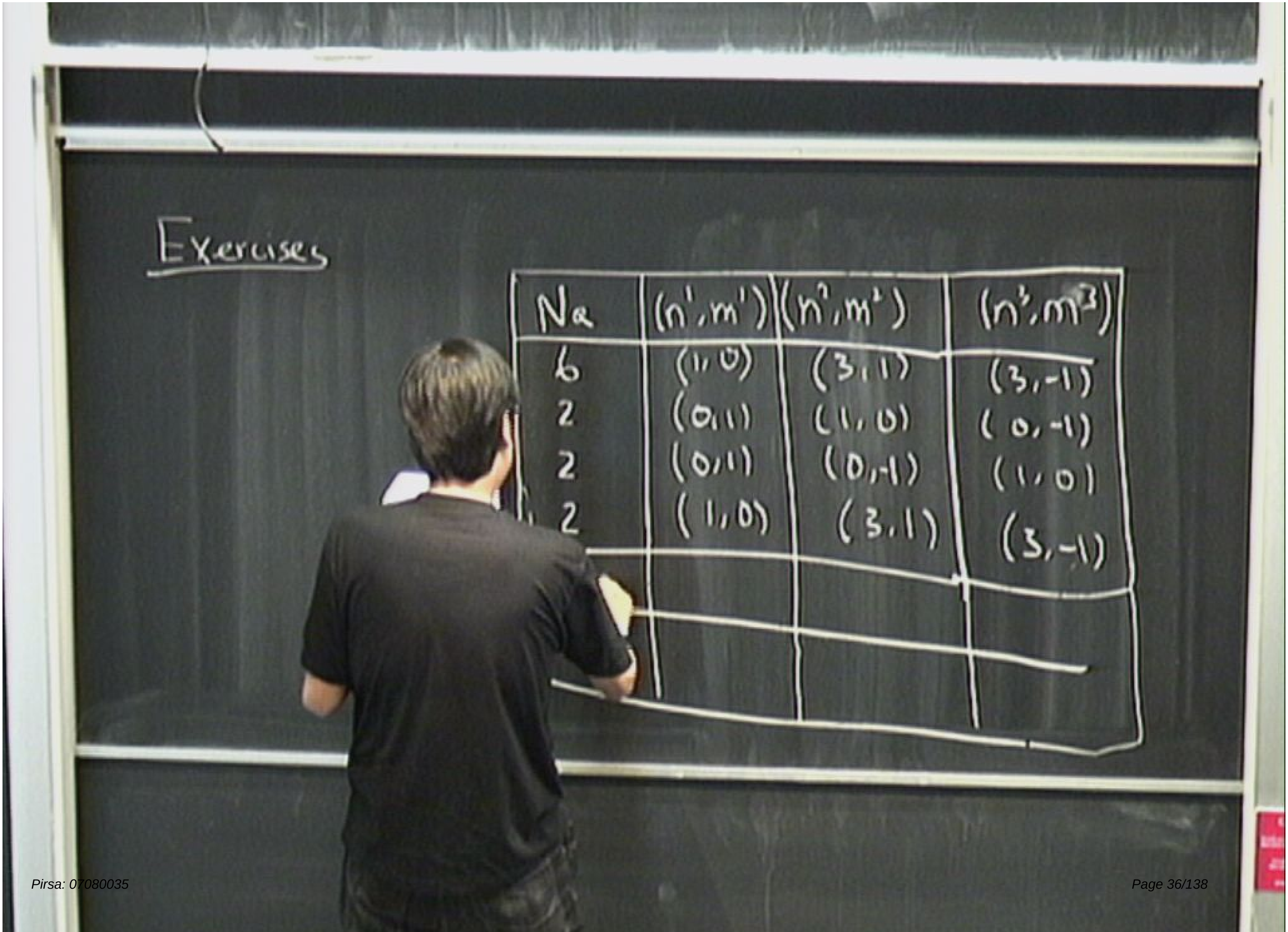
$\Omega \bar{\sigma}$ $[\pi]$

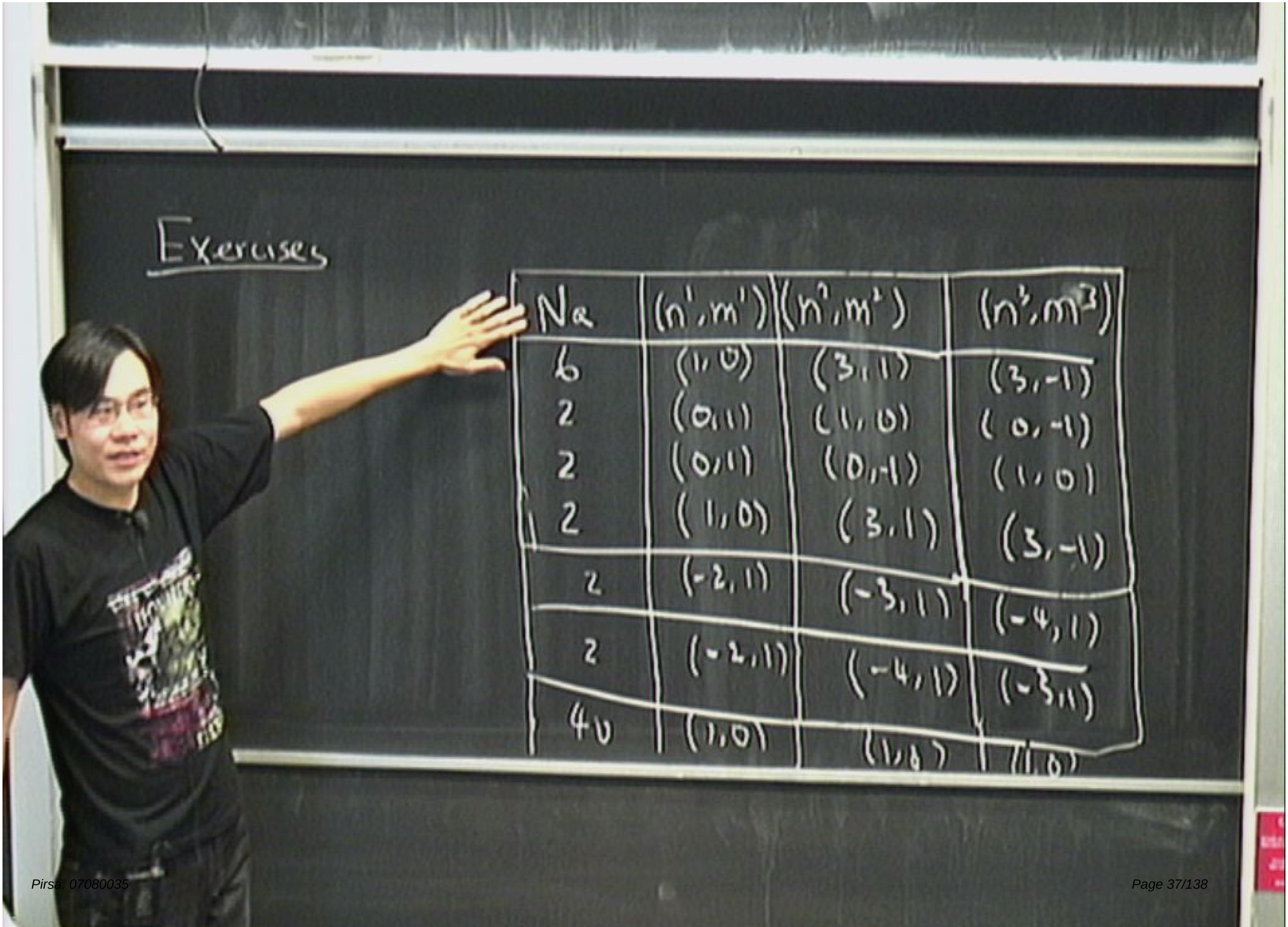
$\Omega \underline{R \theta}$

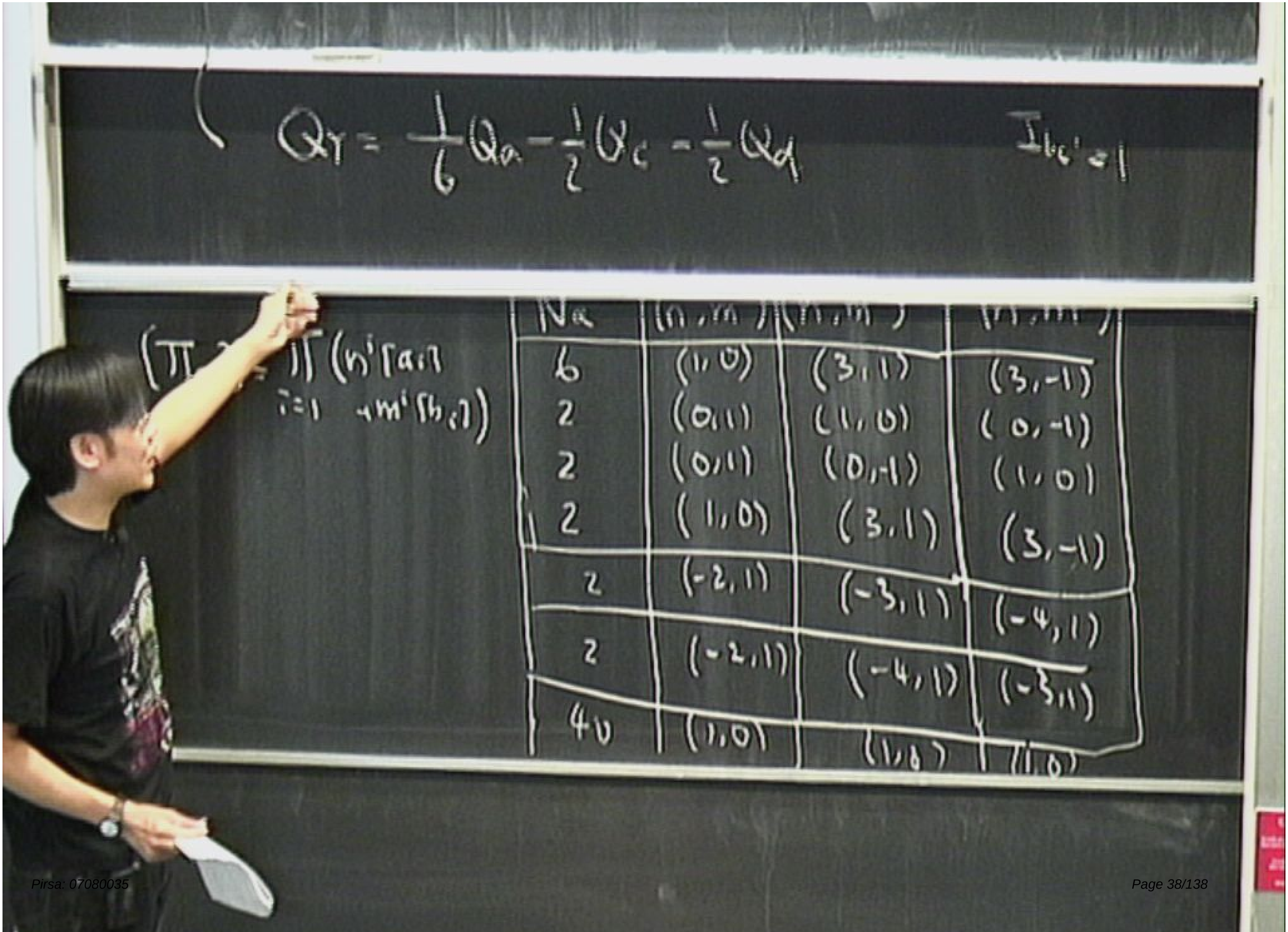
$\Omega \underline{R w}$

$\Omega \underline{R \theta w}$


ΩR → O6
ΩRθ
ΩRW
ΩRθW


Exercises
N_a
(n^1,m^1)
(n^2,m^2)
(n^3,m^3)
6 (1,0) (3,1) (3,-1)
2 (0,1) (1,0) (0,-1)
2 (0,1) (0,-1) (1,0)
2 (1,0) (3,1) (3,-1)


Exercises
Na (n¹,m¹) (n²,m²) (n³,m³)
6 (1,0) (3,1) (3,-1)
2 (0,1) (1,0) (0,-1)
2 (0,1) (0,-1) (1,0)
2 (1,0) (3,1) (3,-1)
2 (-2,1) (-3,1) (-4,1)
2 (-2,1) (-4,1) (-3,1)
4υ (1,0) (1,0) (1,0)


Qγ = 1/6 Qa − 1/2 Qc − 1/2 Qd
I_bc' = 1
Na
6 (1,0) (3,1) (3,−1)
2 (0,1) (1,0) (0,−1)
2 (0,1) (0,−1) (1,0)
2 (1,0) (3,1) (3,−1)
2 (−2,1) (−3,1) (−4,1)
2 (−2,1) (−4,1) (−3,1)
4υ (1,0) (1,0) (1,0)

$$Q_Y = \frac{1}{6}Q_a - \frac{1}{2}Q_c - \frac{1}{2}Q_d \qquad I_{bc'} = 1$$

Exercise

$$(\Pi_a) = \prod_{i=1}^{3}\left(n^i[a_i] + m^i[b_i]\right)$$

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(3, 1)	(3, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(3, 1)	(3, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
4υ	(1, 0)	(1, 0)	(1, 0)

$Q_Y = \frac{1}{6} Q_a - \frac{1}{2} Q_c - \frac{1}{2} Q_d$

a) $(\Pi_a) = \prod_{i=1}^{3} (n^i [a_i] + m^i [b_i])$

b)

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(3, 1)	(3, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(3, 1)	(3, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
4v	(1, 0)	(1, 0)	(1, 0)

$Q_Y = \frac{1}{6} Q_a - \frac{1}{2} Q_c - \frac{1}{2} Q_d$

$I_{bc'} = 1$

Exercises

a) $(\Pi_a) = \prod_{i=1}^{3} (n^i [a_i] + m^i [b_i])$

Satisfies RR tadpoles

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(3, 1)	(3, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(3, 1)	(3, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
4v	(1, 0)	(1, 0)	(1, 0)

$Q_Y = \frac{1}{6} Q_a - \frac{1}{2} Q_c - \frac{1}{2} Q_d$ $\qquad I_{bc'} = 1$

Exercises

a) $(\Pi_a) = \prod_{i=1}^{3} (n^i [a_i] + m^i [b_i])$

Satisfies RR tadpoles

b)

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(3, 1)	(3, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(3, 1)	(3, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
4ν	(1, 0)	(1, 0)	(1, 0)

$$Q_Y = \frac{1}{6}Q_a - \frac{1}{2}Q_c - \frac{1}{2}Q_d \qquad I_{bc'} = 1$$

Exercises

a) $(\Pi_a) = \prod_{i=1}^{3} (n^i [a_i] + m^i [b_i])$

Satisfies RR tadpoles

b) Compute Chiral Spectrum

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1,0)	(3,1)	(3,-1)
2	(0,1)	(1,0)	(0,-1)
2	(0,1)	(0,-1)	(1,0)
2	(1,0)	(3,1)	(3,-1)
2	(-2,1)	(-3,1)	(-4,1)
2	(-2,1)	(-4,1)	(-3,1)
4v	(1,0)	(1,0)	(1,0)

$Q_Y = \frac{1}{6} Q_a - \frac{1}{2} Q_c - \frac{1}{2} Q_d$ $\quad \ldots = 1$

Exercises

a) $(\Pi_a) = \prod_{i=1}^{3} (n^i [a_i] + m^i [b_i])$

Satisfies RR tadpoles

b) Compute Chiral Spectrum

c)

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(3, 1)	(3, −1)
2	(0, 1)	(1, 0)	(0, −1)
2	(0, 1)	(0, −1)	(1, 0)
2	(1, 0)	(3, 1)	(3, −1)
2	(−2, 1)	(−3, 1)	(−4, 1)
2	(−2, 1)	(−4, 1)	(−3, 1)
4υ	(1, 0)	(1, 0)	(1, 0)

$Q_Y = \frac{1}{6} Q_a - \frac{1}{2} Q_c - \frac{1}{2} Q_d$

$I_{bc'} = 1$

Exercises

a) $(\Pi_a) = \prod_{i=1}^{3} (n^i [a_i] + m^i [b_i])$

Satisfies RR tadpoles

b) Compute Chiral Spectrum

c) $\chi_1 = \frac{R_2}{R_1}$

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(3, 1)	(3, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(3, 1)	(3, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
4v	(1, 0)	(1, 0)	(1, 0)

$Q_Y = \frac{1}{6} Q_a - \frac{1}{2} Q_c - \frac{1}{2} Q_d$

$\# b_c' = 1$

Exercises

a) $[\Pi_a] = \prod_{i=1}^{3} (n^i [a_i] + m^i [b_i])$

Satisfies RR tadpoles

b) Compute Chiral Spectrum

c) $\chi = \frac{R_2}{R_1}$

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(3, 1)	(3, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(3, 1)	(3, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
40	(1, 0)	(1, 0)	(1, 0)

$$Q_Y = \frac{1}{6}Q_a - \frac{1}{2}Q_c - \frac{1}{2}Q_d \qquad I_{bc'} = 1$$

Exercises

a) $(\Pi_a) = \prod_{i=1}^{3} \left(n^i [a_i] + m^i [b_i]\right)$

Satisfies RR tadpoles

b) Compute Chiral Spectrum

c) $\chi_i = \left(\frac{R_2}{R_1}\right)_i$

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(3, 1)	(3, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(3, 1)	(3, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
40	(1, 0)	(1, 0)	(1, 0)

Supersymmetric Compact Examples

Chiral $\qquad$ $N=1$ susy

$$N=4 \rightarrow N=1$$

$$T^6 / Z_2 \times Z_2 \qquad (z_1, z_2, z_3)$$

$$\theta : (z_1, z_2, z_3) \rightarrow (-z_1, -z_2, z_3)$$

$$\omega : (z_1, z_2, z_3) \rightarrow (z_1, -z_2, -z_3)$$

$Q_Y = \frac{1}{6} Q_a - \frac{1}{2} Q_c - \frac{1}{2} Q_d$ $\qquad I_{bc'} = 1$

Exercises

a) $(\Pi_a) = \prod_{i=1}^{3} \left(n^i [a_i] + m^i [b_i] \right)$

Satisfies RR-tadpoles

b) Compute Chiral Spectrum

c) $\chi_i = \left(\frac{R_2}{R_1} \right)_i$

d) U(1)-gravitational anomaly

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(3, 1)	(3, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(3, 1)	(3, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
4υ	(1, 0)	(1, 0)	(1, 0)

Exercises

a) $(\Pi_a) = \prod_{i=1}^{3} (n^i [a_i] + m^i [b_i])$ R_2 □ R_1

Satisfies RR tadpoles

b) Compute Chiral Spectrum

c) $\chi_1 = \left(\frac{R_2}{R_1}\right)_i$

d) U(1)-gravitational anomaly

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(3, 1)	(3, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(3, 1)	(3, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
4υ	(1, 0)	(1, 0)	(1, 0)

Supersymmetric Compact Examples

Chiral $\qquad$ $N=1$ susy

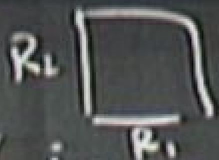
$$N=4 \rightarrow N=1$$

$T^6/\mathbb{Z}_2 \times \mathbb{Z}_2 \qquad (z_1, z_2, z_3)$

$$\theta: (z_1, z_2, z_3) \rightarrow (-z_1, -z_2, z_3)$$

$$\omega: (z_1, z_2, z_3) \rightarrow (z_1, -z_2, -z_3)$$

Exercises



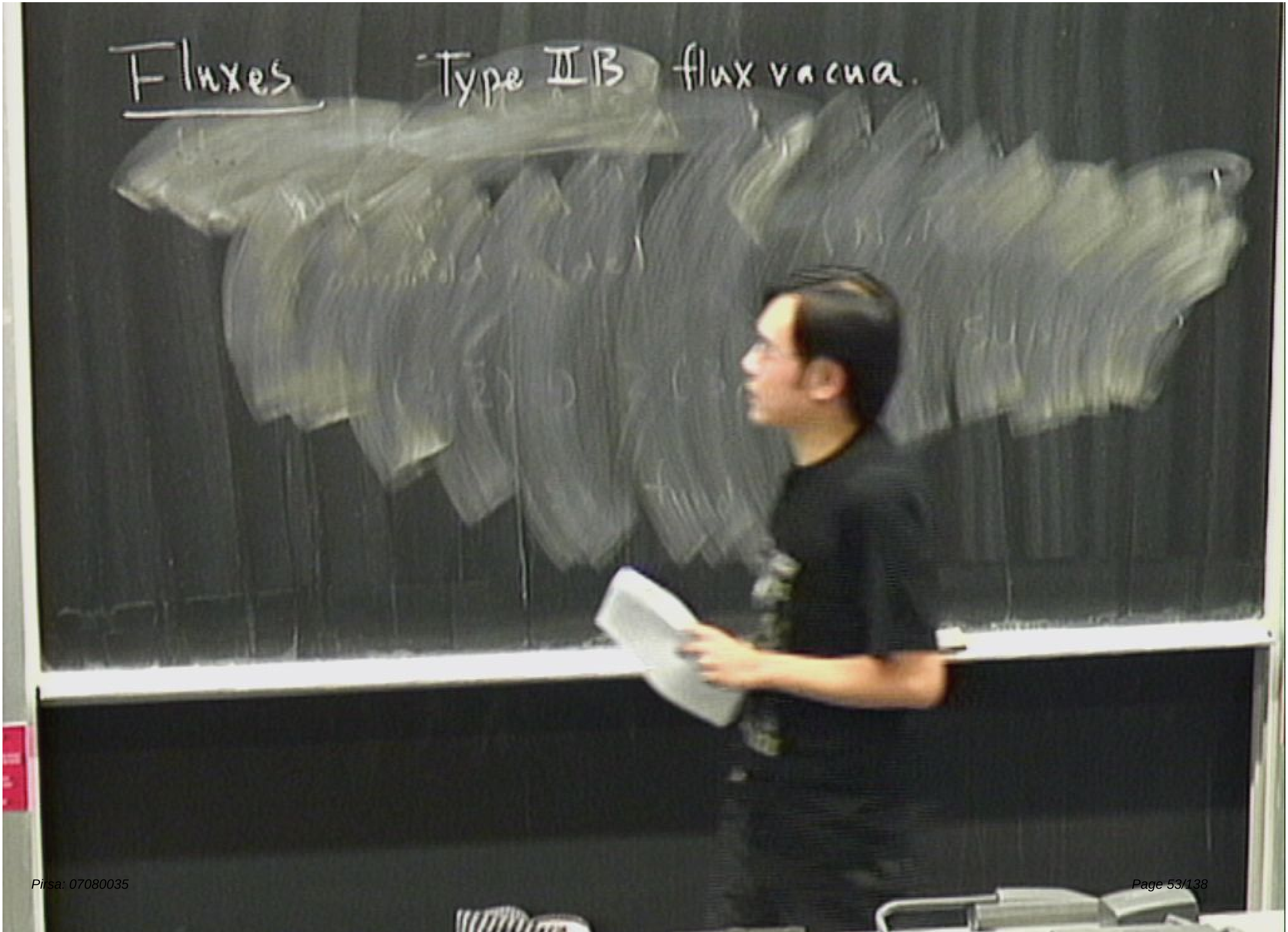
$$I(\Pi_a) = \prod_{i=1}^{3} \left(n^i [a_i] + m^i [b_i]\right)$$

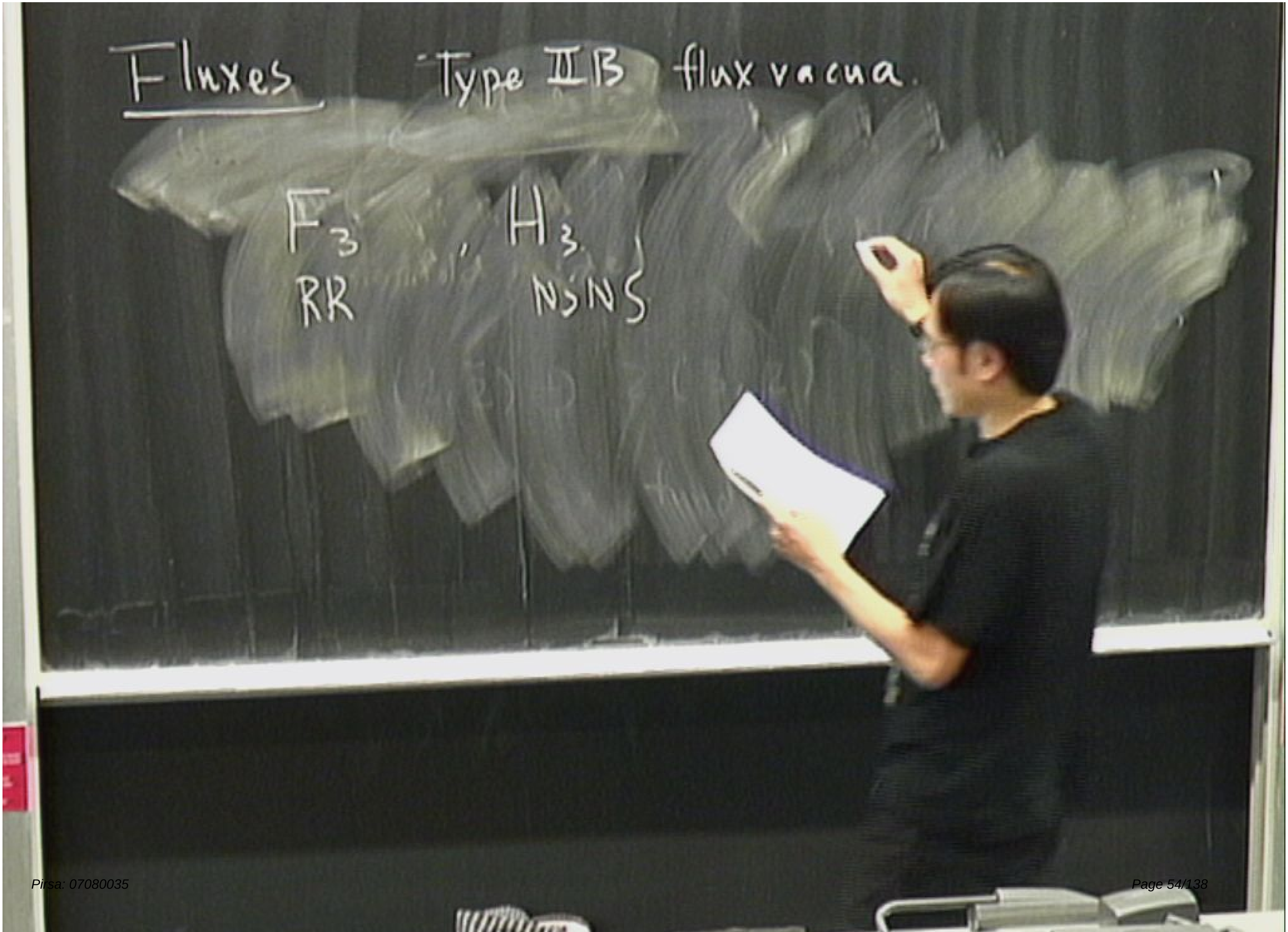
- Satisfies RR-tadpoles
- Compute Chiral Spectrum

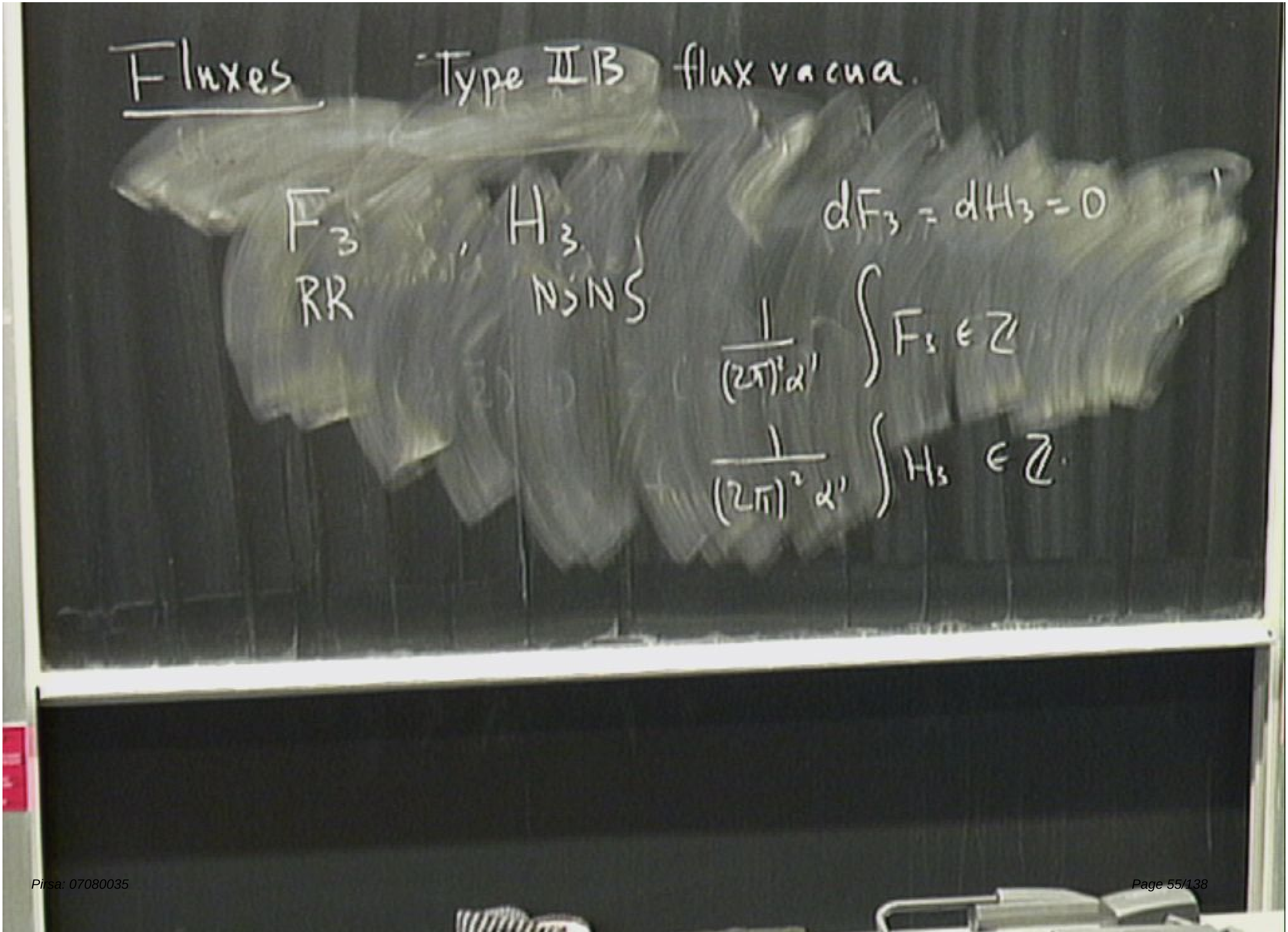
$$\chi_i = \left(\frac{R_2}{R_1}\right)_i$$

- U(1)-gravitational anomaly

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(3, 1)	(3, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(3, 1)	(3, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
40	(1, 0)	(1, 0)	(1, 0)

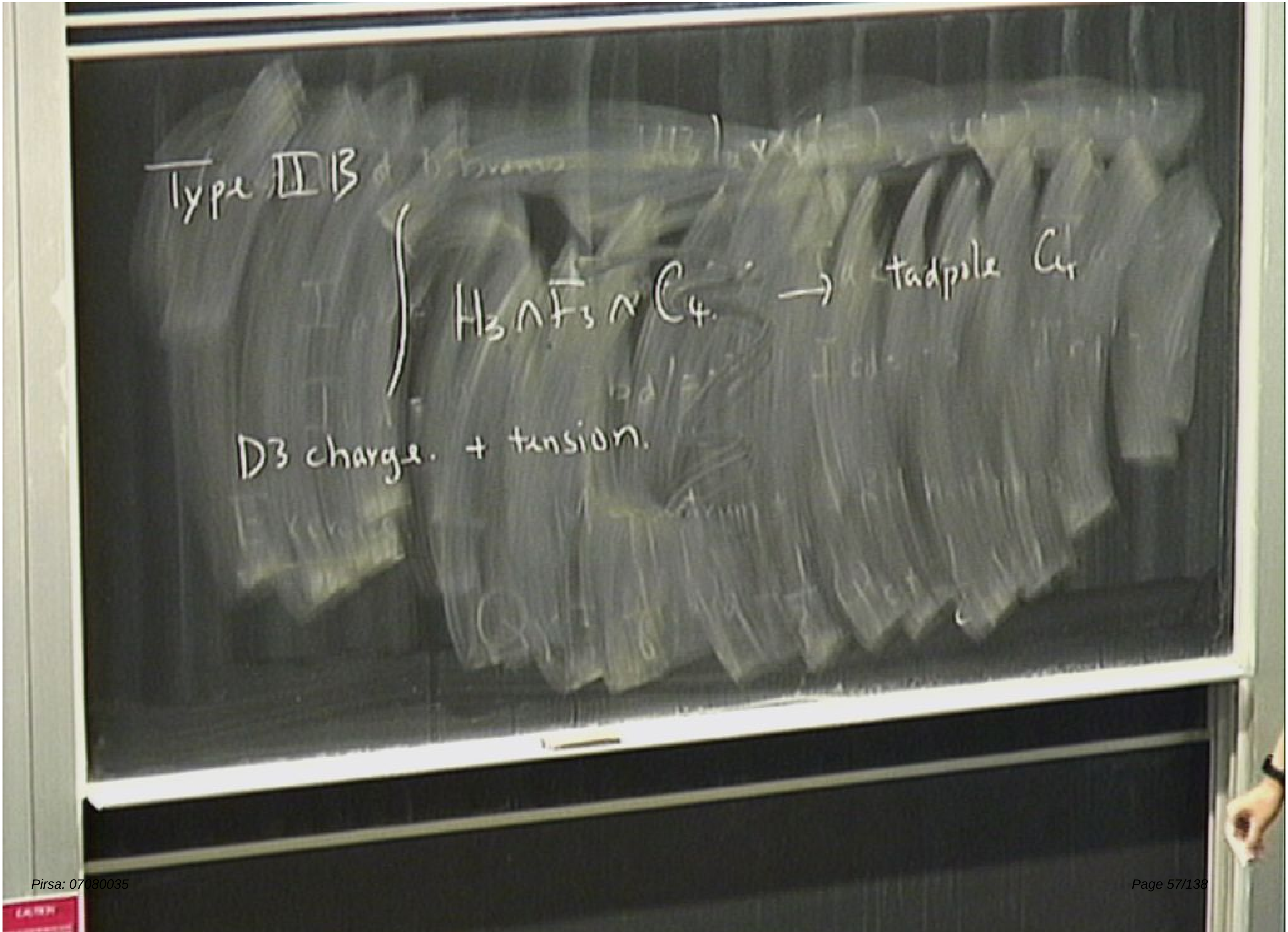

Fluxes
Type IIB flux vacua.

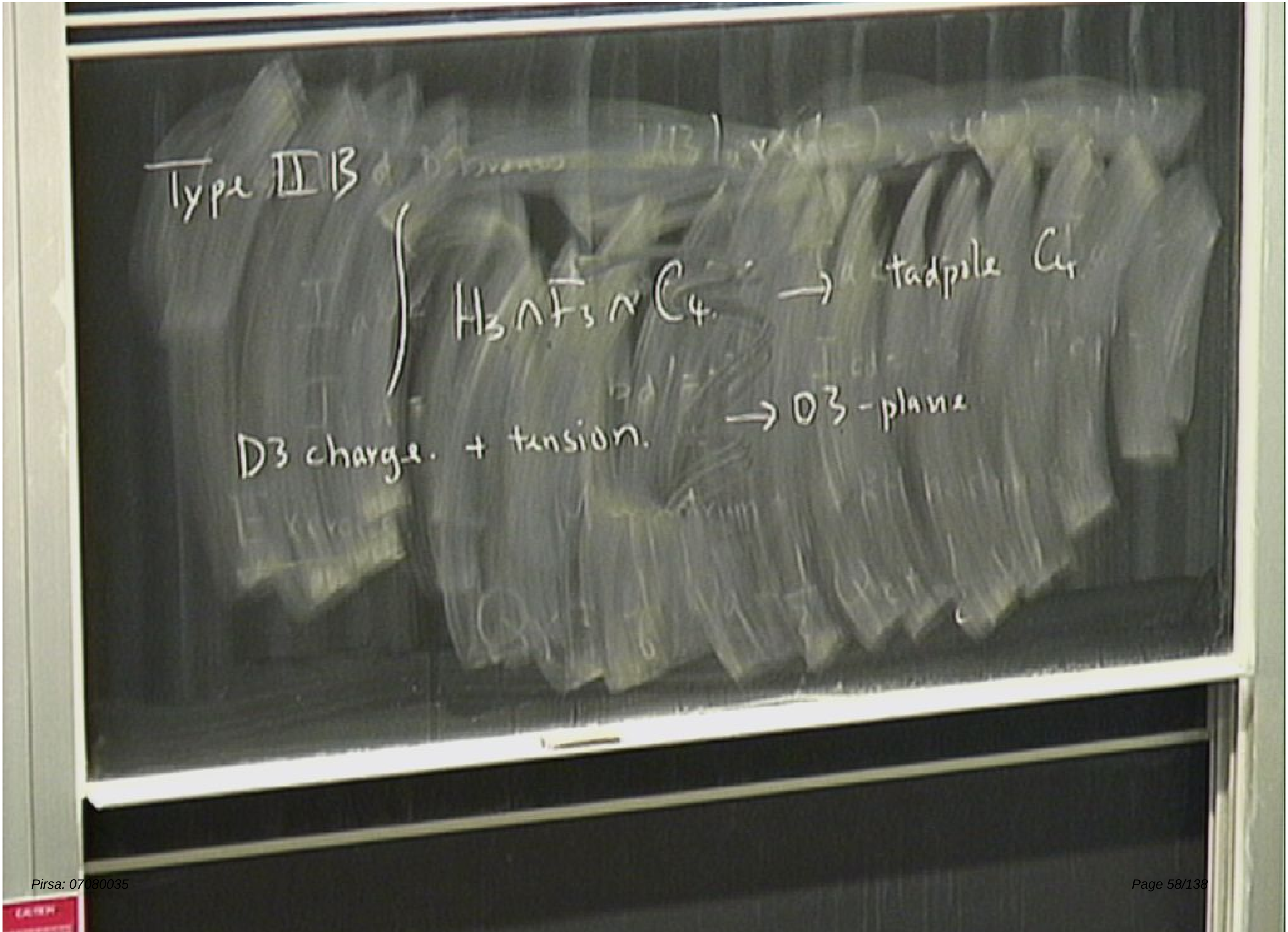

Fluxes
Type IIB flux vacua
F_3, H_3
RR NSNS

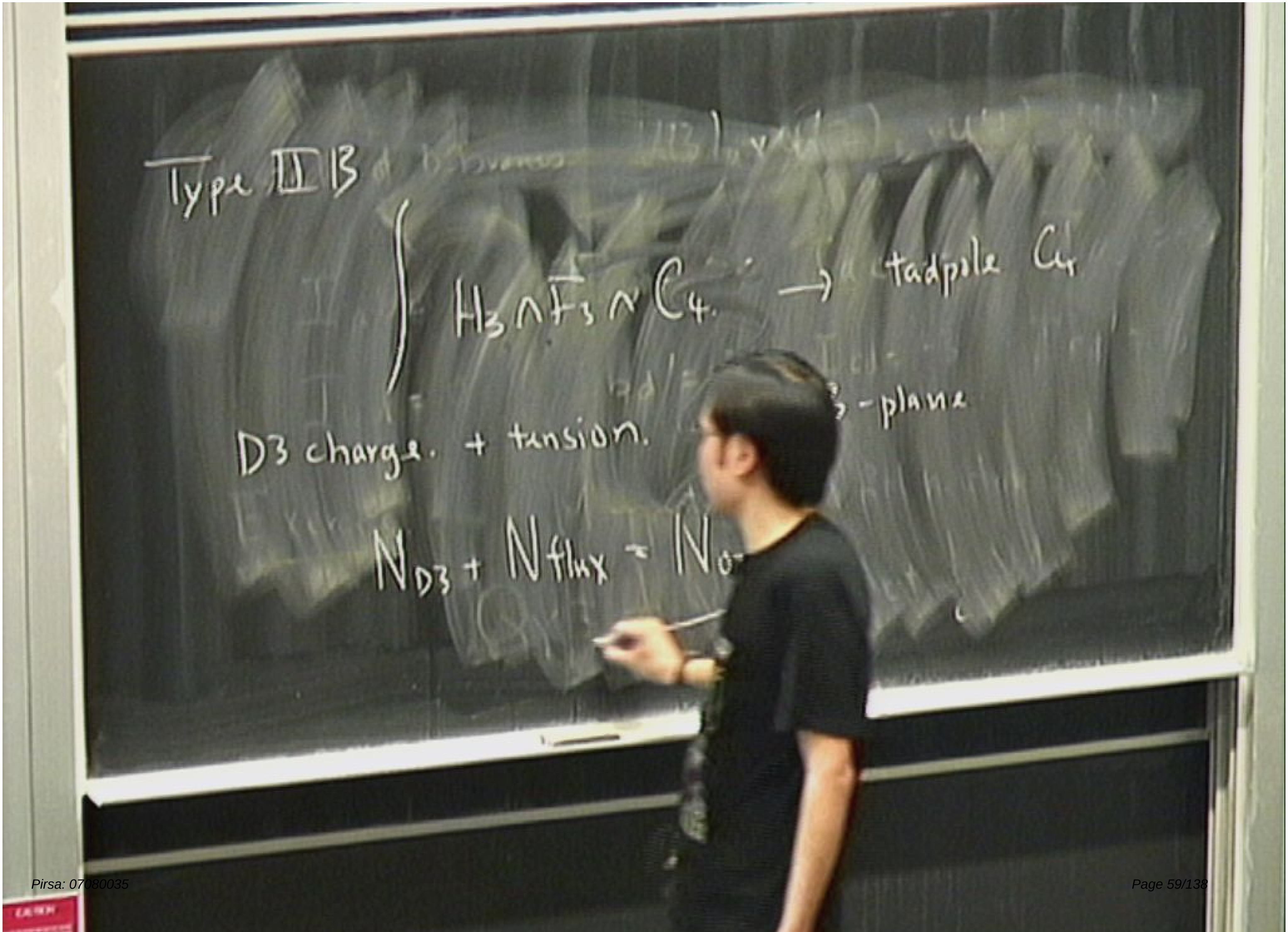

Fluxes
Type IIB flux vacua
F_3 , H_3
RR NSNS
$dF_3 = dH_3 = 0$
$\frac{1}{(2\pi)^2\alpha'}\int F_3 \in \mathbb{Z}$
$\frac{1}{(2\pi)^2\alpha'}\int H_3 \in \mathbb{Z}$

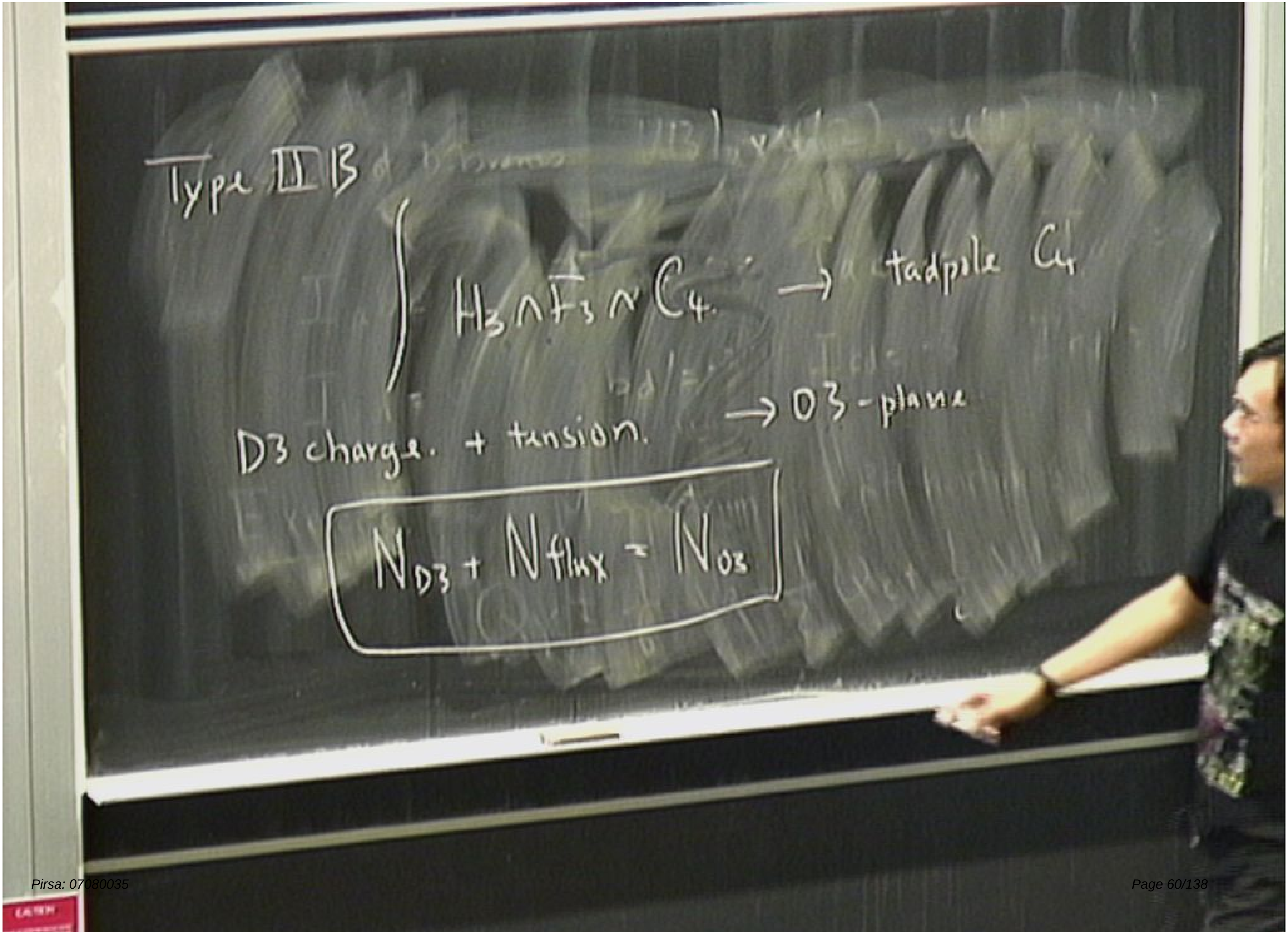
Type IIB

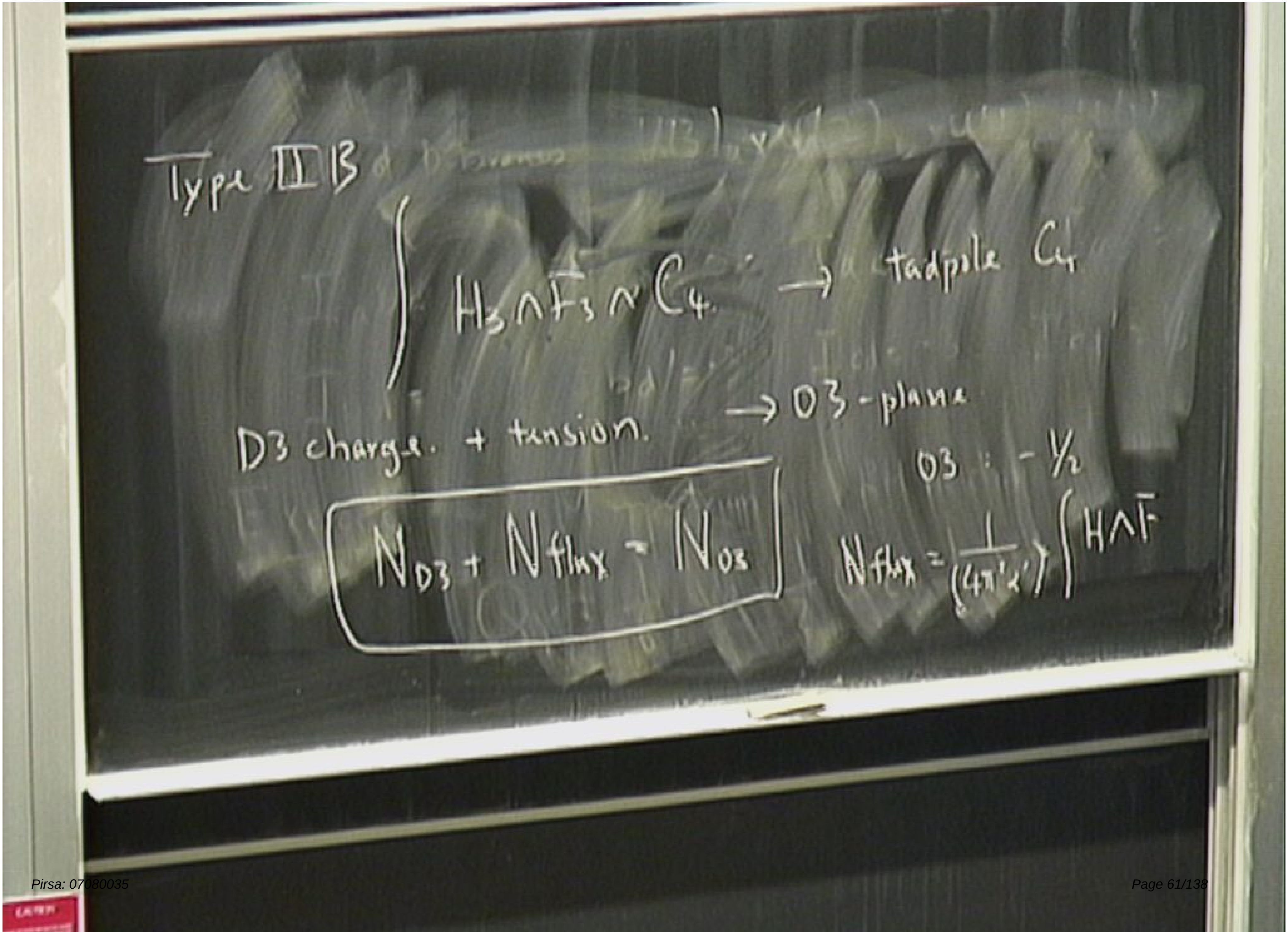
$\int H_3 \wedge F_3 \wedge C_4 \longrightarrow$ tadpole C_4

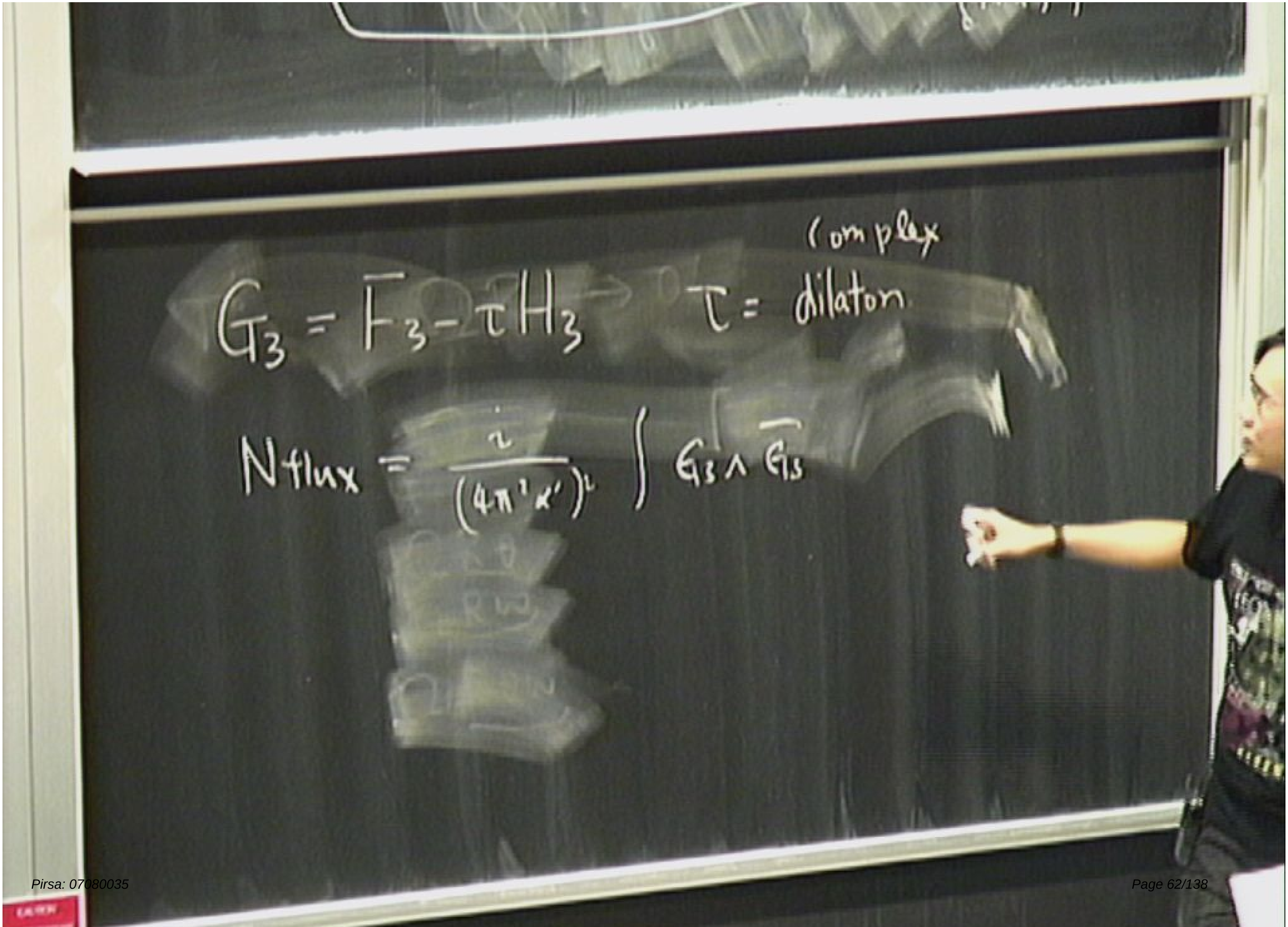

Type IIB
∫ H3 ∧ F3 ∧ C4 → tadpole C4
D3 charge + tension.


Type IIB
∫ H3 ∧ F3 ∧ C4 → tadpole C4
D3 charge + tension
→ O3-plane


Type IIB
∫ H3 ∧ F3 ∧ C4 → tadpole C4
-plane
D3 charge + tension.
N D3 + N flux =


Type IIB
∫ H3 ∧ F3 ∧ C4 → tadpole C4
D3 charge + tension → O3-plane
N_D3 + N_flux = N_O3


Type IIB
$\int H_3 \wedge F_3 \wedge C_4 \rightarrow$ tadpole C_4
$\rightarrow$ O3-plane
D3 charge + tension.
O3 : $-\frac{1}{2}$
$N_{D3} + N_{flux} = N_{O3}$
$N_{flux} = \frac{1}{(4\pi^2\alpha')} \int H \wedge F$


complex
G3 = F3 - τH3
τ = dilaton
Nflux = 2/(4π²α')² ∫ G3 ∧ Ḡ3

$$N_{D3} + N_{flux} = N_{O3} \qquad N_{flux} = \frac{1}{(4\pi^2\alpha')^2}\int H\wedge F$$

complex

$$G_3 = F_3 - \tau H_3 \qquad \tau = \text{dilaton}$$

$$N_{flux} = \frac{i}{(4\pi^2\alpha')^2}\int G_3 \wedge \bar{G}_3$$

$$N_{D3} + N_{flux} = N_{O3}$$

$$N_{flux} = \frac{1}{(4\pi^2\alpha')} \int H \wedge F$$

$$G_3 = F_3 - \tau H_3 \qquad \tau = \text{complex dilaton}$$

$$N_{flux} = \frac{i}{(4\pi^2\alpha')^2} \int G_3 \wedge \bar{G}_3$$

$$*_6 G_3 = i\, G_3$$

$$\boxed{N_{D3} + N_{flux} = N_{O3}} \qquad N_{flux} = \frac{1}{(4\pi^2\alpha')^2} \int H \wedge F$$

$$G_3 = F_3 - \tau H_3 \qquad \tau = \text{complex dilaton}$$

$$N_{flux} = \frac{i}{(4\pi^2\alpha')^2} \int G_3 \wedge \bar{G}_3$$

$$*_6 G_3 = i\, G_3 \qquad W = \int G_3 \wedge \Omega$$

$$N_{D3} + N_{flux} = N_{O3}$$

$$N_{flux} = \frac{1}{(4\pi^2\alpha')} \int H \wedge F$$

$$G_3 = F_3 - \tau H_3 \qquad \tau = \text{complex dilaton}$$

$$N_{flux} = \frac{i}{(4\pi^2\alpha')^2} \int G_3 \wedge \bar{G}_3$$

$$*_6\, G_3 = i\, G_3 \qquad W = \int G_3 \wedge \Omega$$

$$\downarrow$$

$$(2,1) + (0,3)$$

$$N_{D3} + N_{flux} = N_{O3} \qquad N_{flux} = \frac{1}{(4\pi^2\alpha')} \int H \wedge F$$

$$N_{flux} = \frac{2}{(4\pi^2\alpha')^2} \int G_3 \wedge \overline{G_3}$$

$$*_6 G_3 = i\, G_3 \qquad W = \int G_3 \wedge \Omega$$

$$\downarrow$$

$$\underline{(2,1)} + (0,3) \qquad D_\rho W \sim W \sim \int G_7 \wedge \Omega$$

$$N_{D3} + N_{flux} = N_{O3} \qquad N_{flux} = \frac{1}{(4\pi^2\alpha')} \int H \wedge F$$

$$N_{flux} = \frac{\tau}{(4\pi^2\alpha')^2} \int G_3 \wedge \overline{G_3}$$

$$*_6 G_3 = i \, G_3 \qquad W = \int G_3 \wedge \Omega$$

$$(2,1) + (0,3) \qquad D_\rho W \sim W \sim \int G_3 \wedge \Omega$$

(2,1) → SUSY

(0,3) → breaks SUSY (preserve no scale structure)

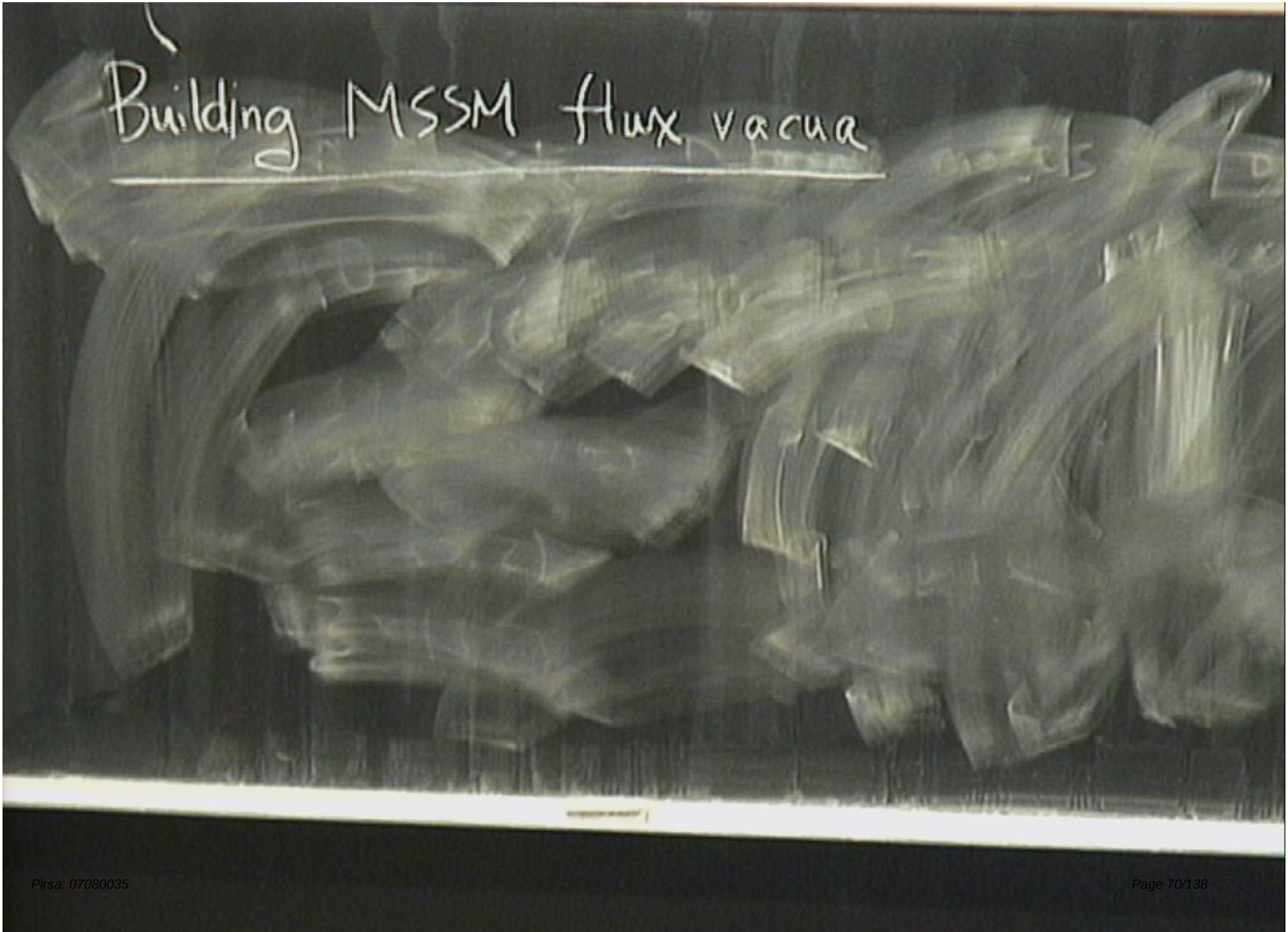
$N_{D3} + N_{flux} = N_{O3}$ $N_{flux} = \frac{1}{(4\pi^2\alpha')}\int$

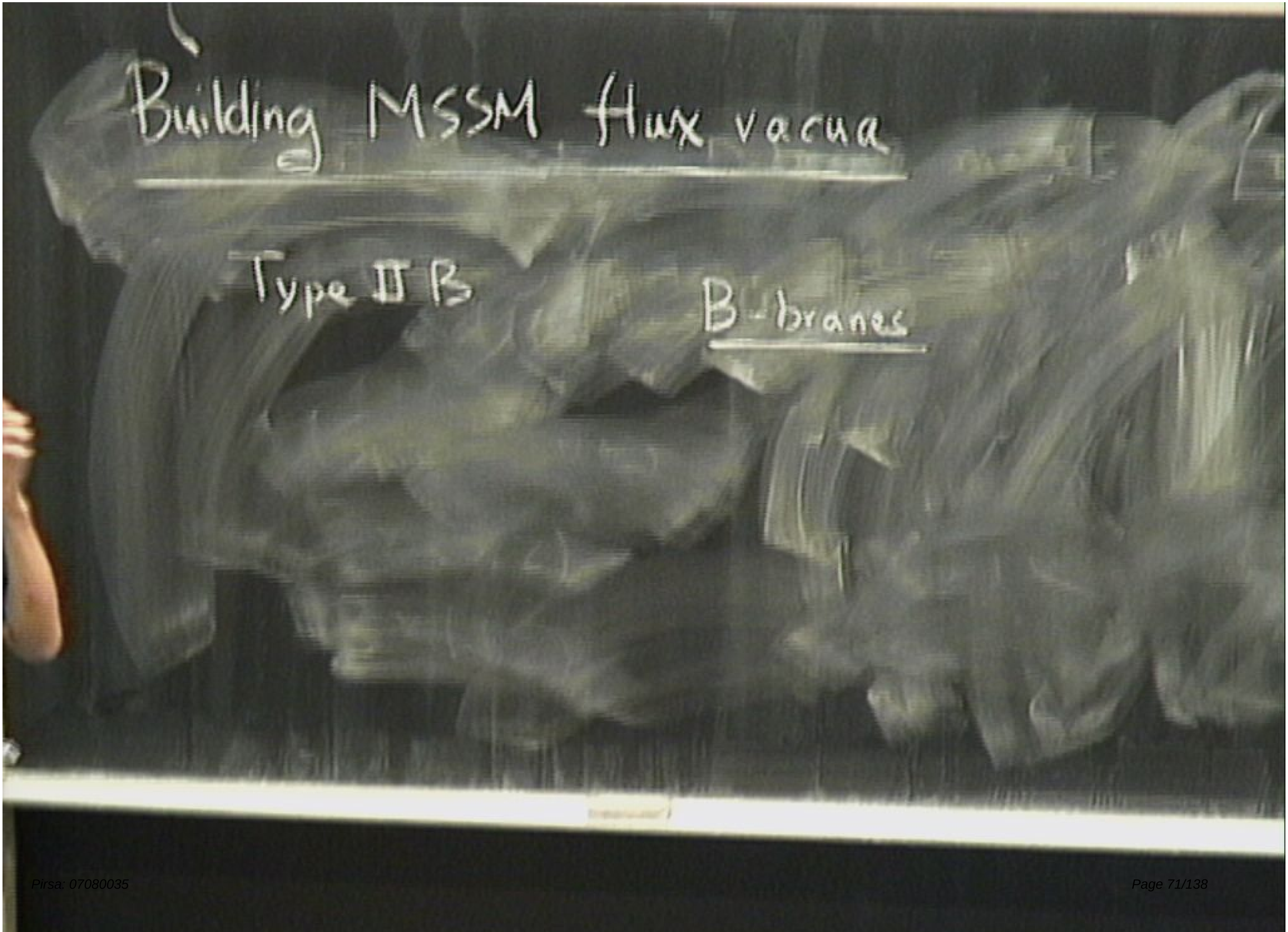
$N_{flux} = \frac{2}{(4\pi^2\alpha')^2}\int G_3 \wedge \bar{G}_3$

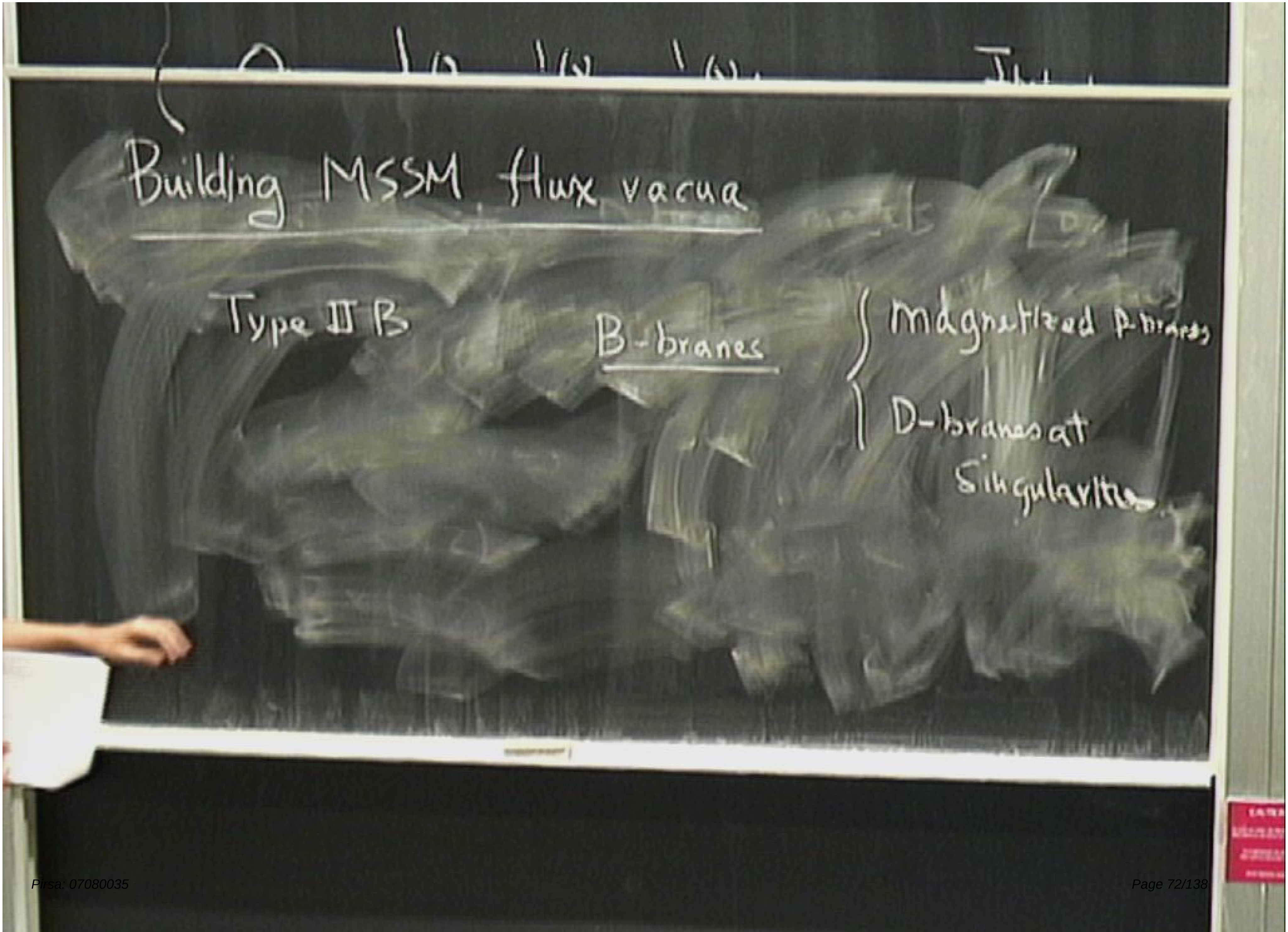
$*_6 G_3 = i\, G_3$ $W = \int G_3 \wedge \Omega$

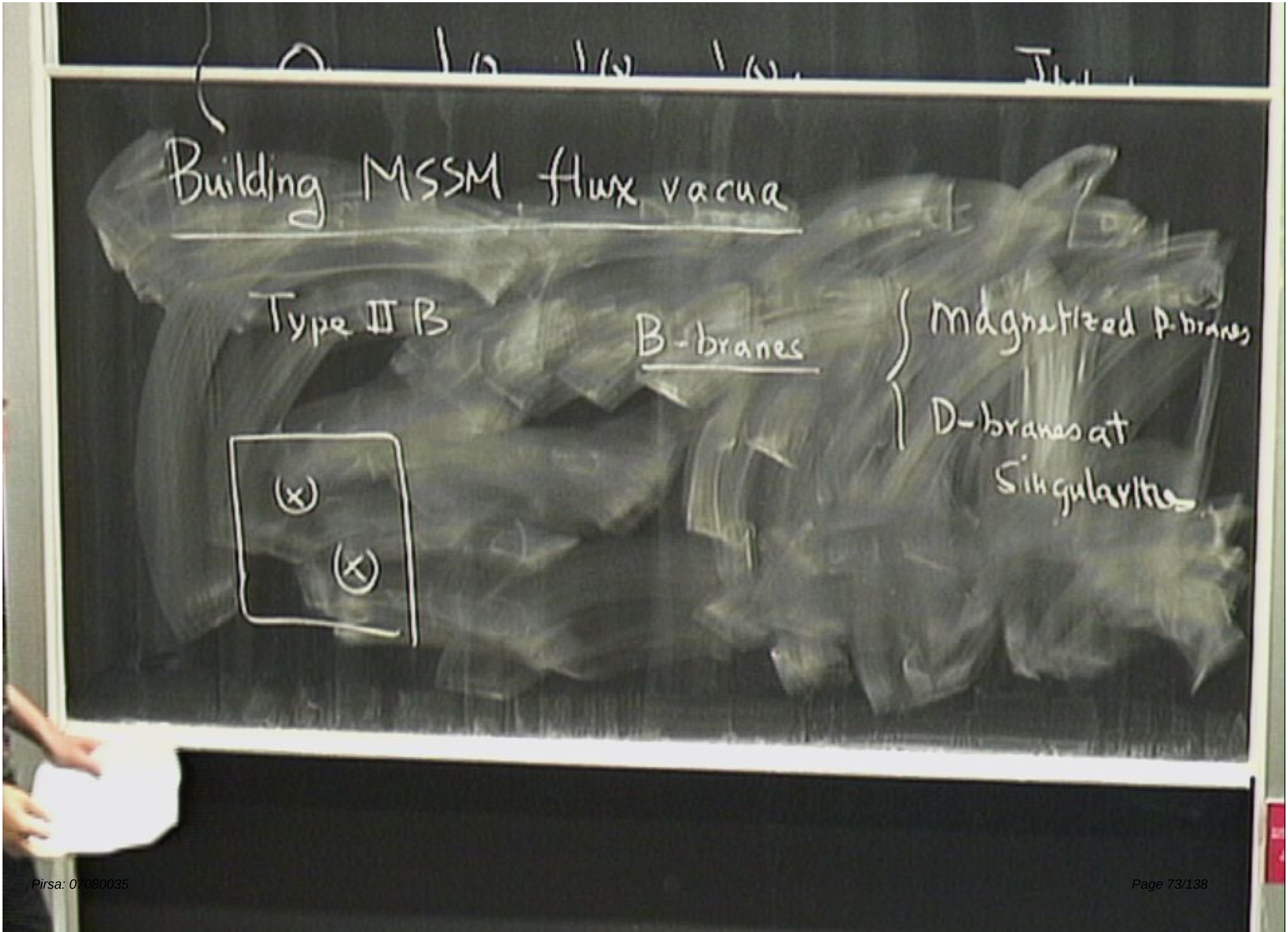
$(2,1) + (0,3)$ $D_\rho W \sim W \sim \int G_3 \wedge \Omega$

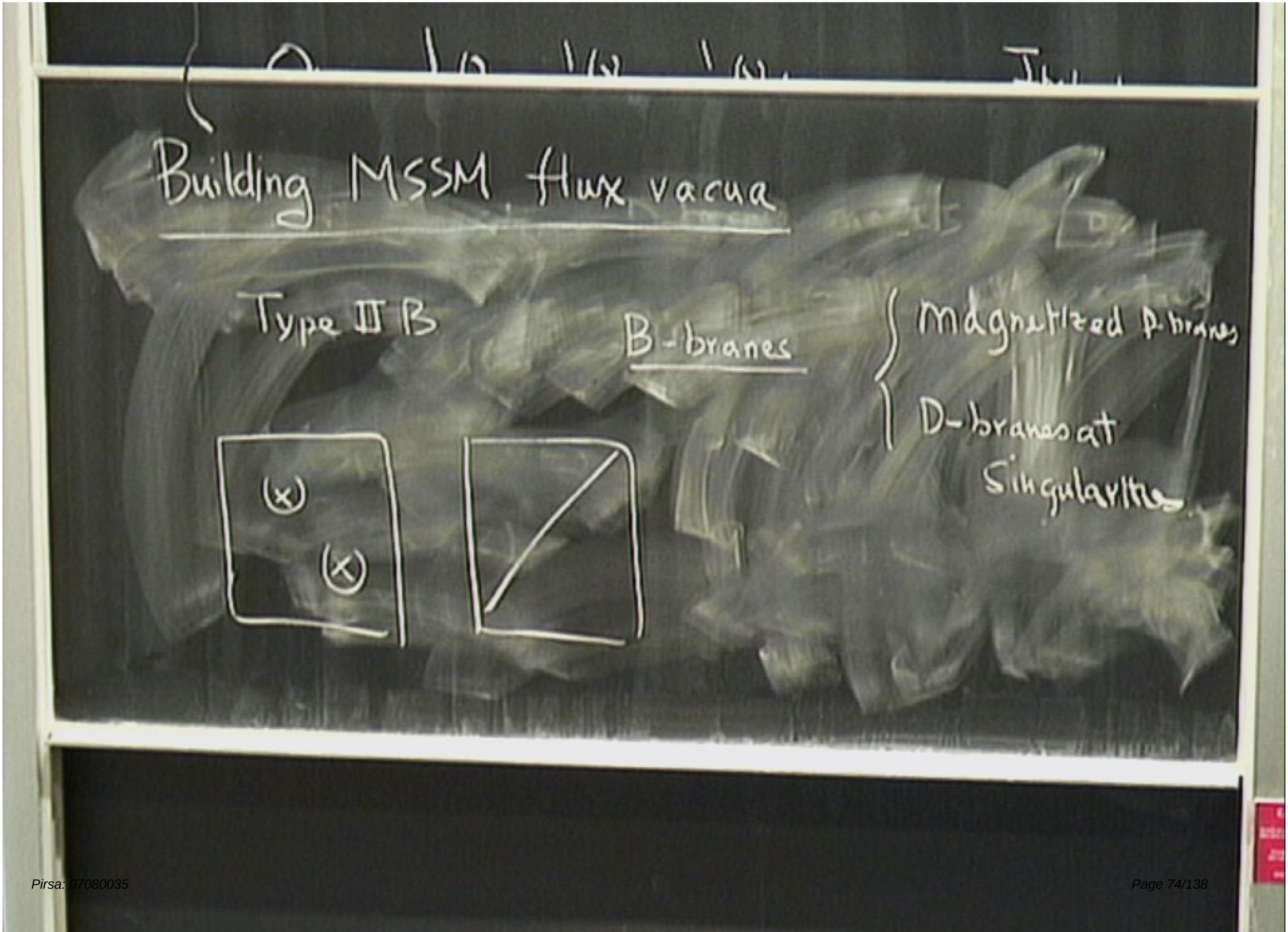
SUSY — breaks SUSY (preserve no scale structure)

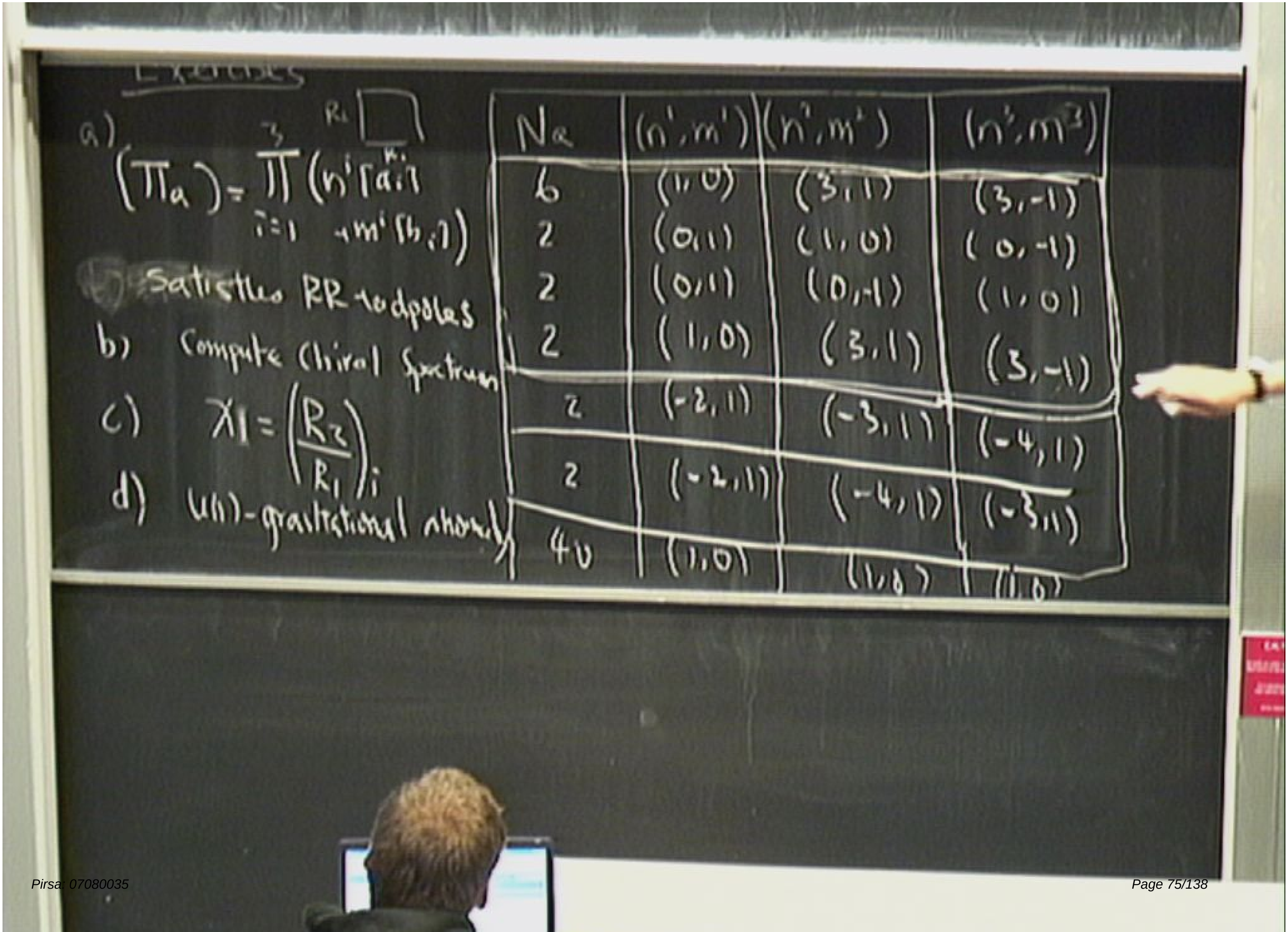

Building MSSM flux vacua

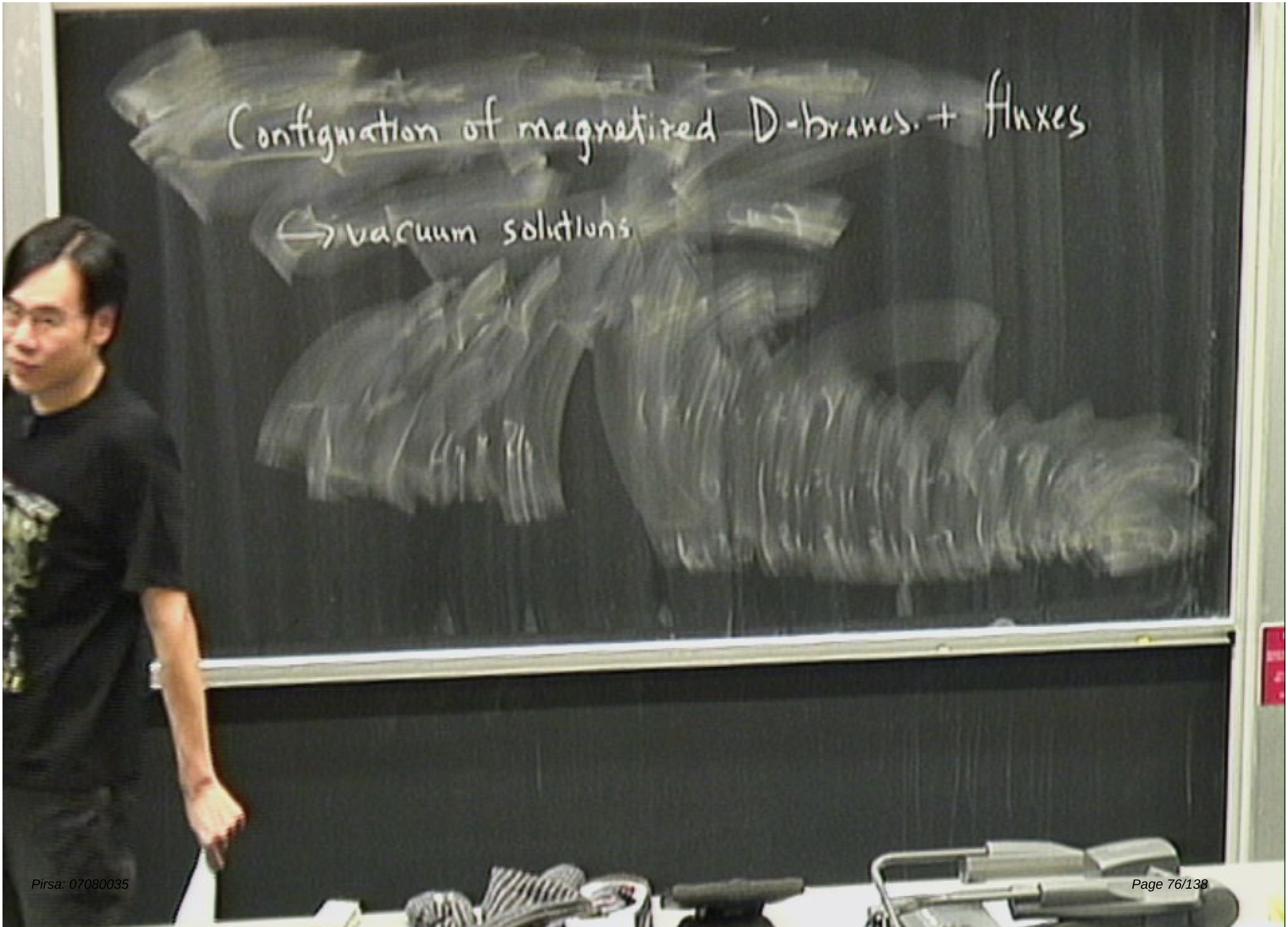

Building MSSM flux vacua
Type IIB
B-branes

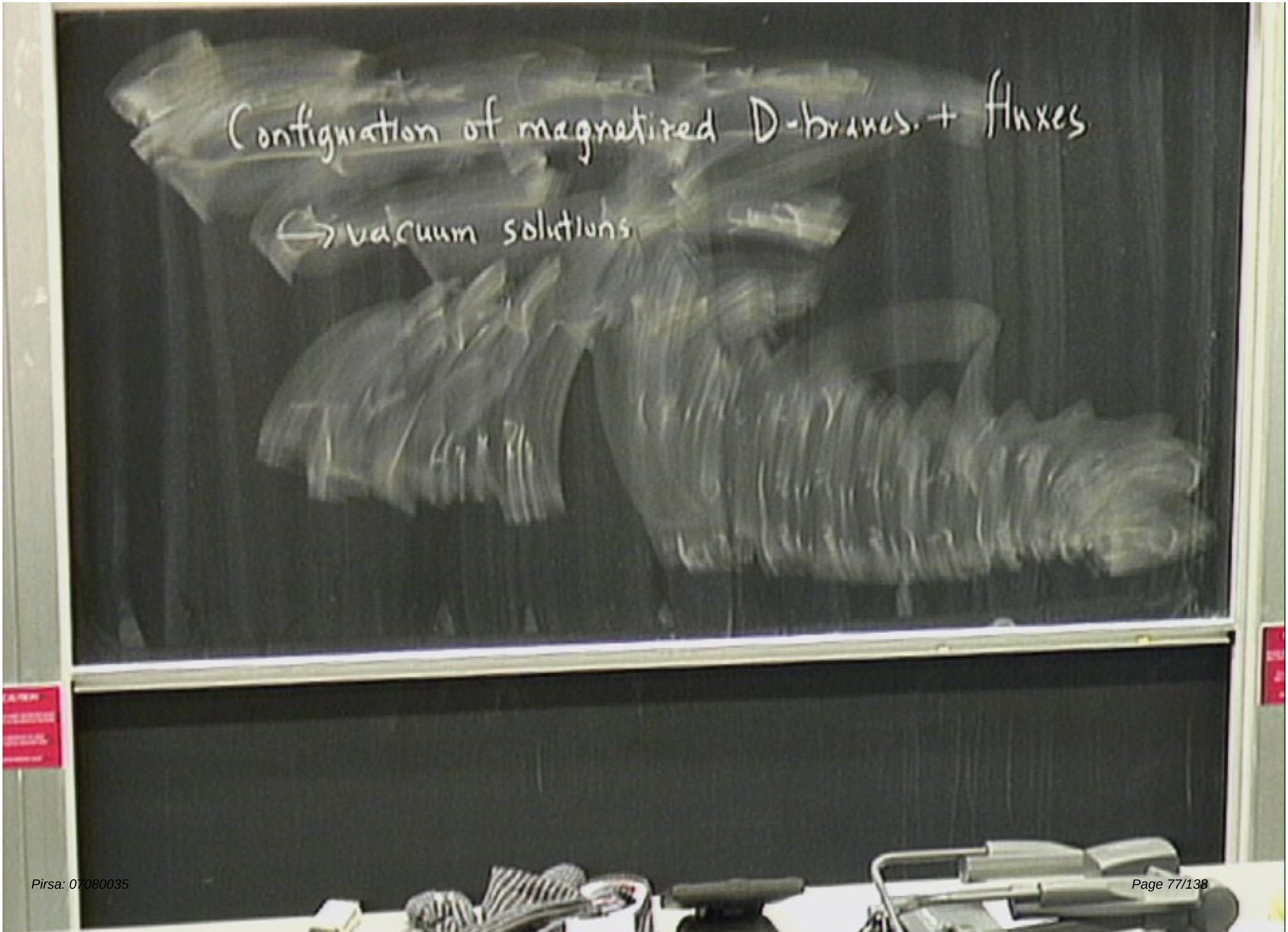

Building MSSM flux vacua
Type IIB
B-branes
Magnetized D-branes
D-branes at singularities


Building MSSM flux vacua
Type IIB
B-branes
Magnetized D-branes
D-branes at singularities


Building MSSM flux vacua
Type IIB
B-branes
Magnetized D-branes
D-branes at Singularities


Exercises
a) $(\Pi_a) = \prod_{i=1}^{3} (n^i [a_i] + m^i [b_i])$
Satisfies RR-tadpoles
b) Compute Chiral Spectrum
c) $\chi_1 = \left(\frac{R_2}{R_1}\right)_i$
d) U(1)-gravitational anomaly
Na
(n^1, m^1)
(n^2, m^2)
(n^3, m^3)
6 (1,0) (3,1) (3,-1)
2 (0,1) (1,0) (0,-1)
2 (0,1) (0,-1) (1,0)
2 (1,0) (3,1) (3,-1)
2 (-2,1) (-3,1) (-4,1)
2 (-2,1) (-4,1) (-3,1)
4v (1,0) (1,0) (1,0)


Configuration of magnetized D-branes + fluxes
⟷ vacuum solutions


Configuration of magnetized D-branes + fluxes
⟺ vacuum solutions

Configuration of magnetized D-branes + fluxes

$\Leftrightarrow$ vacuum solutions

$T^6 / \mathbb{Z}_2 \times \mathbb{Z}_2$ O6

Configuration of magnetized D-branes + fluxes

$\Leftrightarrow$ vacuum solutions

$T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$ 4 O6 $\longrightarrow$ O3 + 3 O7

Configuration of magnetized D-branes + fluxes

$\Leftrightarrow$ vacuum solutions

$T^6/\mathbb{Z}_2\times\mathbb{Z}_2$ 4 O6 $\longrightarrow$ O3 + 3 O7

Configuration of magnetized D-branes + fluxes

$\longleftrightarrow$ vacuum solutions

$T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$ 4 O6 $\longrightarrow$ O3 + 3 O7

↓ pts in compact space

Configuration of magnetized D-branes + fluxes

$\Leftrightarrow$ vacuum solutions

$T^6/\mathbb{Z}_2\times\mathbb{Z}_2$ 4 O6 $\longrightarrow$ O3 + 3 O7

O3 $\downarrow$ pts in compact space

O7 $\downarrow$ differ in transverse directions

RR tadpole for O3

$N_{D3} = 32$

Configuration of magnetized D-branes + fluxes

$\longleftrightarrow$ vacuum solutions

$T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$ 4 O6 $\longrightarrow$ O3 + $\boxed{3\ O7}$

O3 ↓ pts in compact space

3 O7 ↓ differ in transverse directions

Fluxes

Type IIB flux vacua.

F_3 H_3 $dF_3 = dH_3 = 0$

RR   NSNS

$$\frac{1}{(2\pi)^2\alpha'}\int F_3 \in \mathbb{Z}$$

$$\frac{1}{(2\pi)^2\alpha'}\int H_3 \in \mathbb{Z}$$

pts in compact space

directions

RR tadpole for O3

$N_{flux} + N_{D3} = 32$

↑

on T^6

$\int_{T^6} F_3 = N_{min}\,\mathbb{Z}$

RR tadpole for O3

$$N_{flux} + N_{D3} = 32$$

↑ on T^6

$$\int_{T^6} F_3 = N_{min} \mathbb{Z}$$

$$\int_{T^6} H_3 = N_{min} \mathbb{Z}$$

Fluxes Type IIB flux vacua

F_3, H_3 $dF_3 = dH_3 = 0$

RR NSNS

$$\frac{1}{(2\pi)^2\alpha'}\int F_3 \in \mathbb{Z}$$

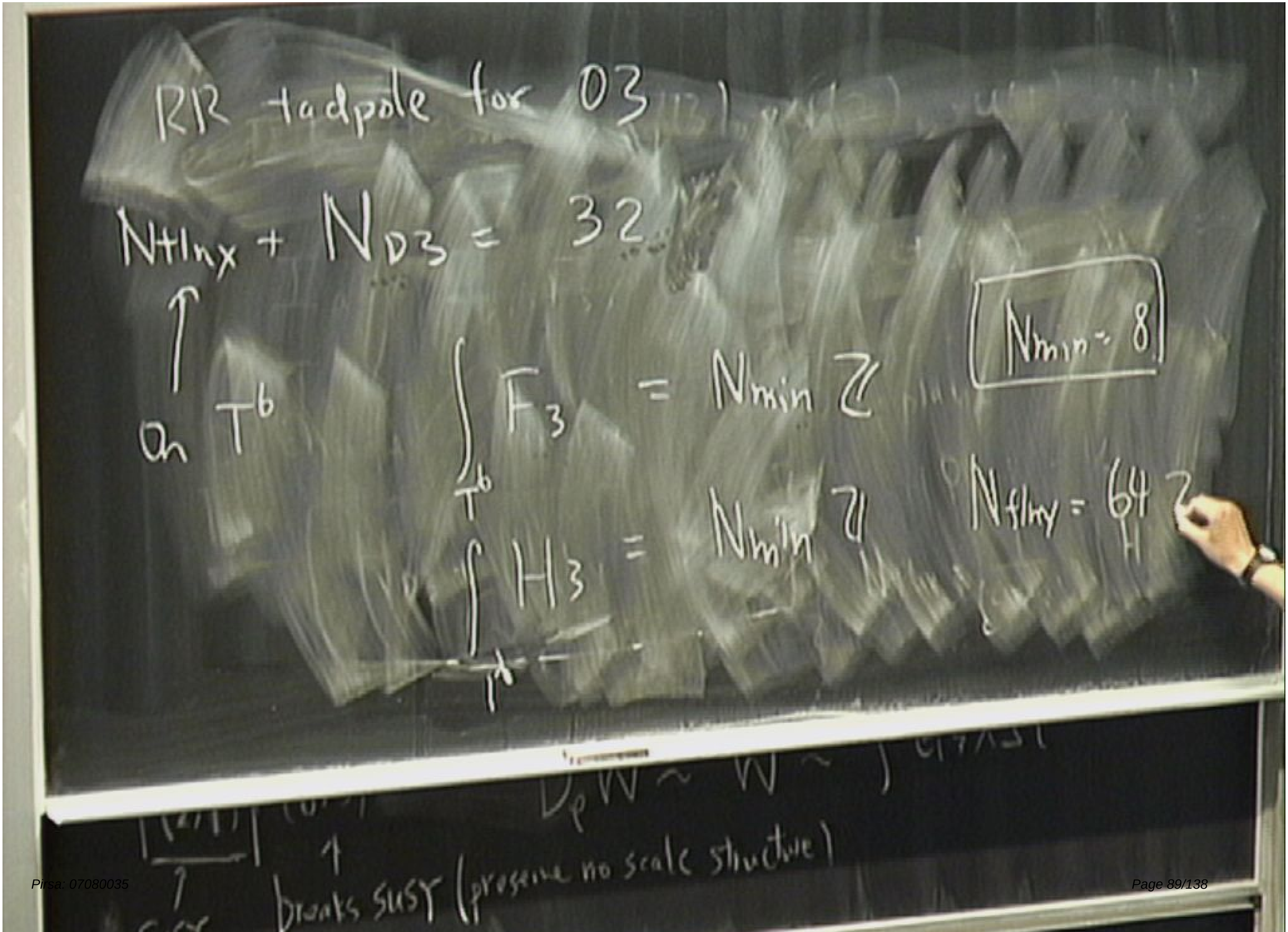
$\mathbb{Z}_2 \times \mathbb{Z}_2$

$$\frac{1}{(2\pi)^2\alpha'}\int H_3 \in \mathbb{Z}$$

Ω

pts in compact space

directions


RR tadpole for D3
Nflux + ND3 = 32
on T6
∫ F3 = Nmin Z
Nmin = 8
∫ H3 = Nmin Z
Nflux = 64 Z
breaks SUSY (preserve no scale structure)

RR tadpole for O3

$$N_{flux} + N_{D3} = 32$$

↑ on T^6

$$\int_{T^6} F_3 = N_{min} \mathbb{Z}$$

$$\boxed{N_{min} = 8}$$

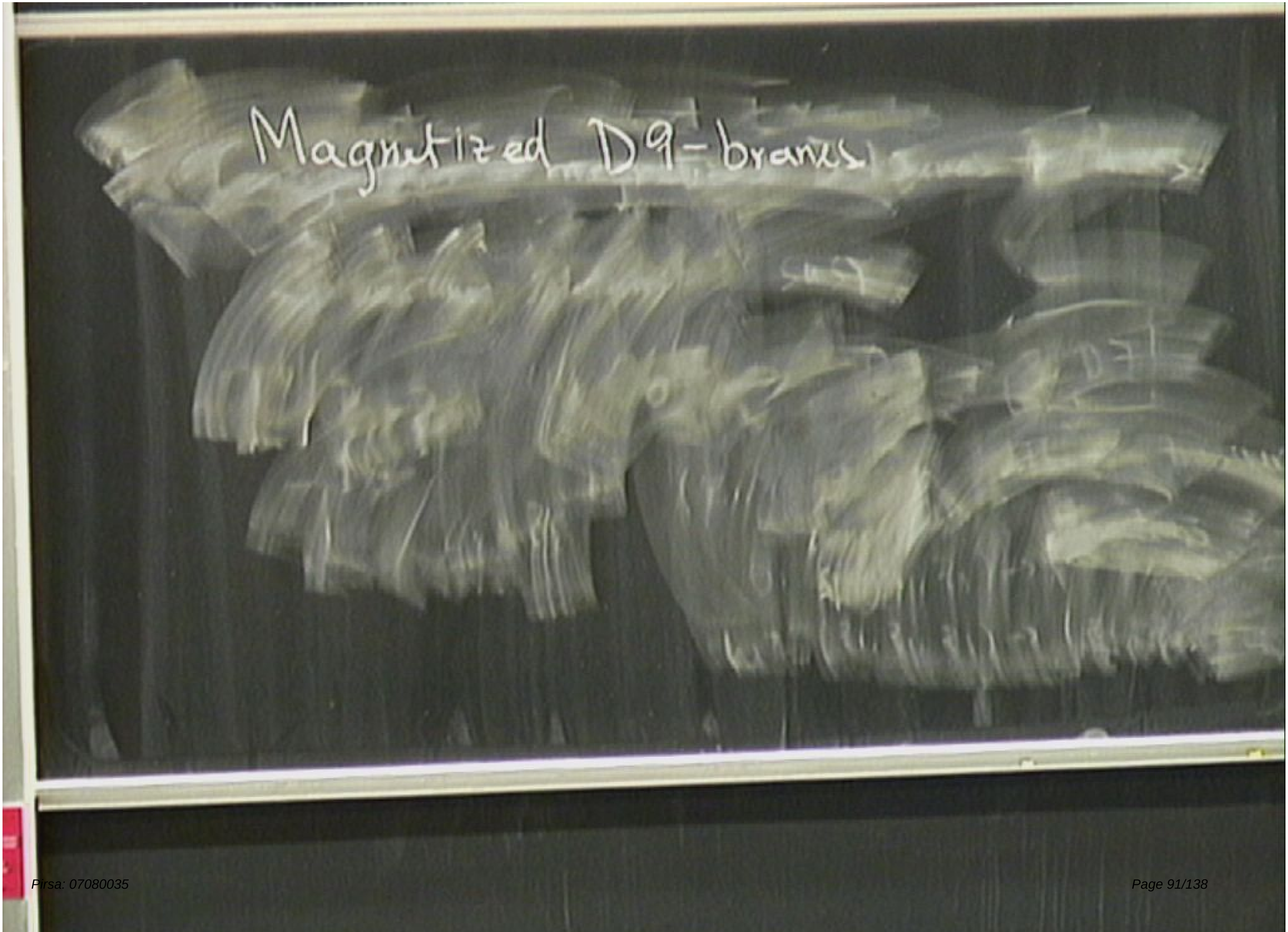
$$\int_{T^6} H_3 = N_{min} \mathbb{Z}$$

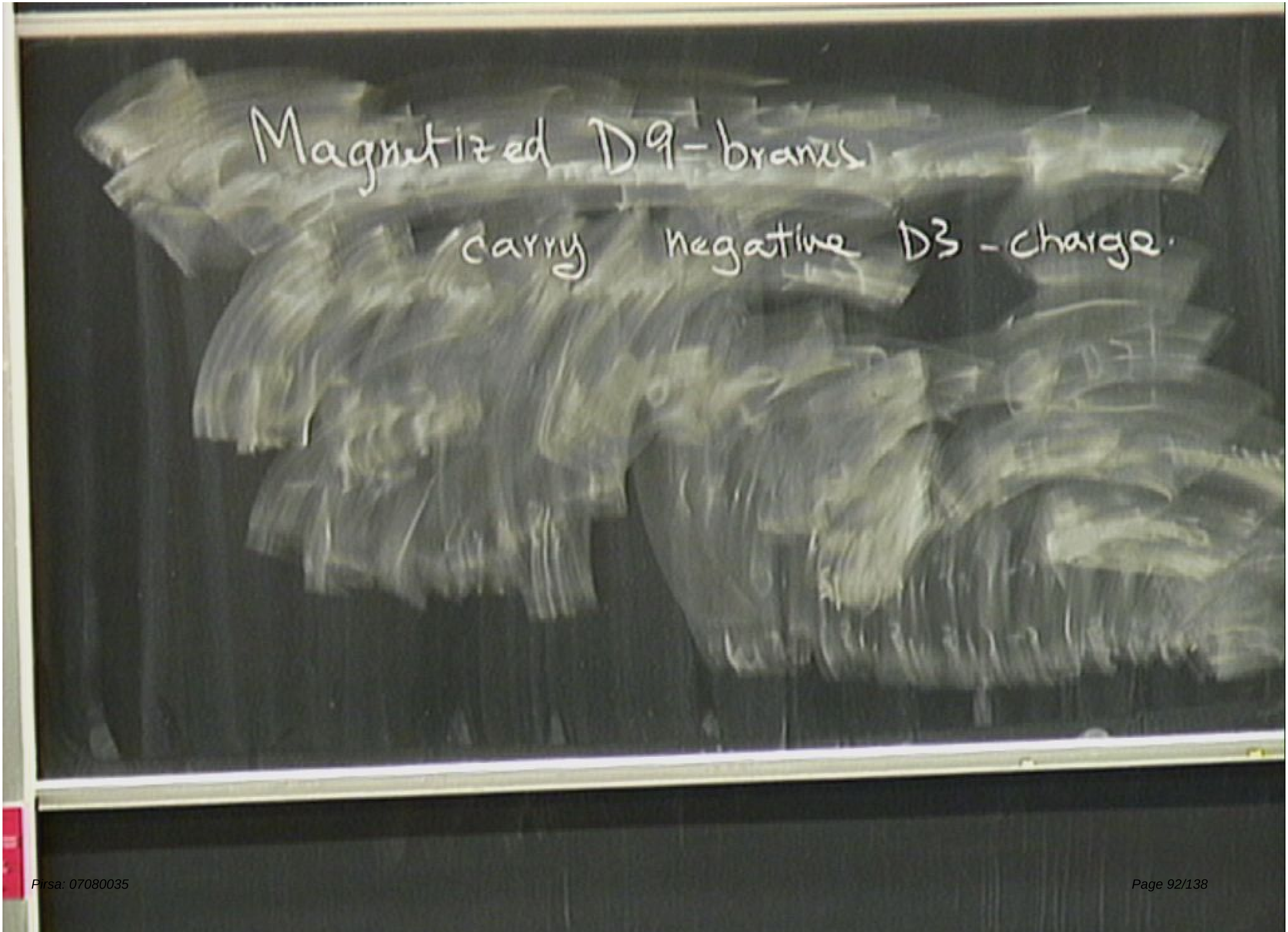
$$N_{flux} \in 64 \mathbb{Z}$$

$$D_\rho W \sim W \sim \int G_3 \wedge \Omega$$

$|(2,1)| + (0,3)|$

↑ breaks SUSY (preserve no scale structure)

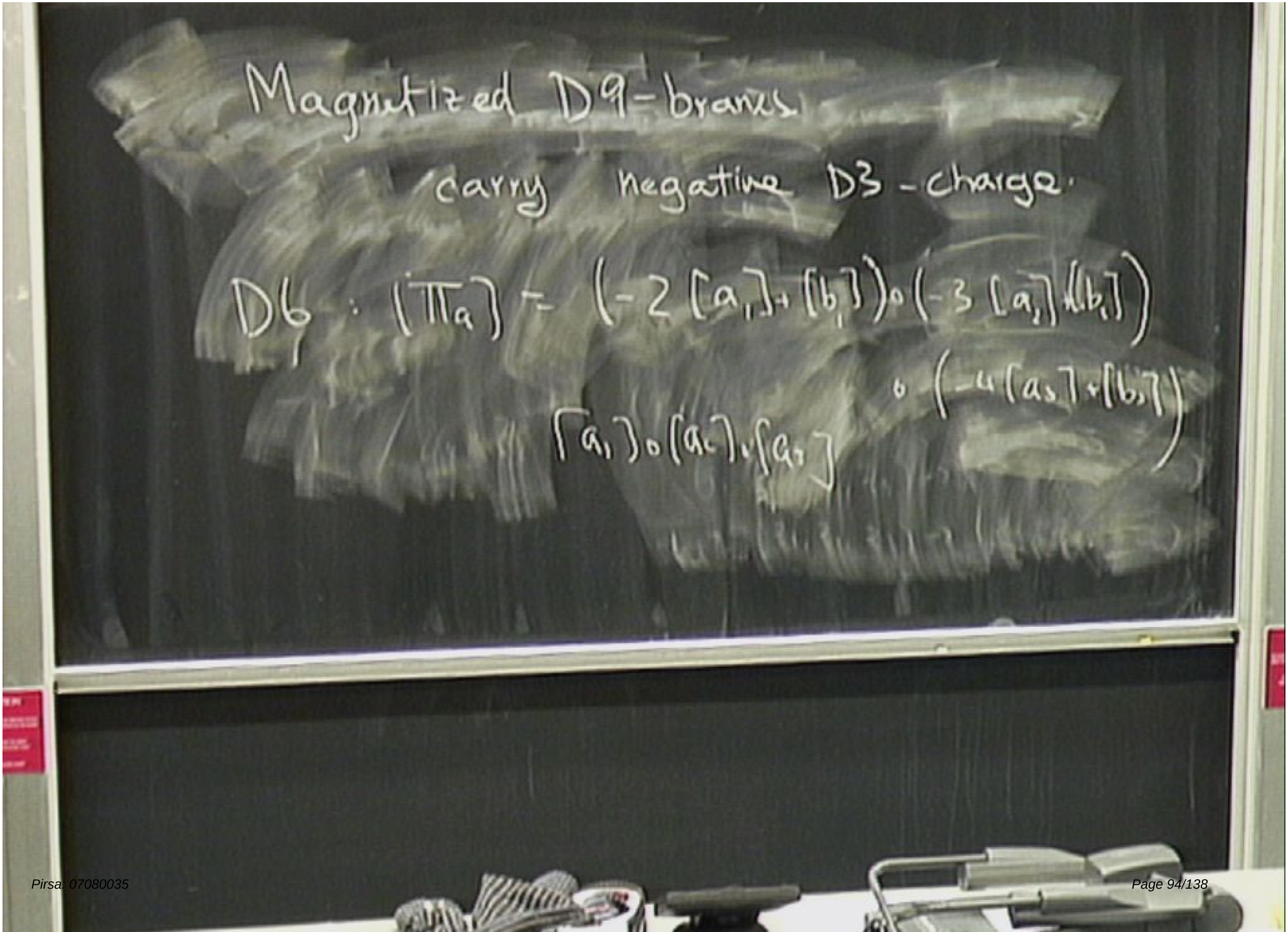

Magnetized D9-branes

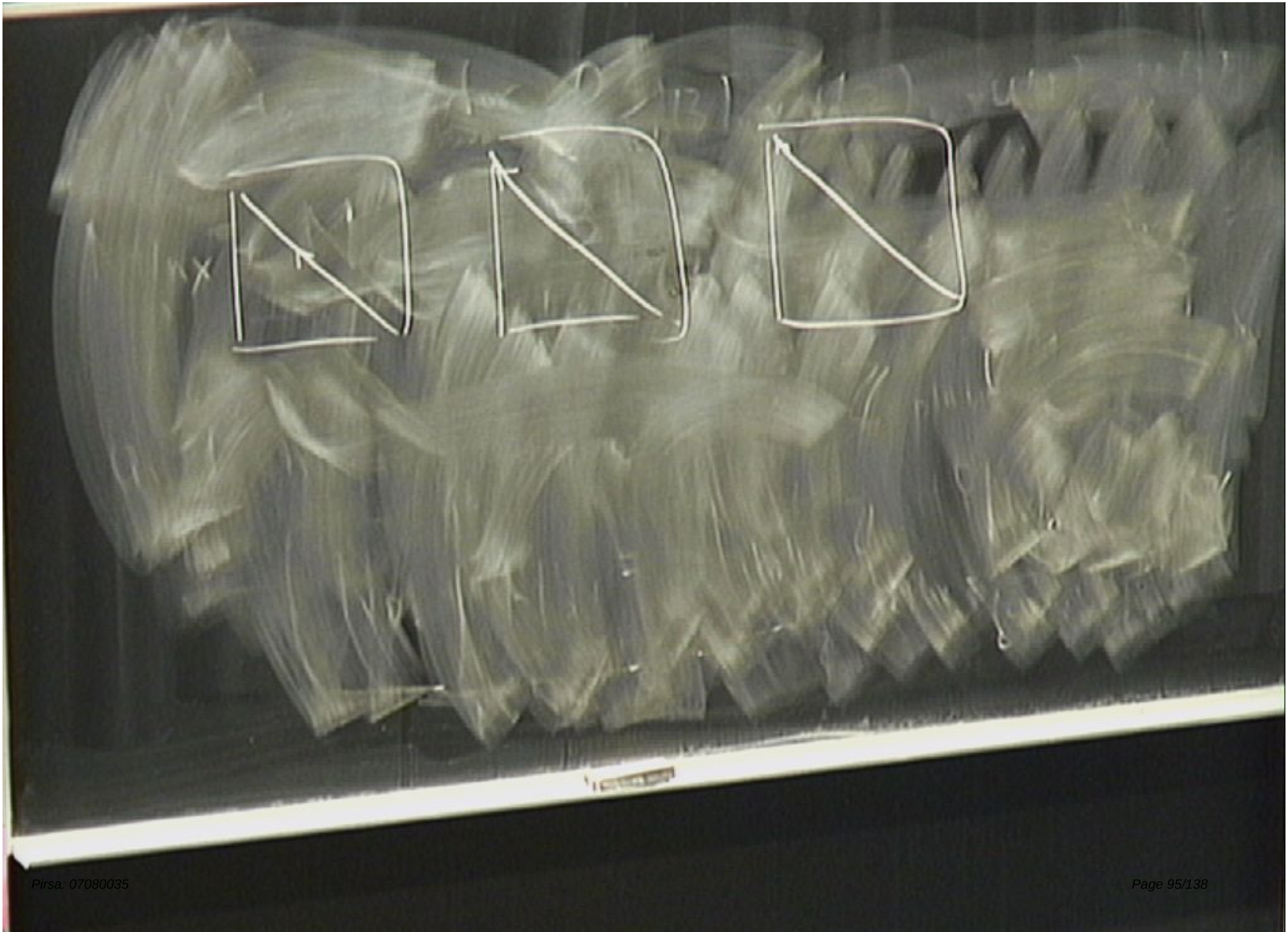

Magnetized D9-branes
carry negative D3-charge.

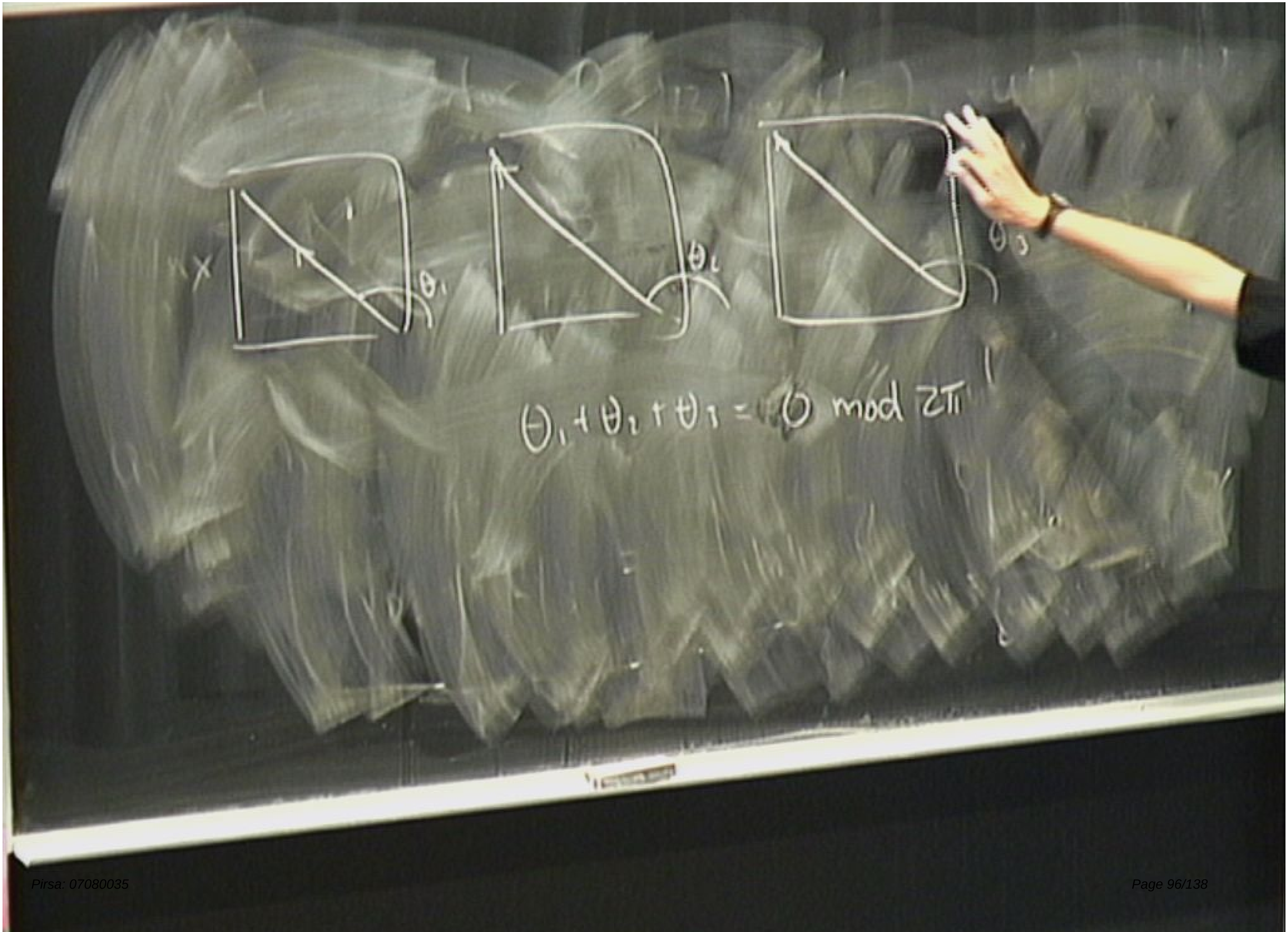
Magnetized D9-branes

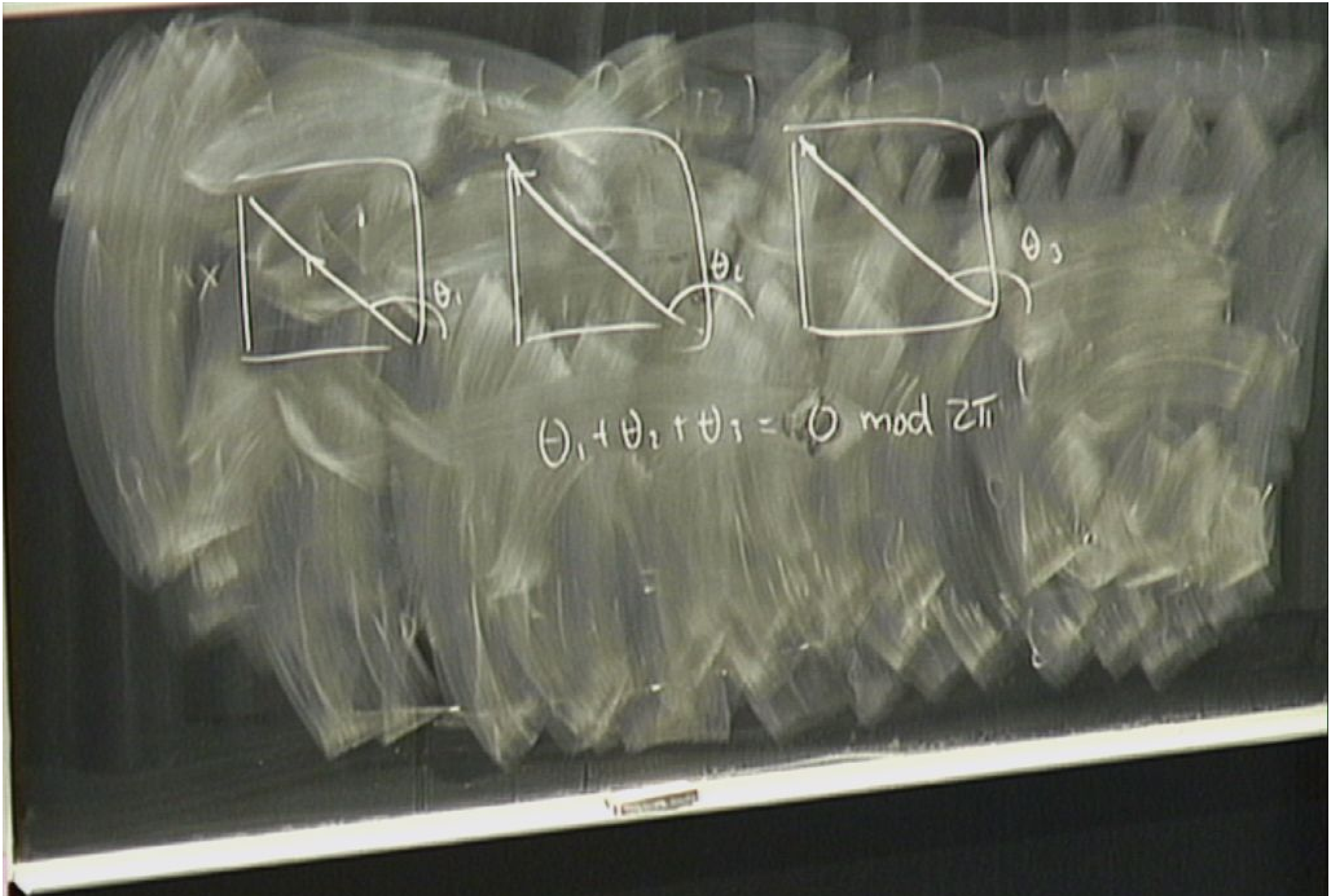
carry negative D3-charge.

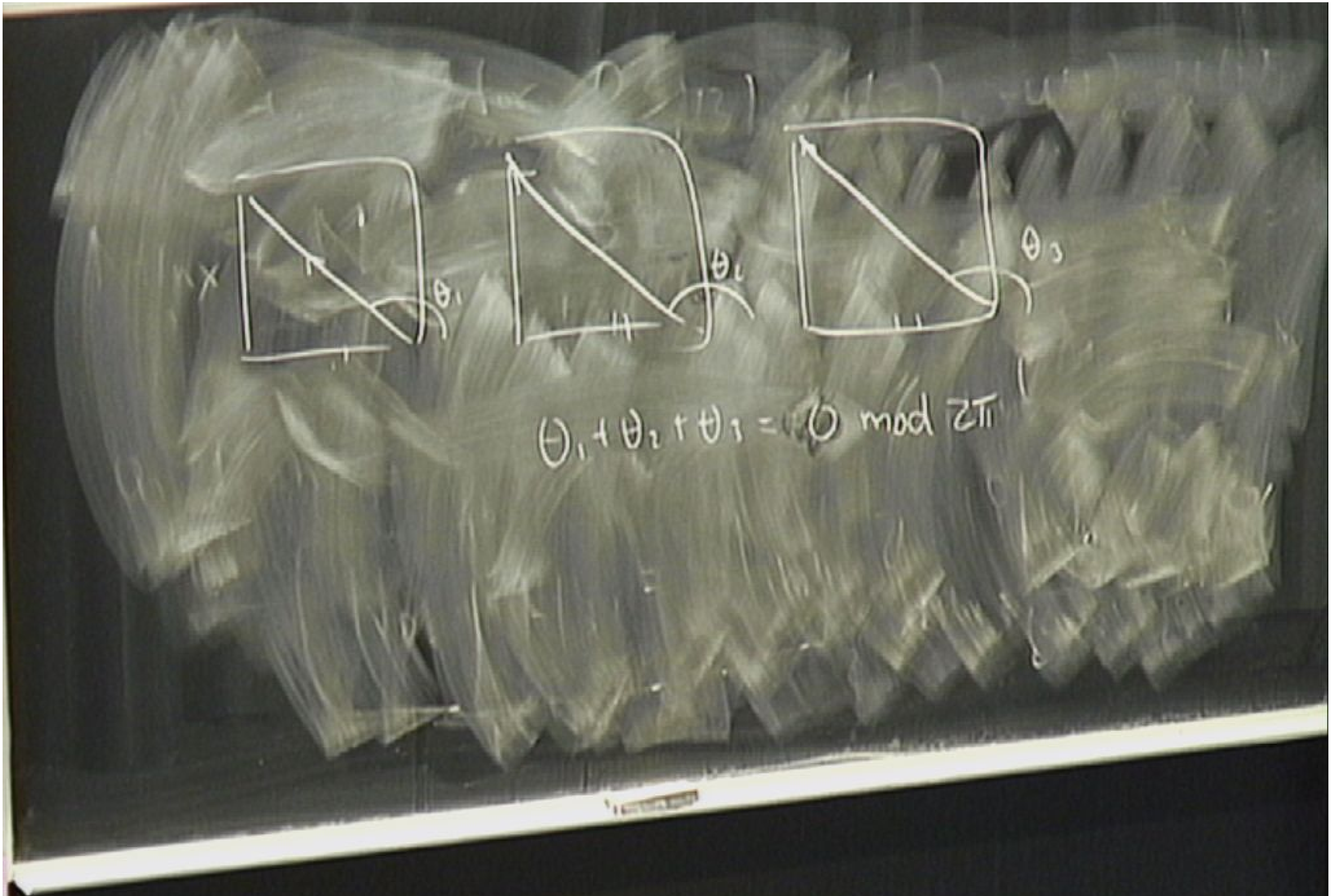
$$D6: \quad [\Pi_a] = (-2[a_1]+[b_1]) \circ (-3[a_2]+[b_2]) \circ (-4[a_3]+[b_3])$$

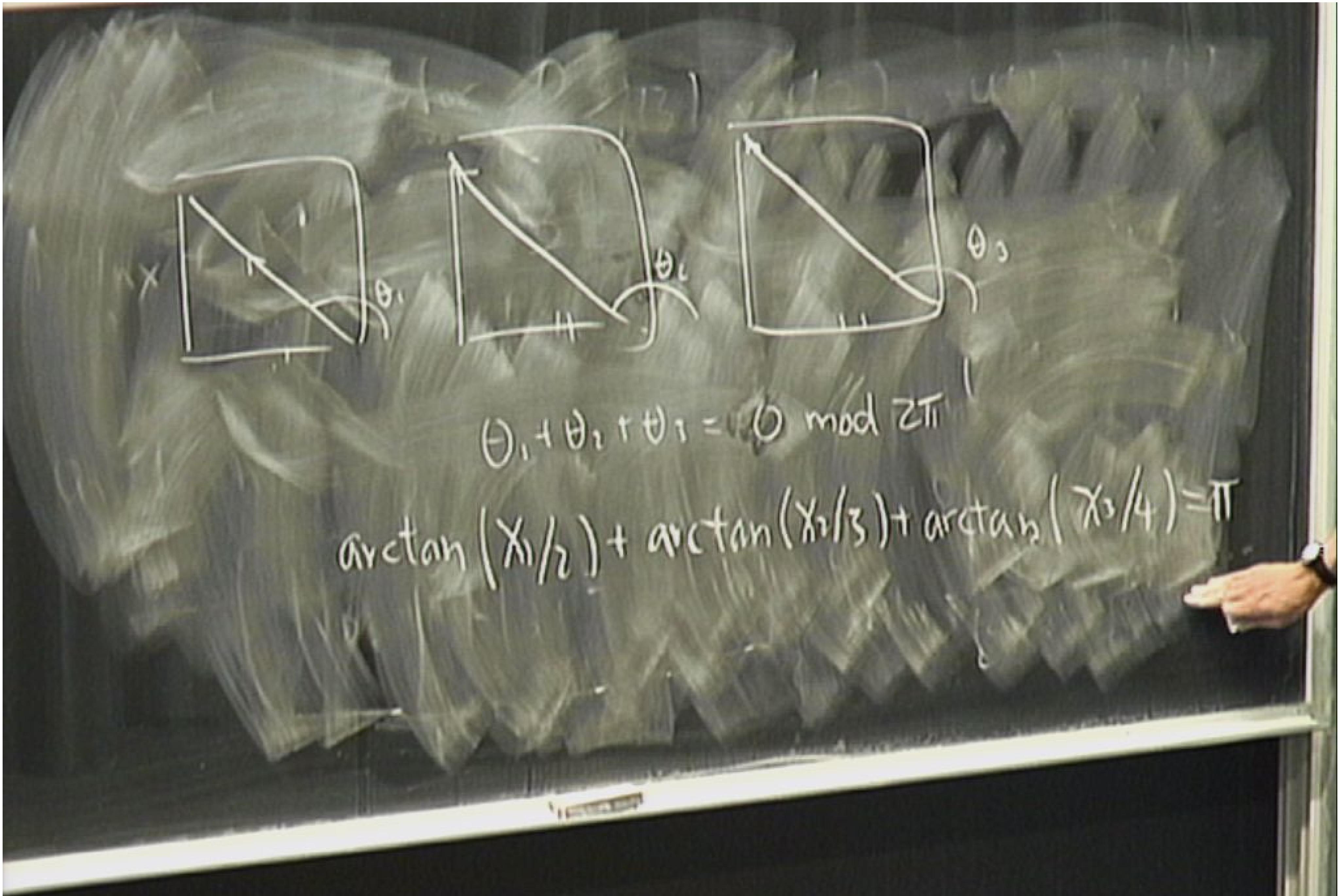

Magnetized D9-branes
carry negative D3-charge.
D6 : [Π_a] = (-2 [a_1] + [b_1]) ∘ (-3 [a_2] + [b_2])
∘ (-4 [a_3] + [b_3])
[a_1] ∘ [a_2] ∘ [a_3]




θ_1
θ_2
θ_3
$\theta_1 + \theta_2 + \theta_3 = 0 \mod 2\pi$


θ1
θ2
θ3
θ1 + θ2 + θ3 = 0 mod 2π


θ1
θ2
θ3
θ1 + θ2 + θ3 = 0 mod 2π

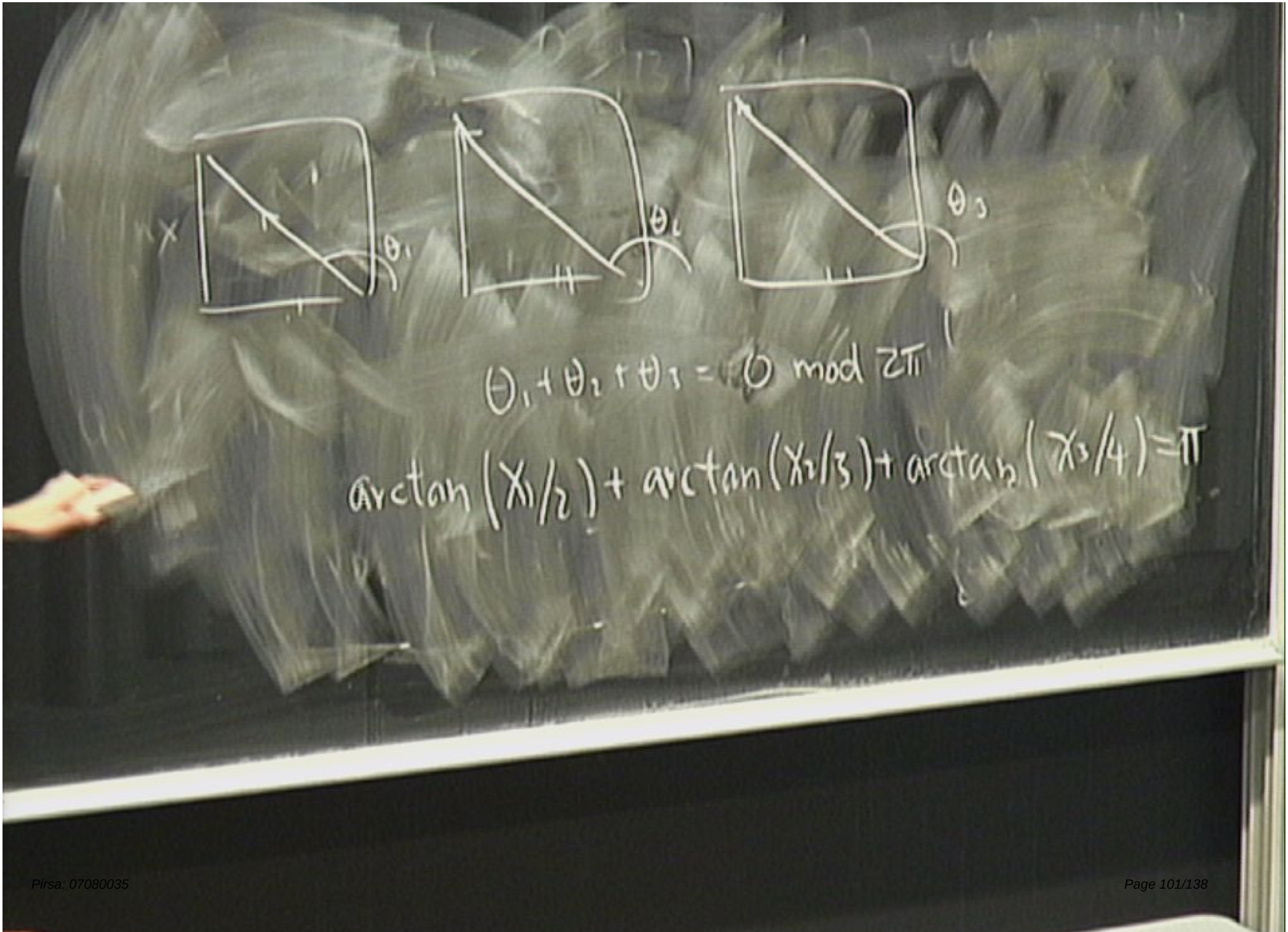

θ1
θ2
θ3
θ1 + θ2 + θ3 = 0 mod 2π
arctan(x1/2) + arctan(x2/3) + arctan(x3/4) = π

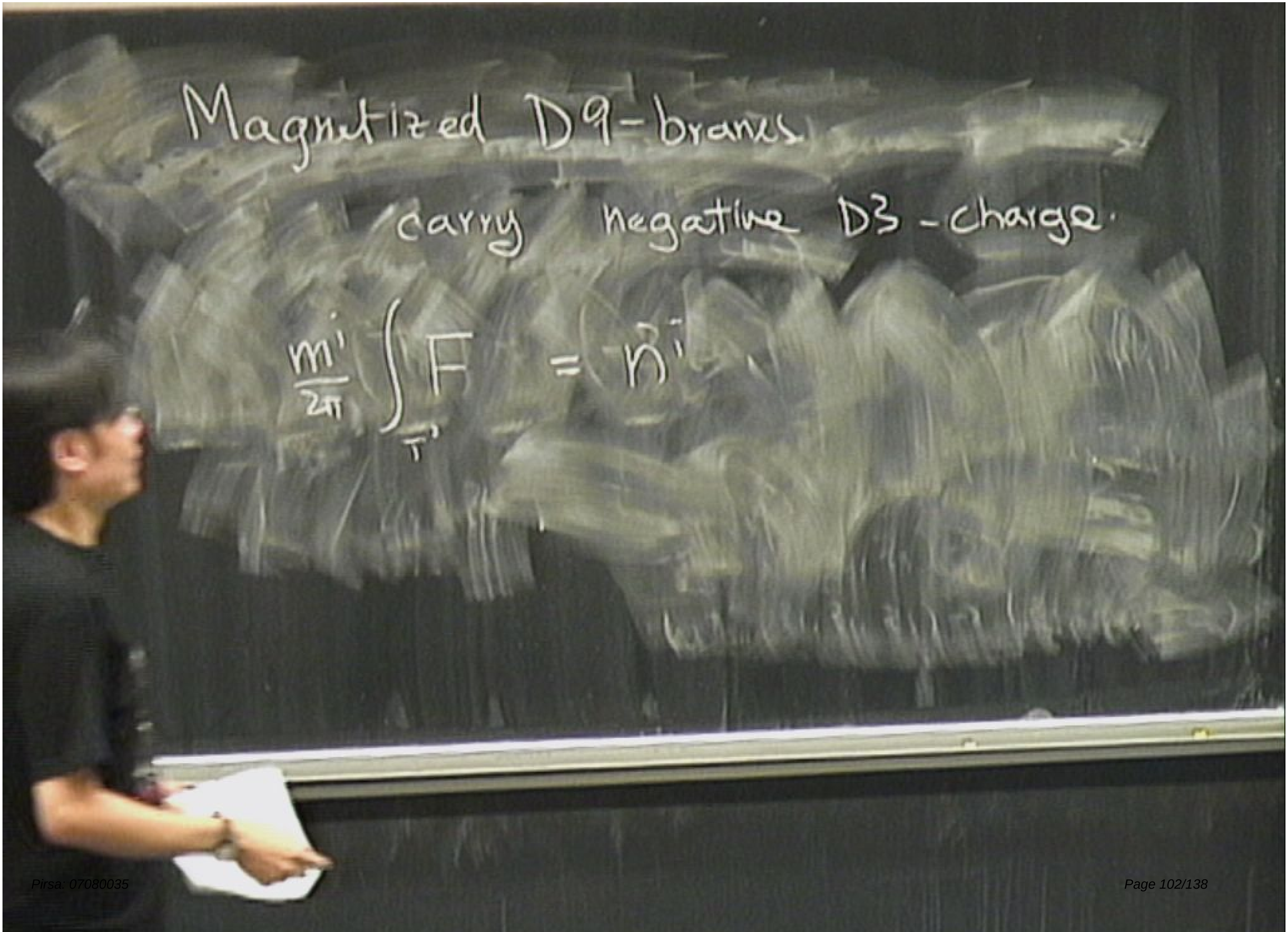
Magnetized D9-branes

carry negative D3-charge.

$$D6: \ [\Pi_a] = (-2[a_1]+[b_1]) \circ (-3[a_2]+[b_2]) \circ (-4[a_3]+[b_3])$$

$$[a_1]\circ[a_2]\circ[a_3]$$


θ₁ + θ₂ + θ₃ = 0 mod 2π
arctan(x₁/2) + arctan(x₂/3) + arctan(x₃/4) = π
θ₁
θ₂
θ₃

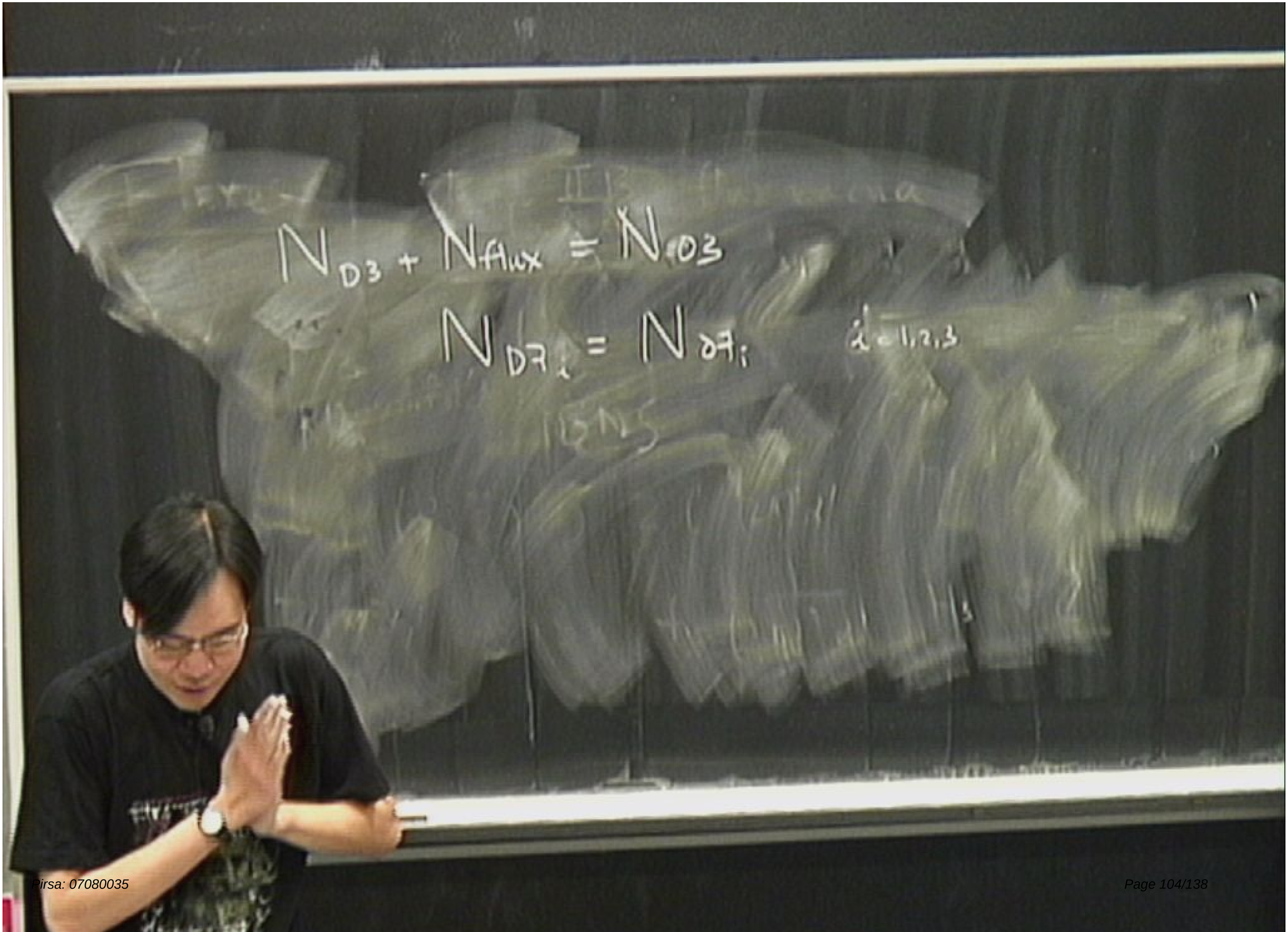

Magnetized D9-branes
carry negative D3-charge.
$\frac{m^i}{2\pi}\int_{T^i} F = n^i$

Magnetized D9-branes.

carry negative D3-charge.

$$\frac{m^i}{2\pi}\int_{T^i} F = n^i$$

$$\arctan\left(\frac{A_1}{2}\right) + \arctan(A_2/5) + \arctan(A_3/4) = \pi$$



$N_{D3} + N_{flux} = N_{O3}$
$N_{D7_i} = N_{O7_i}$ $i = 1,2,3$

$$N_{D3} + N_{flux} = N_{O3}$$

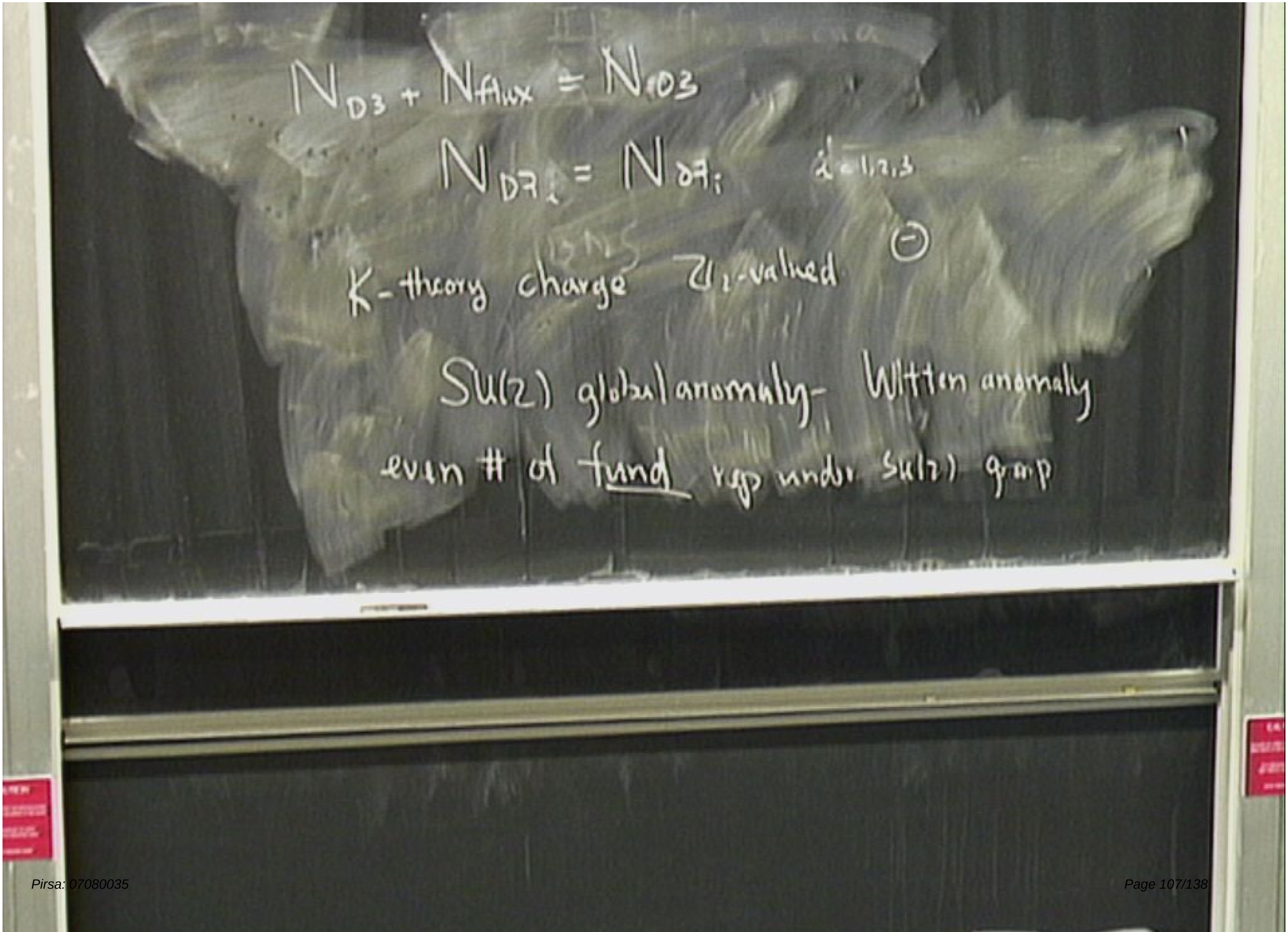
$$N_{D7_i} = N_{O7_i} \qquad i=1,2,3$$

K-theory charge $\mathbb{Z}_2$-valued

$$N_{D3} + N_{flux} = N_{O3}$$

$$N_{D7_i} = N_{O7_i} \quad i = 1,2,3$$

K-theory charge $\mathbb{Z}_2$-valued


$N_{D3} + N_{flux} = N_{O3}$
$N_{D7_i} = N_{O7_i}$ $i = 1,2,3$
K-theory charge $\mathbb{Z}_2$-valued
SU(2) global anomaly - Witten anomaly
even # of fund rep under SU(2) group

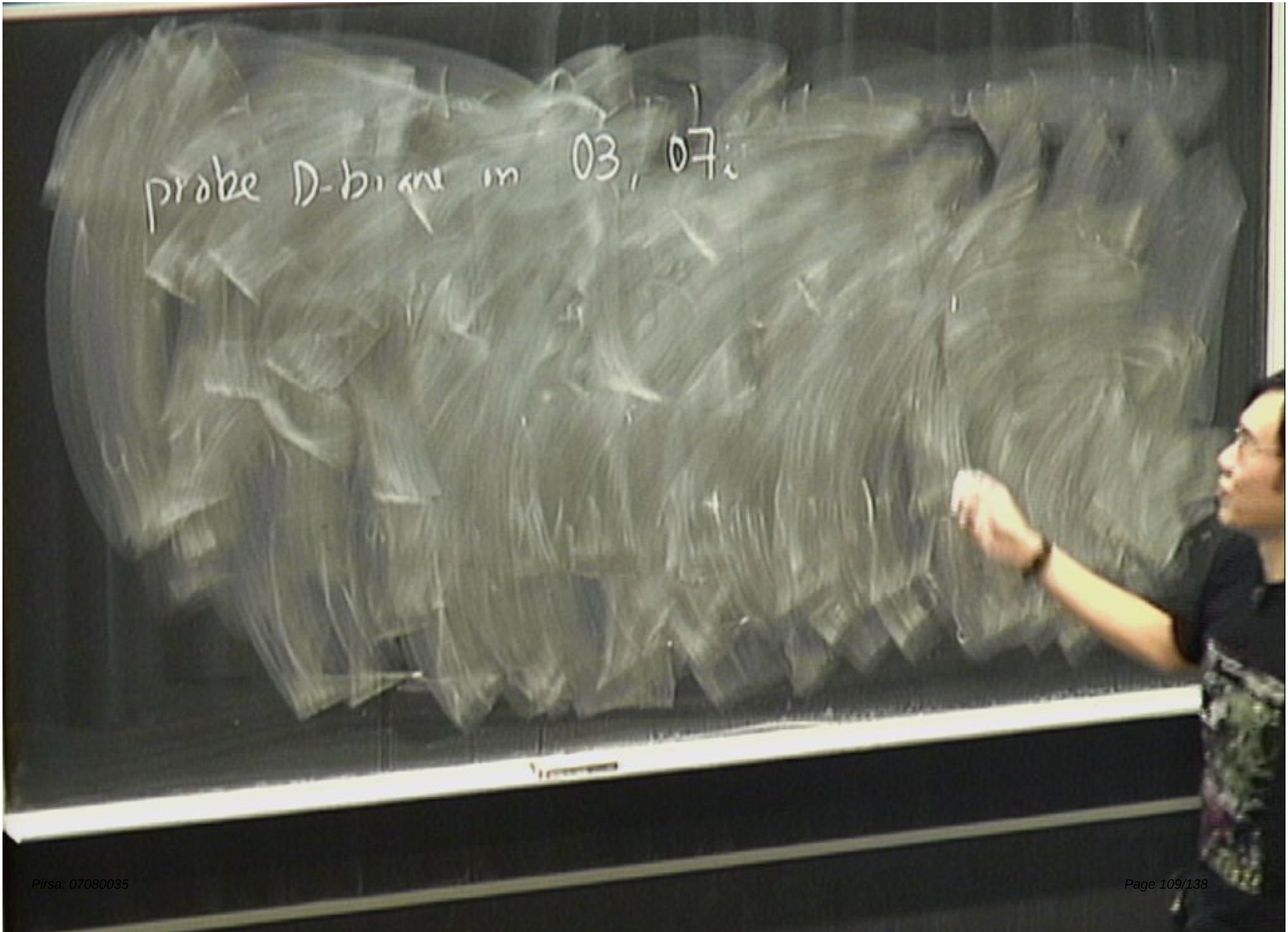
$$N_{D3} + N_{flux} = N_{O3}$$

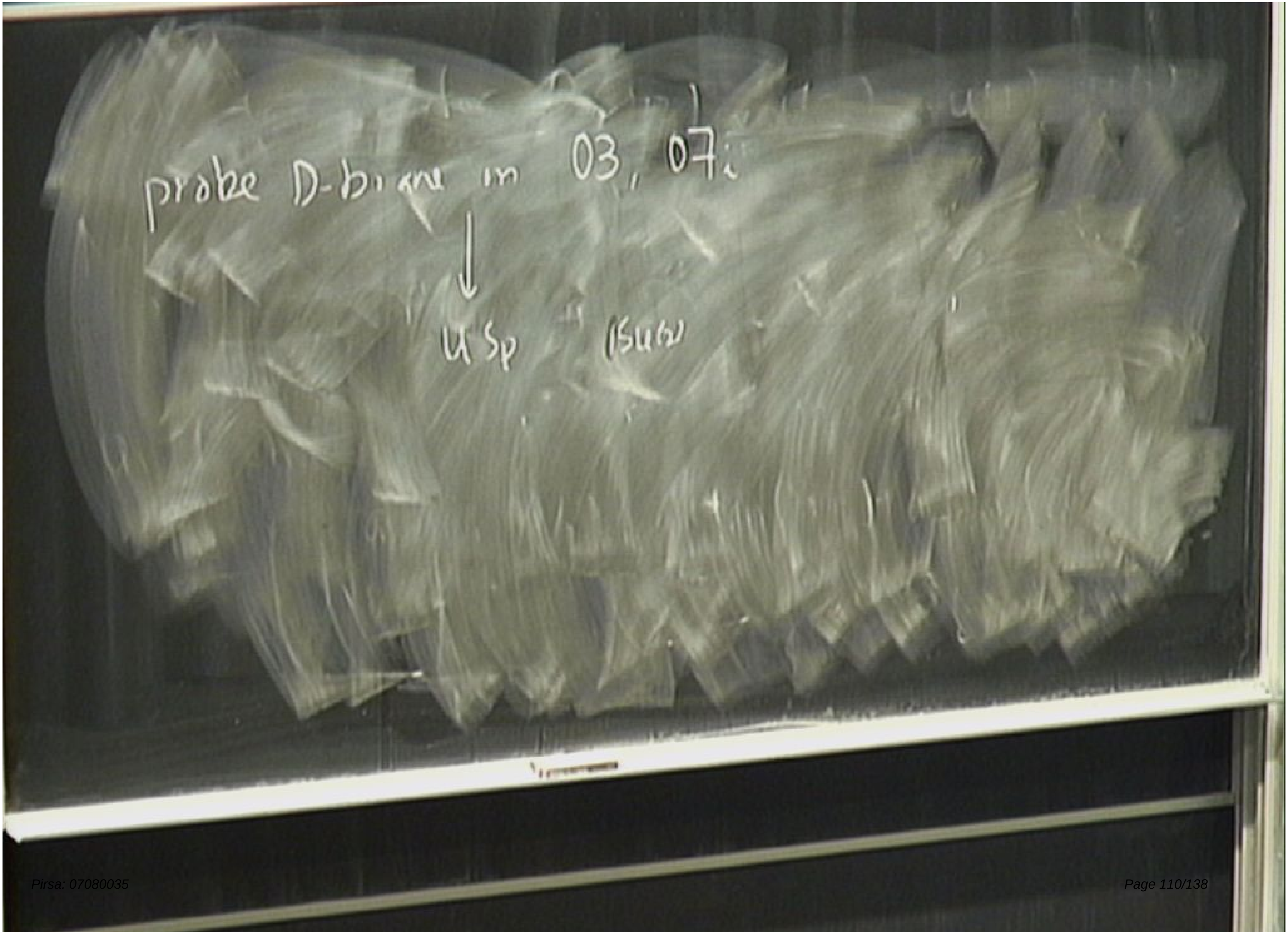
$$N_{D7_i} = N_{O7_i} \qquad i = 1,2,3$$

K-theory charge $\mathbb{Z}_2$-valued

SU(2) global anomaly - Witten anomaly

even # of fund rep under SU(2) group


probe D-brane in 03, 07:


probe D-brane in O3, O7:
USp (SU(2))

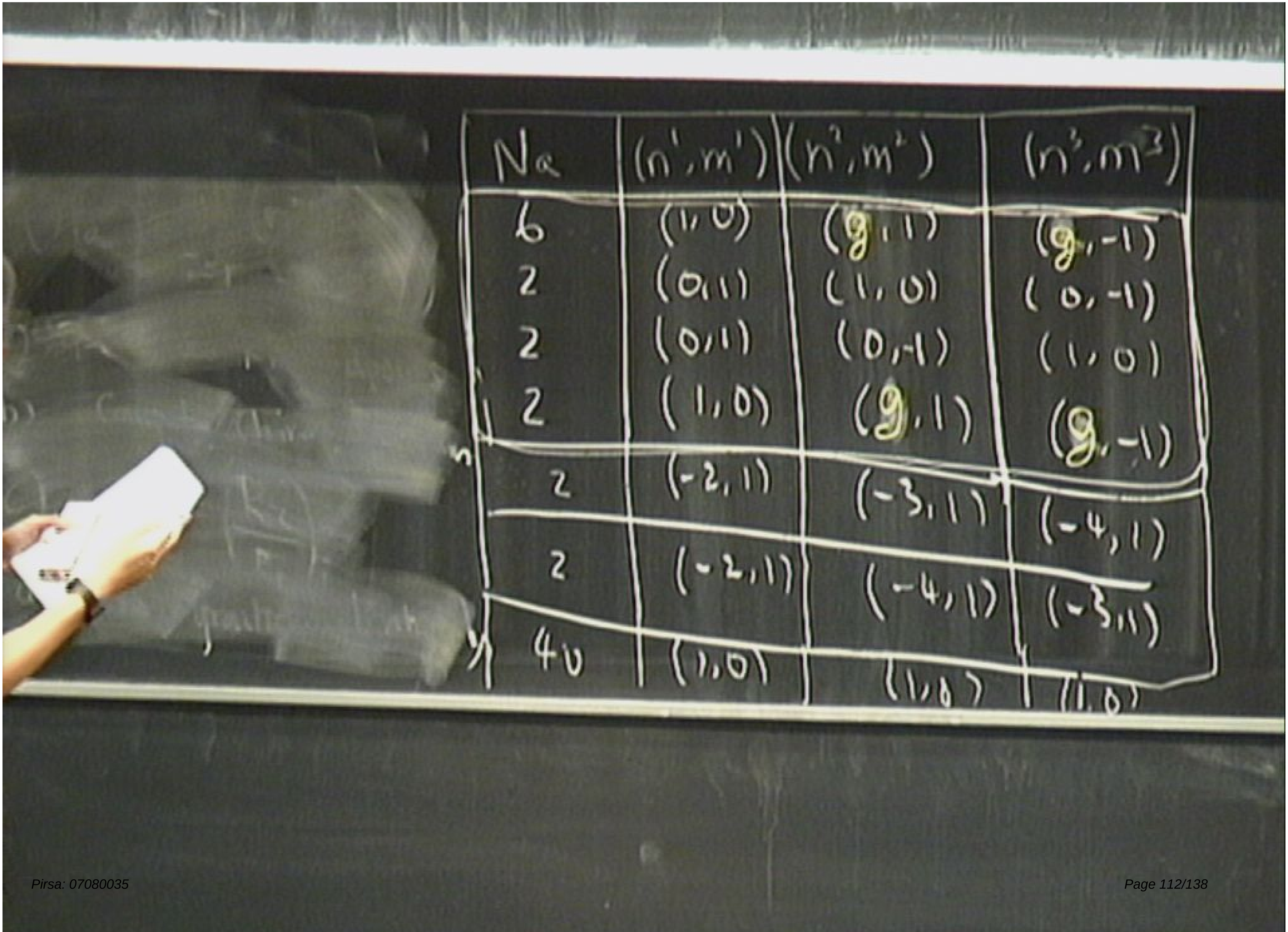
$$N_{D3} + N_{flux} = N_{O3}$$

$$N_{D7_i} = N_{O7_i} \qquad i = 1,2,3$$

K-theory charge $\mathbb{Z}_2$-valued

SU(2) global anomaly - Witten anomaly

even # of <u>fund</u> rep under SU(2) group


Na (n¹,m¹) (n²,m²) (n³,m³)
6 (1,0) (g,1) (g,-1)
2 (0,1) (1,0) (0,-1)
2 (0,1) (0,-1) (1,0)
2 (1,0) (g,1) (g,-1)
2 (-2,1) (-3,1) (-4,1)
2 (-2,1) (-4,1) (-3,1)
4υ (1,0) (1,0) (1,0)

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	$(1,0)$	$(g,1)$	$(g,-1)$
2	$(0,1)$	$(1,0)$	$(0,-1)$
2	$(0,1)$	$(0,-1)$	$(1,0)$
2	$(1,0)$	$(g,1)$	$(g,-1)$
2	$(-2,1)$	$(-3,1)$	$(-4,1)$
2	$(-2,1)$	$(-4,1)$	$(-3,1)$
$8N_f$	$(1,0)$	$(1,0)$	$(1,0)$

Tadpole cancellation

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(g, 1)	(g, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(g, 1)	(g, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
8Nf	(1, 0)	(1, 0)	(1, 0)

Tadpole cancellation

$g^2 + N_4 + 4n = 14$

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(g, 1)	(g, −1)
2	(0, 1)	(1, 0)	(0, −1)
2	(0, 1)	(0, −1)	(1, 0)
2	(1, 0)	(g, 1)	(g, −1)
2	(−2, 1)	(−3, 1)	(−4, 1)
2	(−2, 1)	(−4, 1)	(−3, 1)
8Nf	(1, 0)	(1, 0)	(1, 0)

Tadpole cancellation

$g^2 + N_f + 4n = 14$

$N_{Hwr} = 64n.$

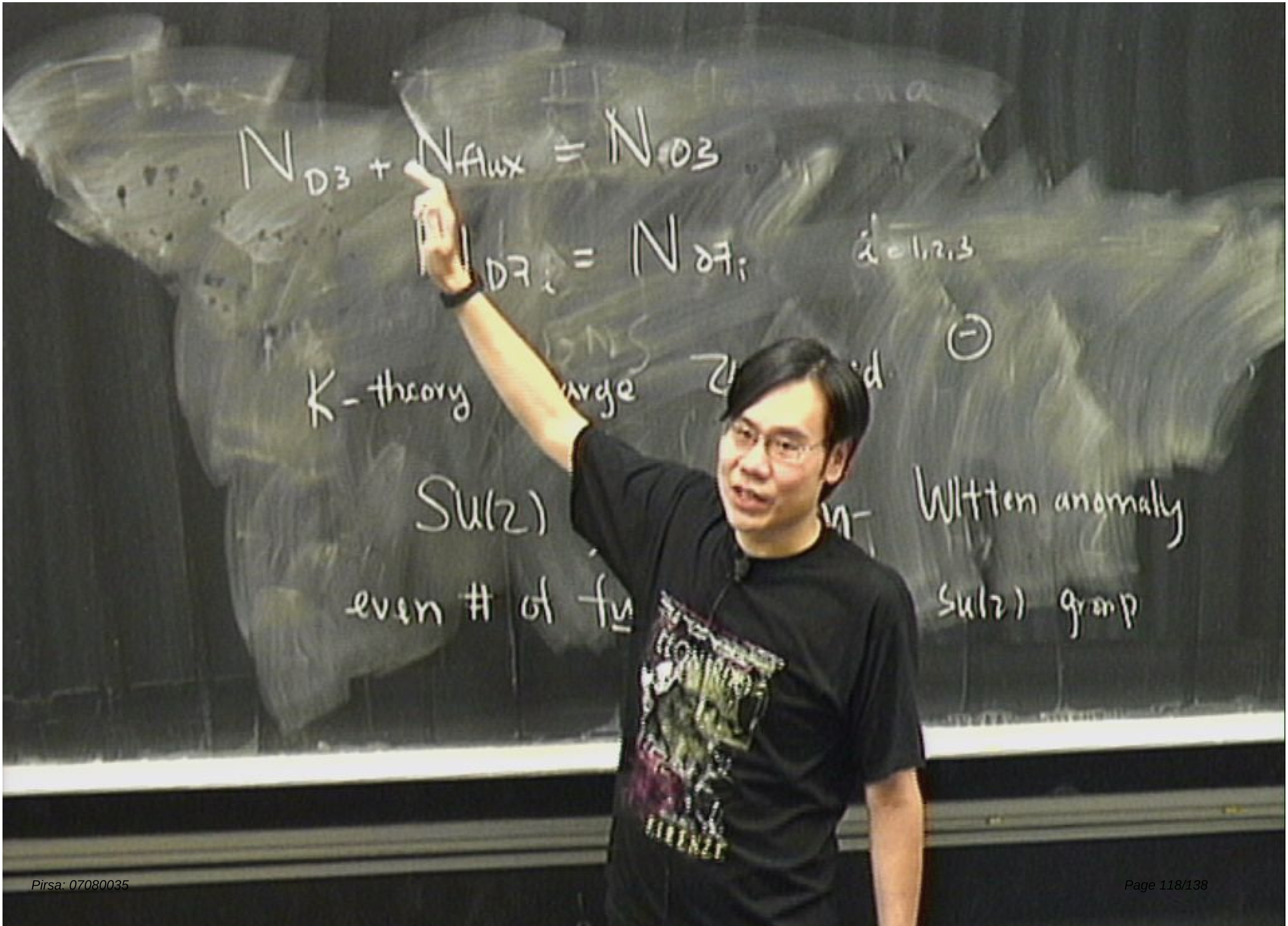
N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(g, 1)	(g, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(g, 1)	(g, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
$8N_f$	(1, 0)	(1, 0)	(1, 0)

Tadpole cancellation

$g^2 + N_f + 4n = 14$

$N_{flux} = 64n.$

N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(g, 1)	(g, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(g, 1)	(g, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
$8N_f$	(1, 0)	(1, 0)	(1, 0)


N D3 + N flux = N O3
N D7 i = N O7 i
i ∈ 1,2,3
K- theory
Witten anomaly
SU(2)
even # of
SU(2) group

$$N_{D3} + N_{flux} = N_{O3}$$

$$N_{D7_i} = N_{O7_i} \qquad i = 1,2,3$$

K-theory charge $\mathbb{Z}_2$-valued $\ominus$

SU(2) global anomaly – Witten anomaly

even # of <u>fund</u> rep under SU(2) group

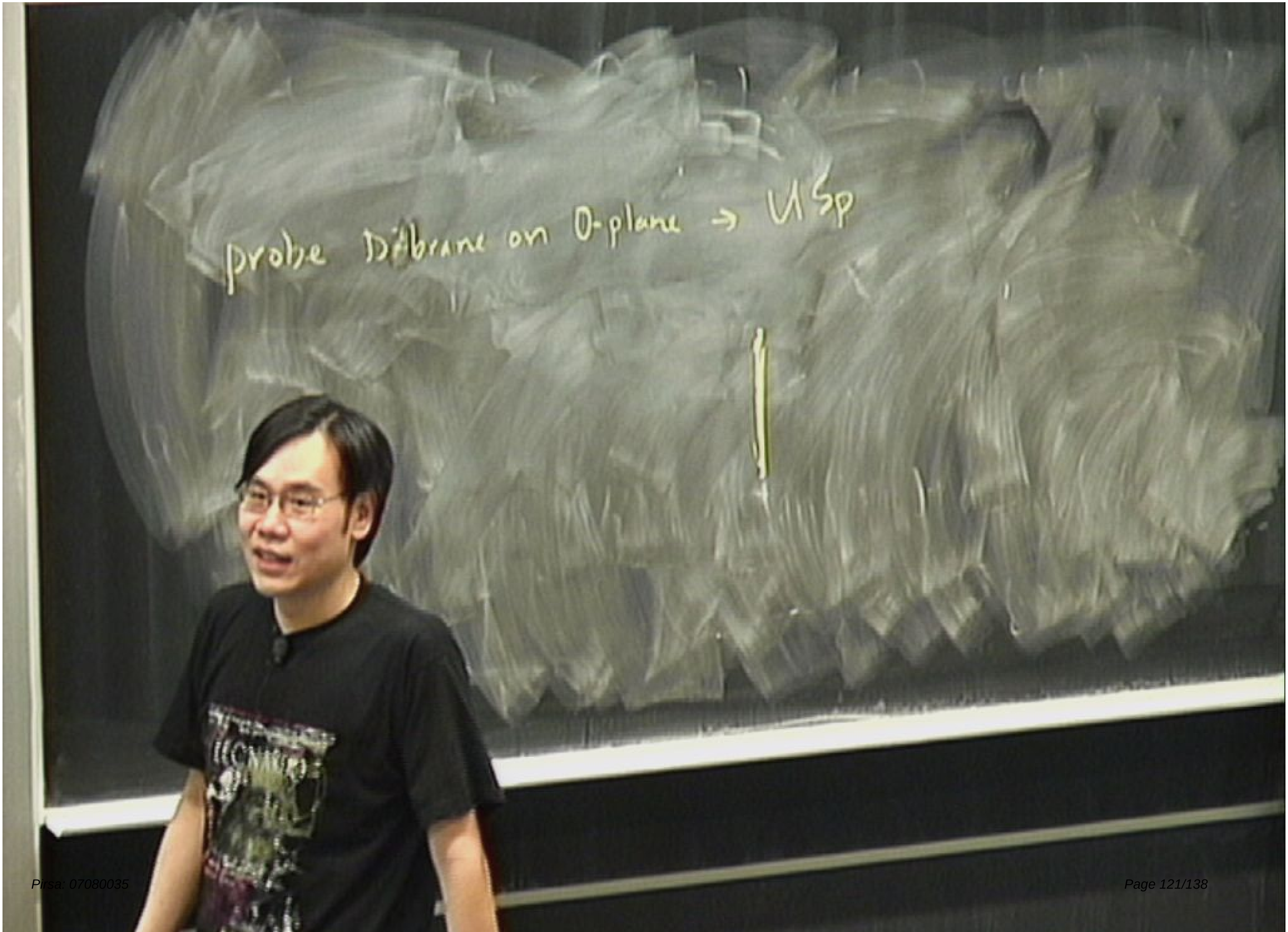
$N_{D3} + N_{flux} = N_{O3}$

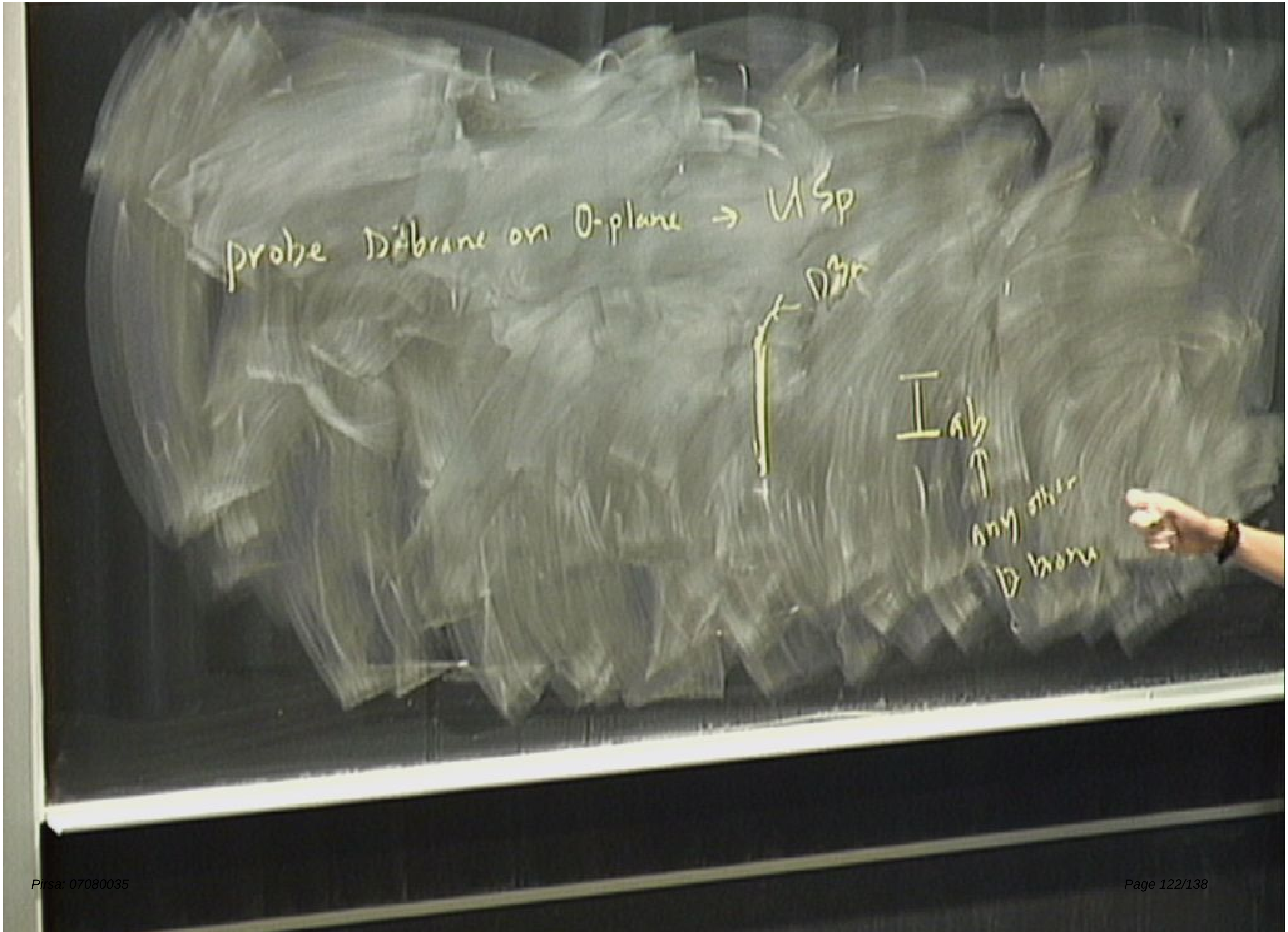
$N_{D7_i} = N_{O7_i}$ $i = 1,2,3$

K-theory charge $\mathbb{Z}_2$-valued ⊖ RR potential

SU(2) global anomaly - Witten anomaly

even # of fund rep under SU(2) group


probe D-brane on O-plane → USp


probe D-brane on O-plane → USp
I_{ab}
any other
D brane

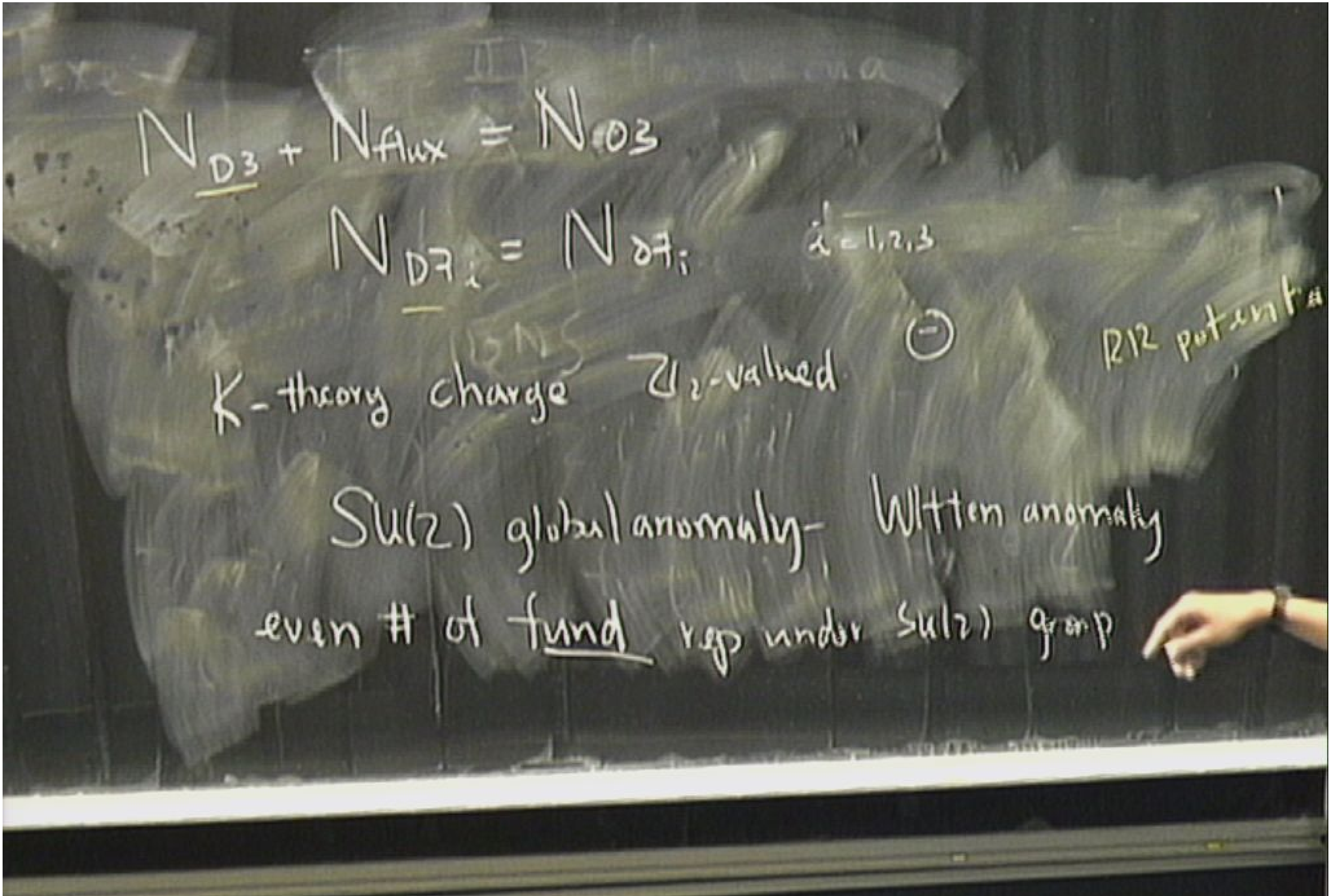
probe D4brane on O-plane → USp

D3 [illegible]

I_{ab}

↑

any other D brane

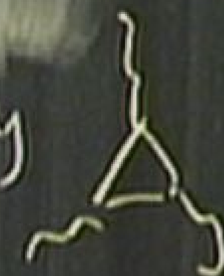

$N_{D3} + N_{flux} = N_{O3}$
$N_{D7_i} = N_{O7_i}$ $i = 1,2,3$
RR potential
K-theory charge $\mathbb{Z}_2$-valued
SU(2) global anomaly - Witten anomaly
even # of fund rep under SU(2) group

$$N_{D3} + N_{flux} = N_{O3}$$

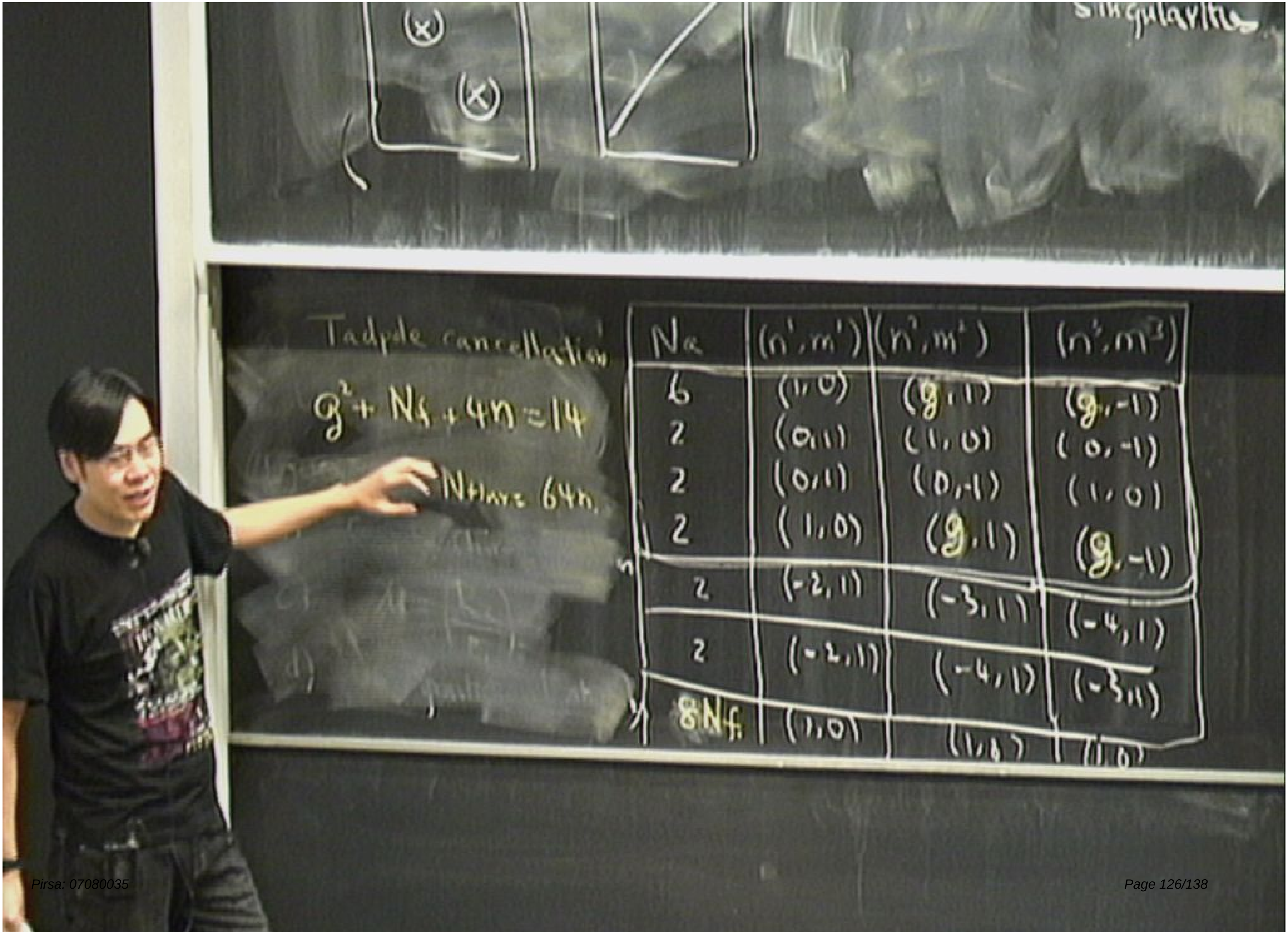
$$N_{D7_i} = N_{O7_i} \qquad i = 1,2,3$$

K-theory charge $\mathbb{Z}_2$-valued ⊖ RR potential

SU(2) global anomaly - Witten anomaly



even # of fund rep under SU(2) group

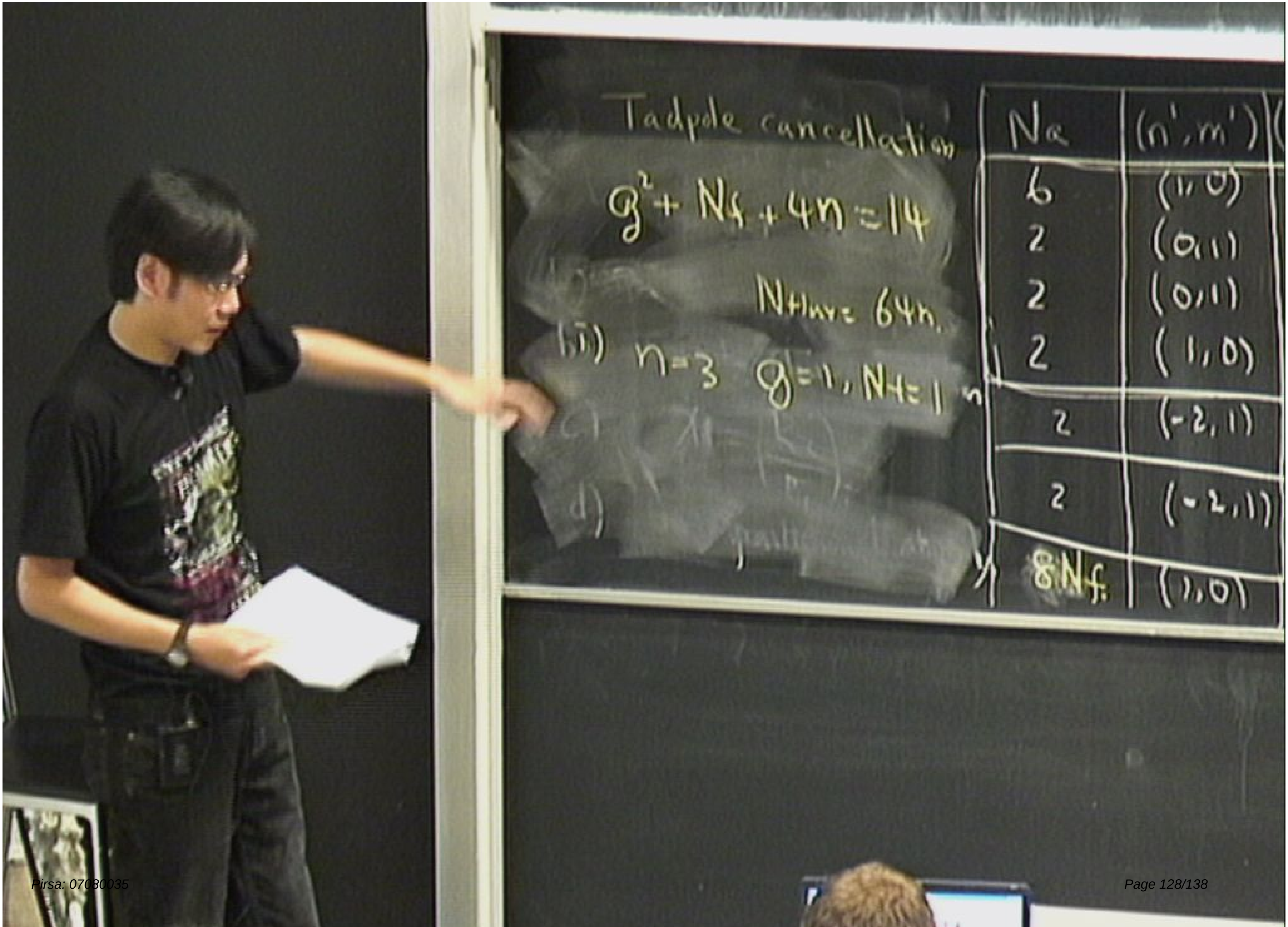

Tadpole cancellation
$g^2 + N_f + 4n = 14$
Nflavs 64n
N_a | (n^1, m^1) | (n^2, m^2) | (n^3, m^3)
6 | (1, 0) | (g, 1) | (g, -1)
2 | (0, 1) | (1, 0) | (0, -1)
2 | (0, 1) | (0, -1) | (1, 0)
2 | (1, 0) | (g, 1) | (g, -1)
2 | (-2, 1) | (-3, 1) | (-4, 1)
2 | (-2, 1) | (-4, 1) | (-3, 1)
$8N_f$ | (1, 0) | (1, 0) | (1, 0)

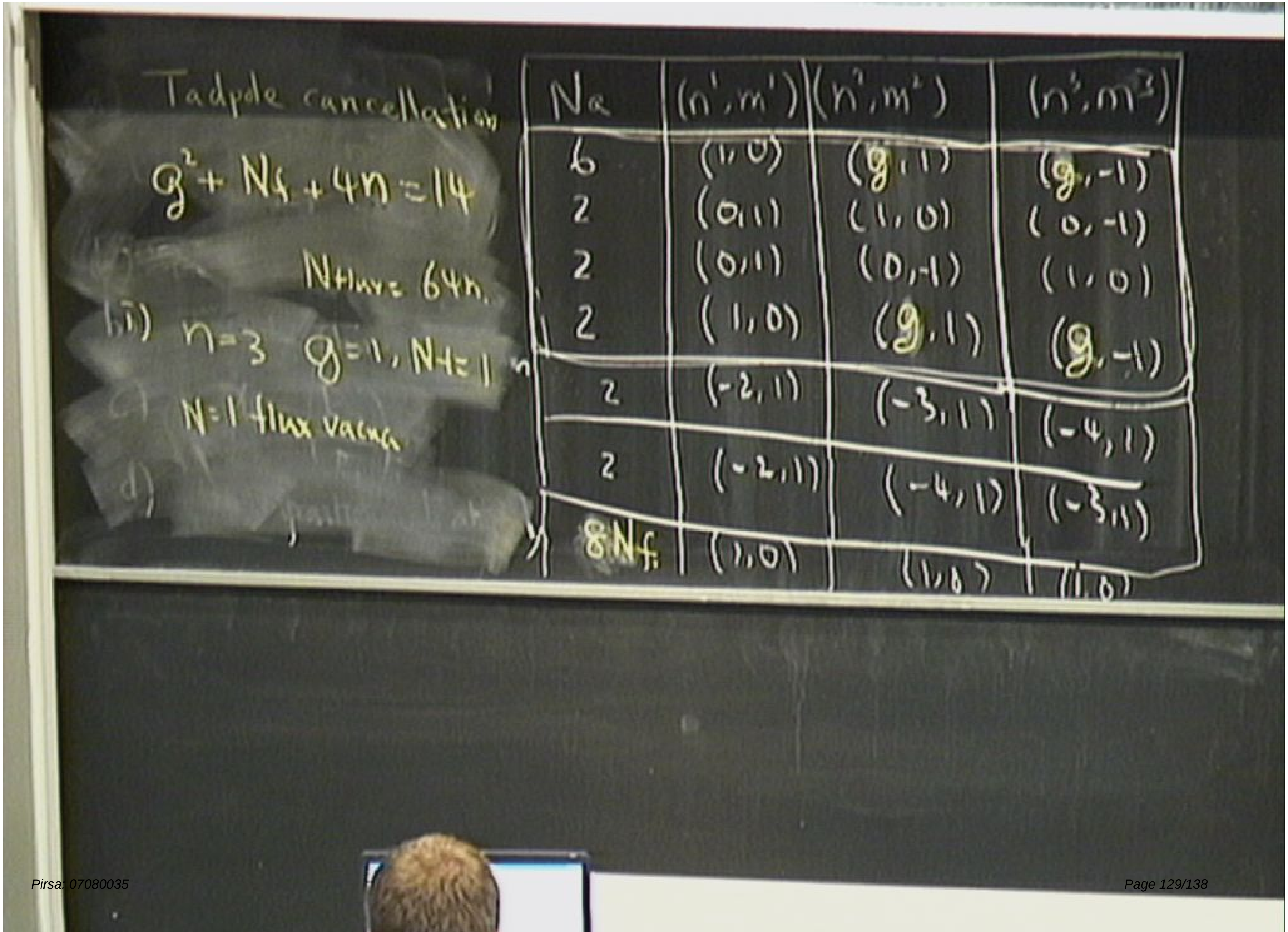
Tadpole cancellation

$g^2 + N_f + 4n = 14$

$N_{three} = 6 + n$.

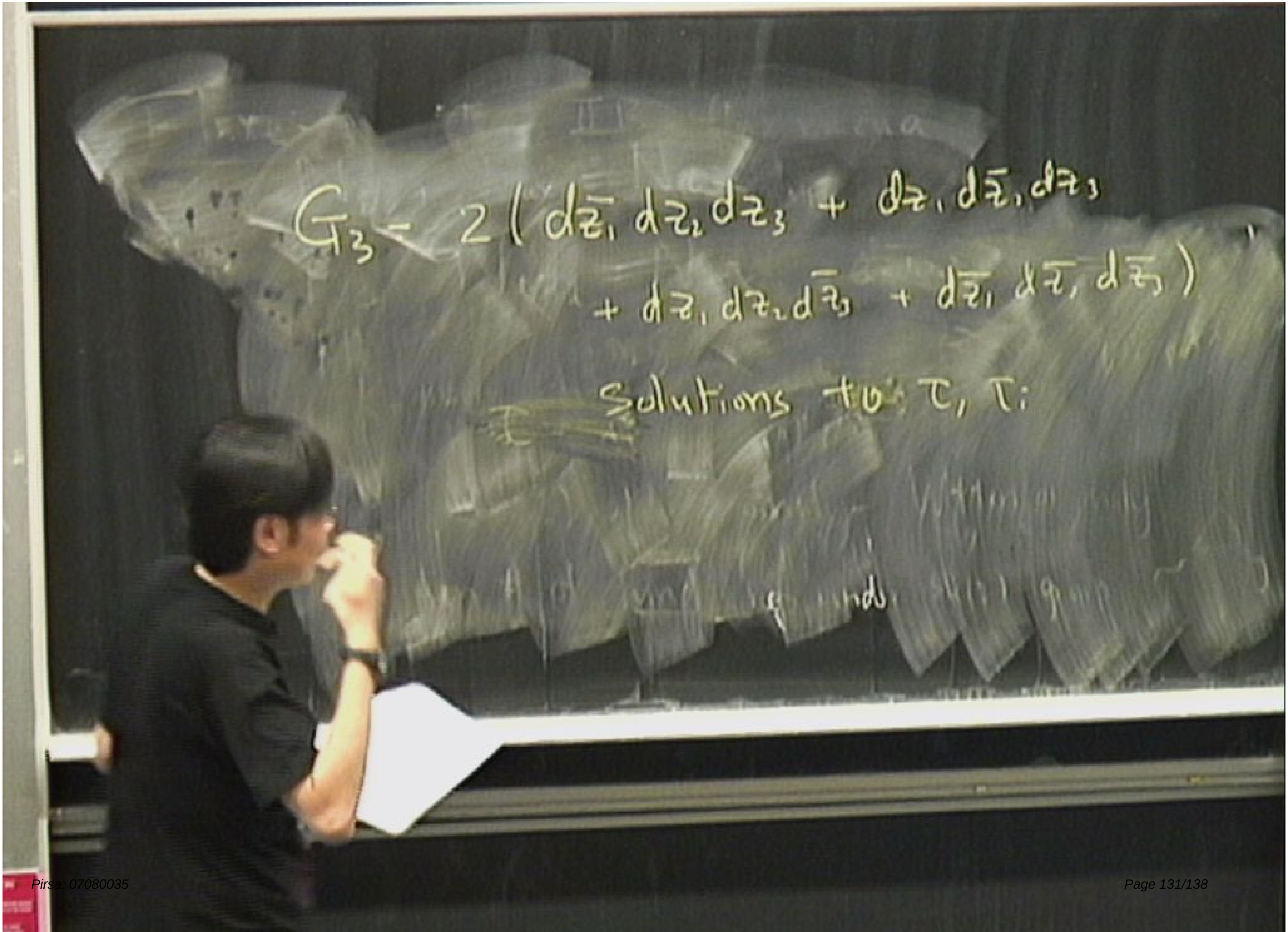
N_a	(n^1, m^1)	(n^2, m^2)	(n^3, m^3)
6	(1, 0)	(g, 1)	(g, -1)
2	(0, 1)	(1, 0)	(0, -1)
2	(0, 1)	(0, -1)	(1, 0)
2	(1, 0)	(g, 1)	(g, -1)
2	(-2, 1)	(-3, 1)	(-4, 1)
2	(-2, 1)	(-4, 1)	(-3, 1)
8 N_f	(1, 0)	(1, 0)	(1, 0)


Tadpole cancellation
g² + Nf + 4n = 14
(iii) n=3 g=1, Nf=1
Na
(n',m')
6
(1,0)
2
(0,1)
2
(0,1)
2
(1,0)
2
(-2,1)
2
(-2,1)
8Nf
(1,0)



Tadpole cancellation
g² + Nf + 4n = 14
Nflux = 64n.
(ii) n=3 g=1, Nf=1
N=1 flux vacua
Na (n¹,m¹) (n²,m²) (n³,m³)
6 (1,0) (g,1) (g,-1)
2 (0,1) (1,0) (0,-1)
2 (0,1) (0,-1) (1,0)
2 (1,0) (g,1) (g,-1)
2 (-2,1) (-3,1) (-4,1)
2 (-2,1) (-4,1) (-3,1)
8Nf (1,0) (1,0) (1,0)

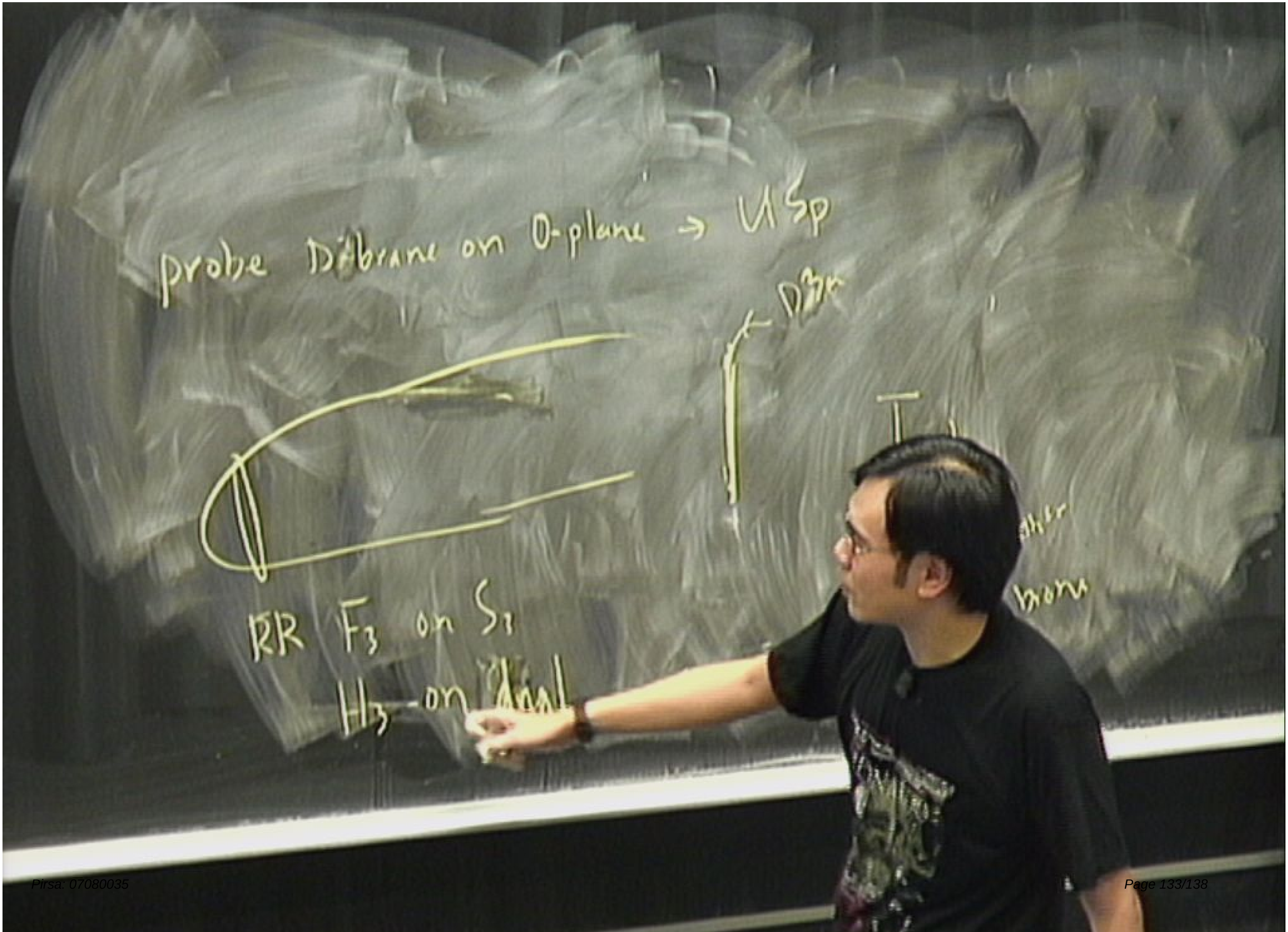
$$G_3 = 2\left(d\bar{z}_1\, dz_2\, dz_3 + dz_1\, d\bar{z}_2\, dz_3 + dz_1\, dz_2\, d\bar{z}_3 + d\bar{z}_1\, d\bar{z}_2\, d\bar{z}_3 \right)$$

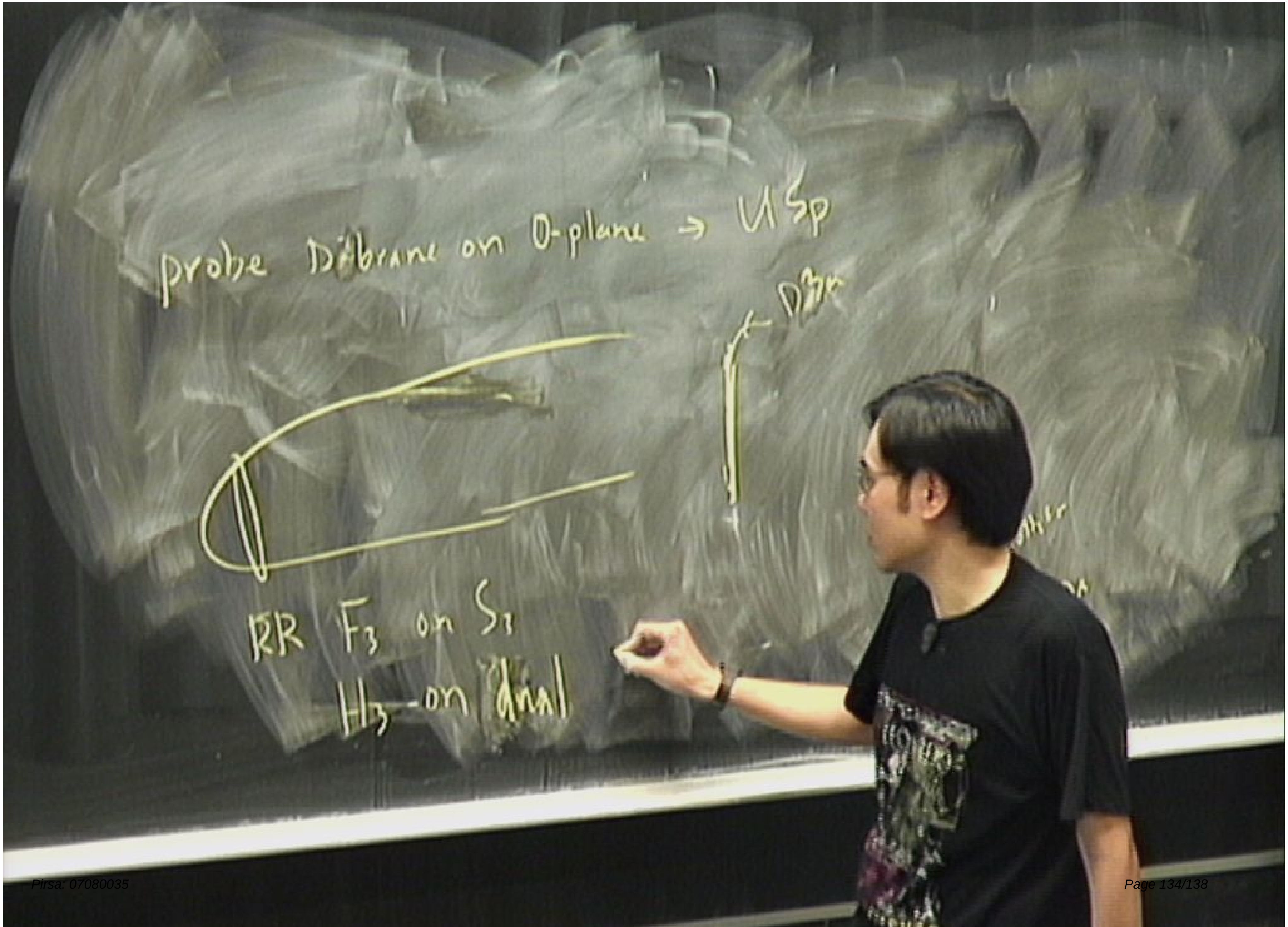

G3 = 2 (dz̄1 dz2 dz3 + dz1 dz̄2 dz3
+ dz1 dz2 dz̄3 + dz̄1 dz̄2 dz̄3)
Solutions to τ, τ̄:

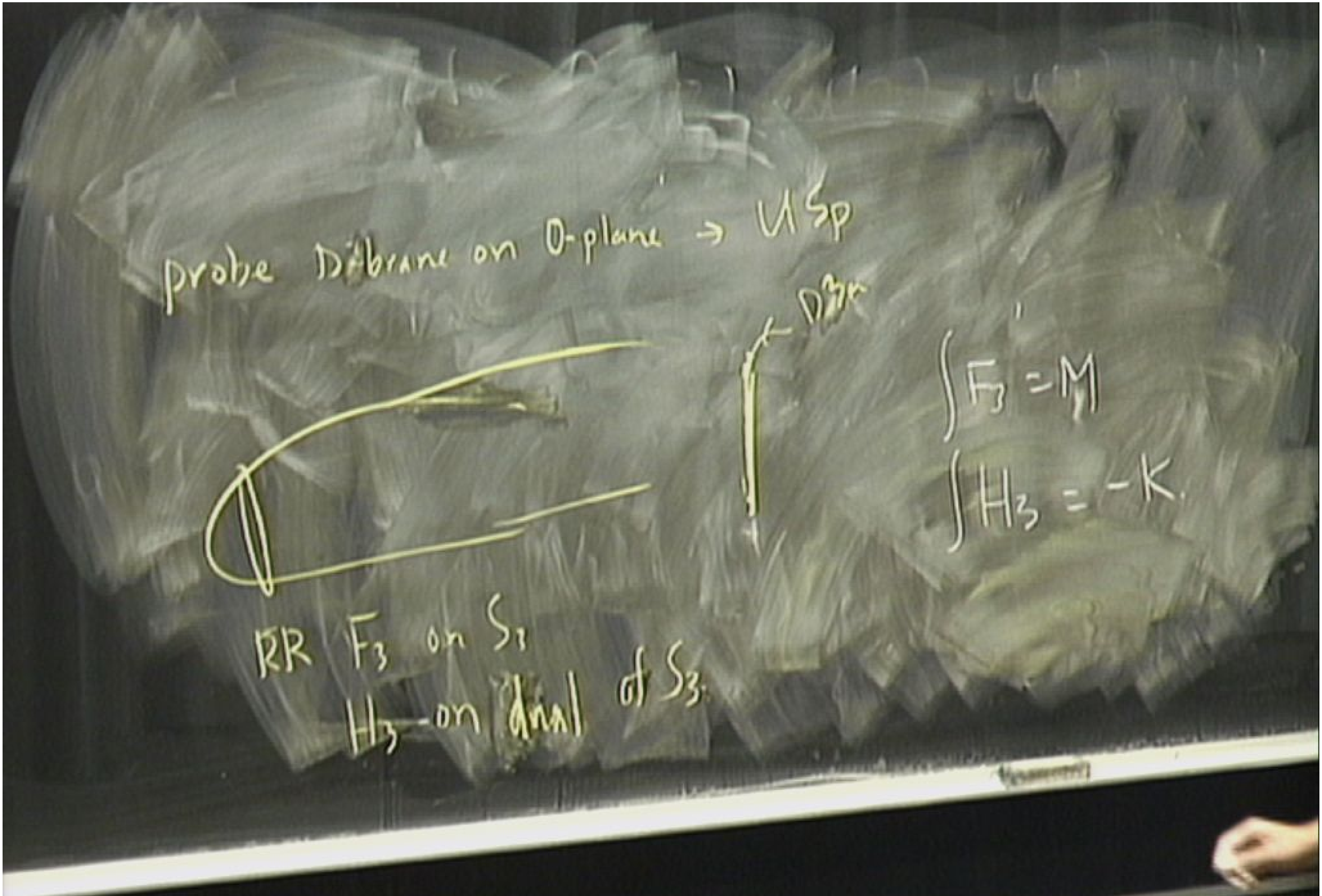
$$G_3 = 2\,(d\bar{z}_1\, dz_2\, dz_3 + dz_1\, d\bar{z}_2\, dz_3 + dz_1\, dz_2\, d\bar{z}_3 + d\bar{z}_1\, d\bar{z}_2\, d\bar{z}_3)$$

Solutions to τ, τ:

minimize V.


probe D-brane on O-plane → USp
RR F3 on S3


probe D-brane on O-plane → USp
RR F3 on S3
H3 on dual


probe D-brane on O-plane → USp
D3
∫F3 = M
∫H3 = -K.
RR F3 on S3
H3 on dual of S3.

probe D3brane on O-plane → USp

$$\int F_3 = -M$$

$$\int H_3 = -K$$

RR F_3 on S_3

H_3 on dual of S_3.

$$e^{-\frac{2\pi K}{3 M g_s}}$$

probe D3brane on O-plane → USp

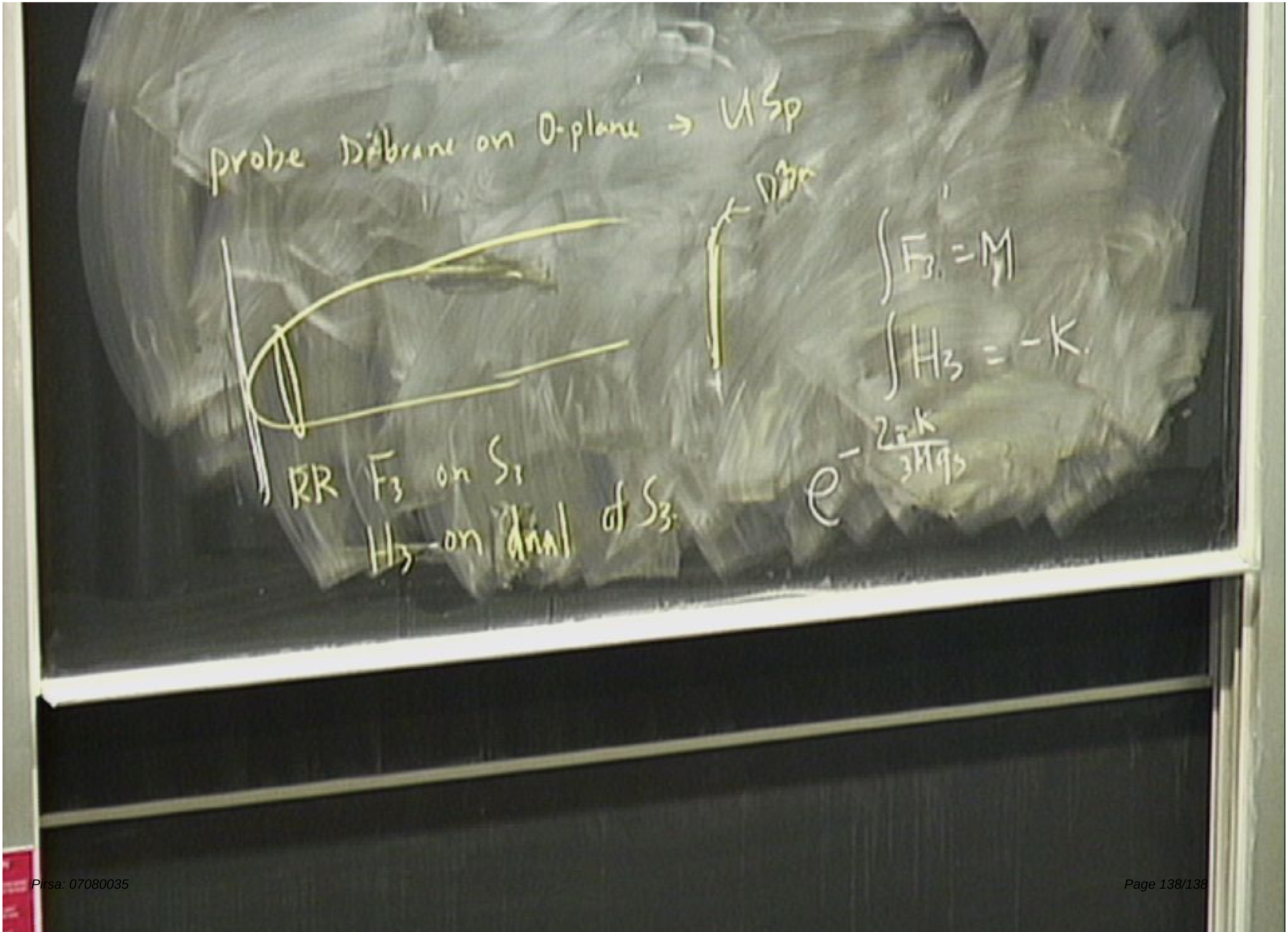
$\int F_3 = -M$

$\int H_3 = -K$

RR F_3 on S_3

H_3 on dual of S_3

$e^{-\frac{2\pi K}{3 M g_s}}$


probe D3brane on O-plane → USp
D3br
∫F3 = -M
∫H3 = -K
RR F3 on S3
H3 on dual of S3
e^{-2πK/3Mgs}