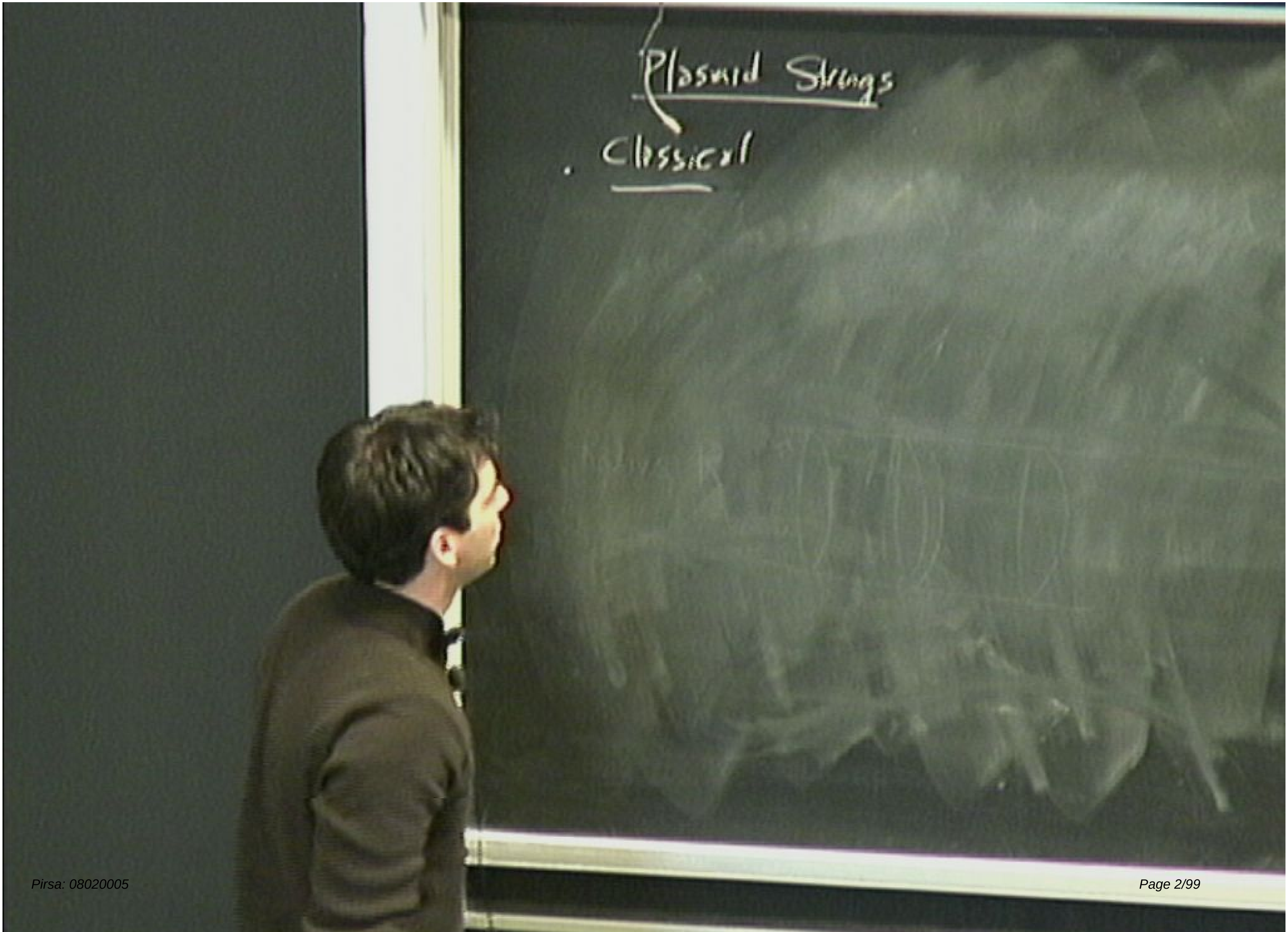
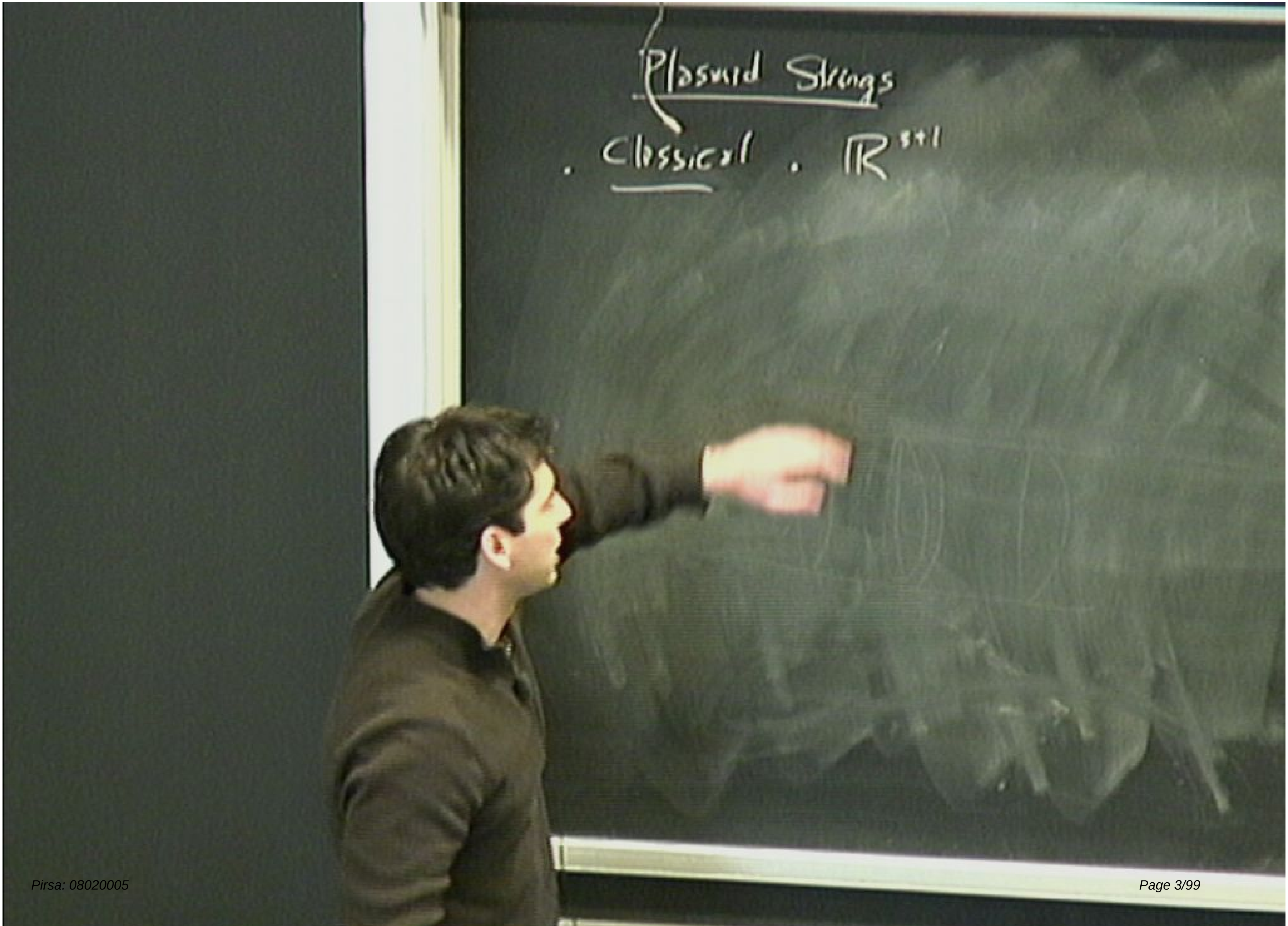
Title: Plasmid Strings

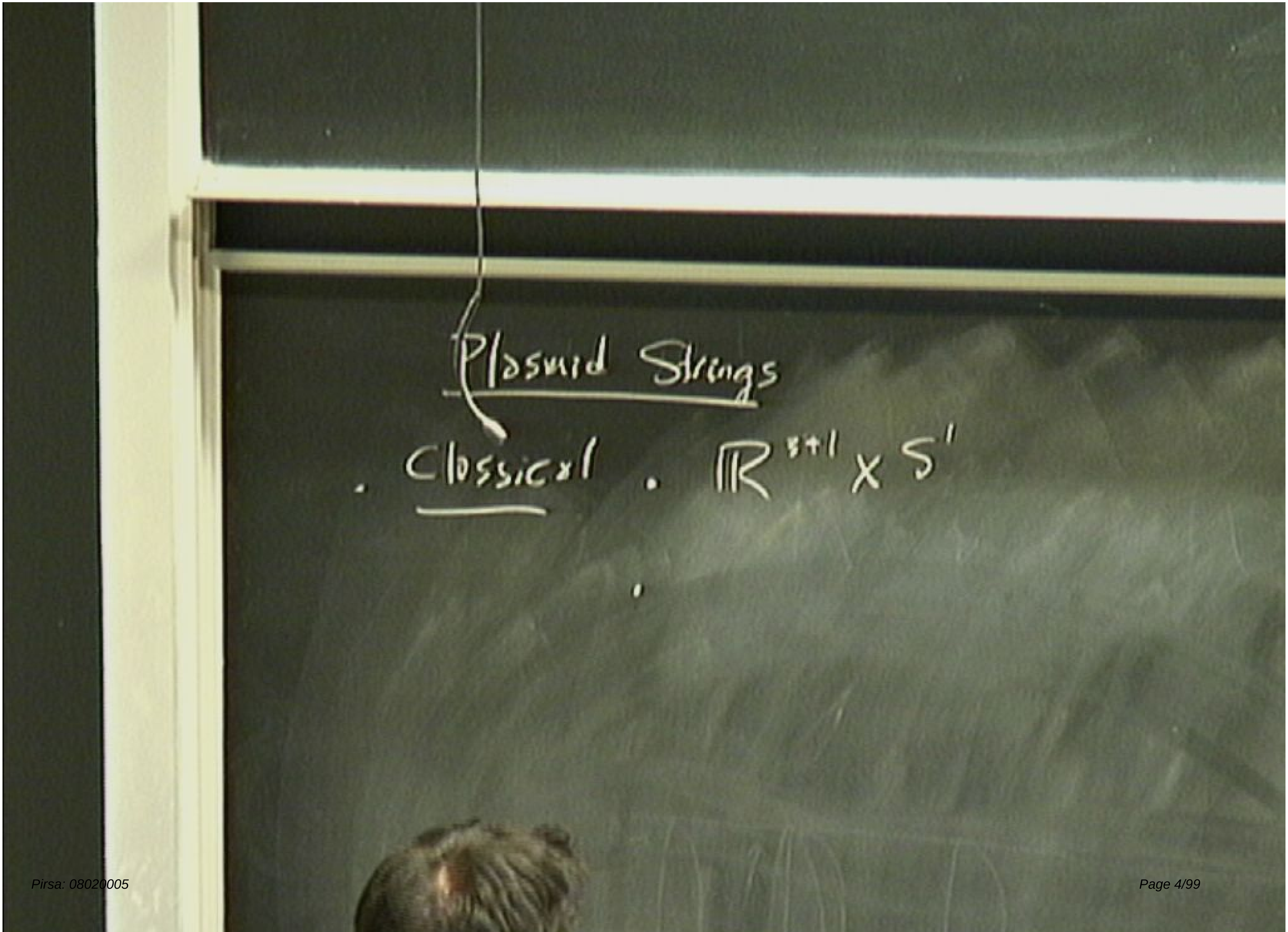
Date: Feb 12, 2008 02:00 PM

URL: http://pirsa.org/08020005

Abstract: I\'ll introduce a particular class of fundamental string configurations in the form of closed loops stabilized by internal dynamics. I\\\'ll describe their classical treatment and embedding in models of string cosmology. I\\\'ll present the quantum version and the semiclassical limit that provides a microscopic description of dipole black rings. I\\\'ll show the parametric matching between the degeneracy of microstates and the entropy of the supergravity solution.


Plasmid Strings
Classical


Plasmid Strings
· Classical · $\mathbb{R}^{3+1}$

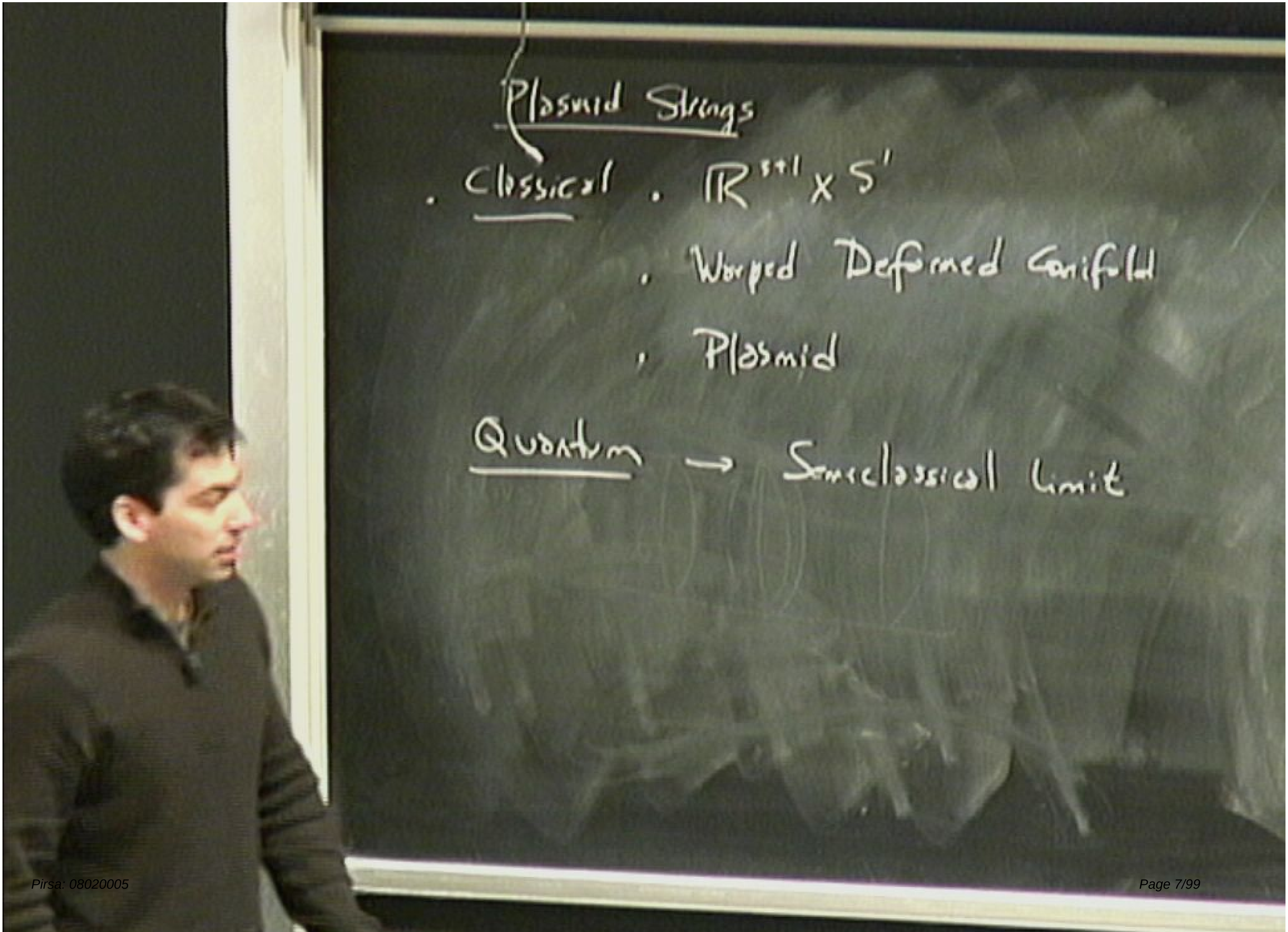

Plasmid Strings
Classical
$\mathbb{R}^{3+1} \times S^1$

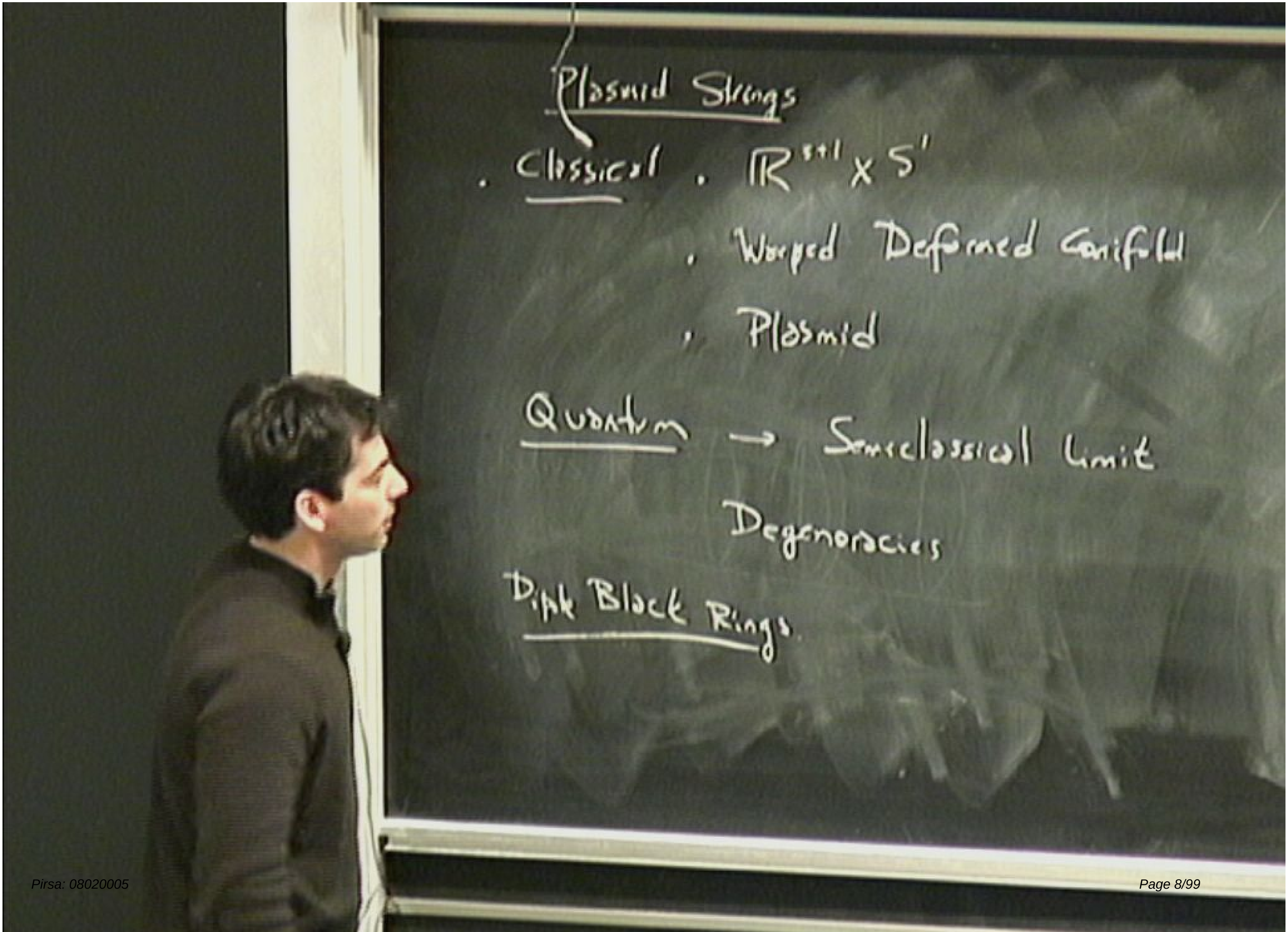
Plasmid Strings

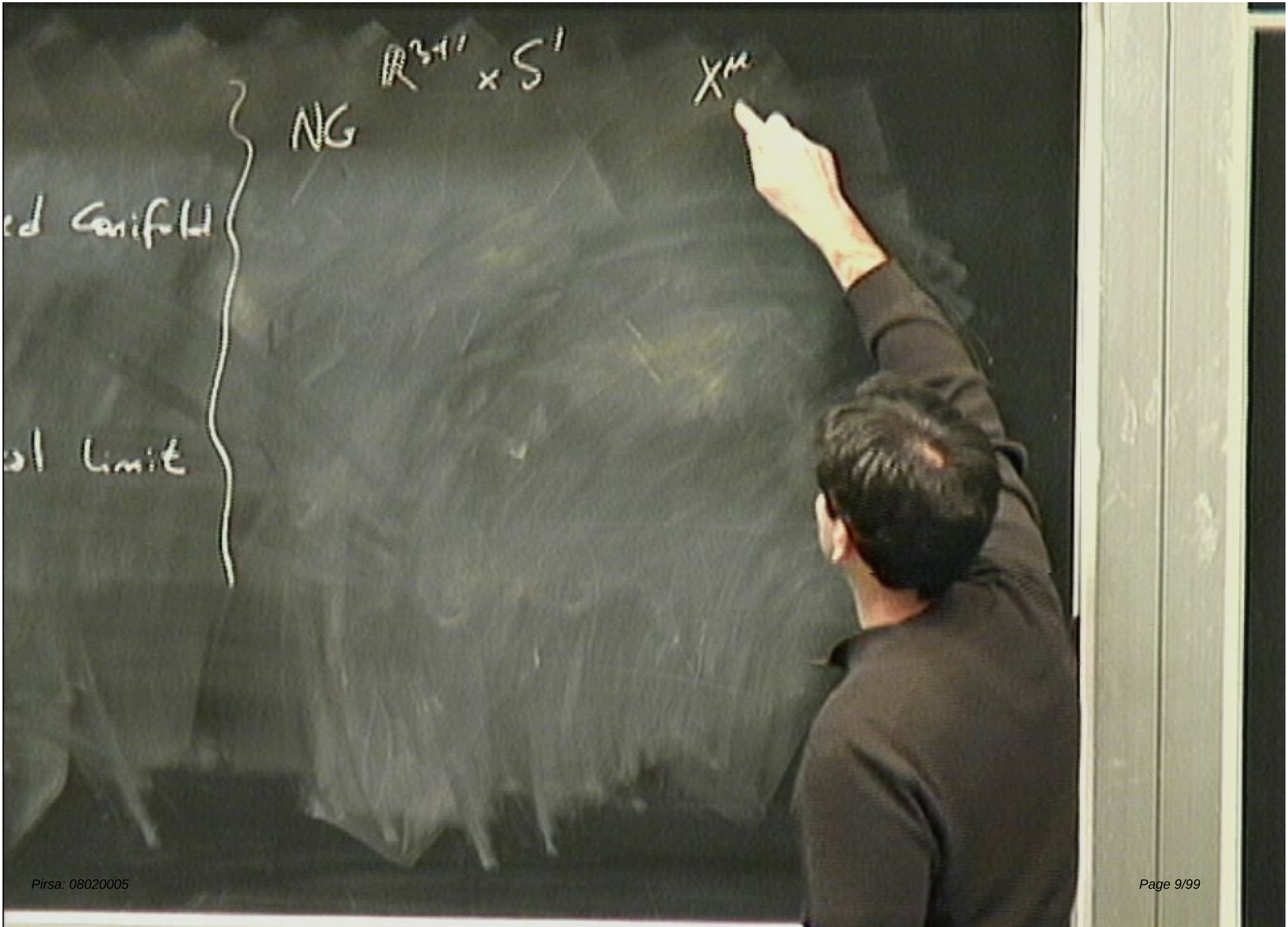
- Classical
    - $\mathbb{R}^{3+1} \times S^1$
    - Warped Deformed Conifold

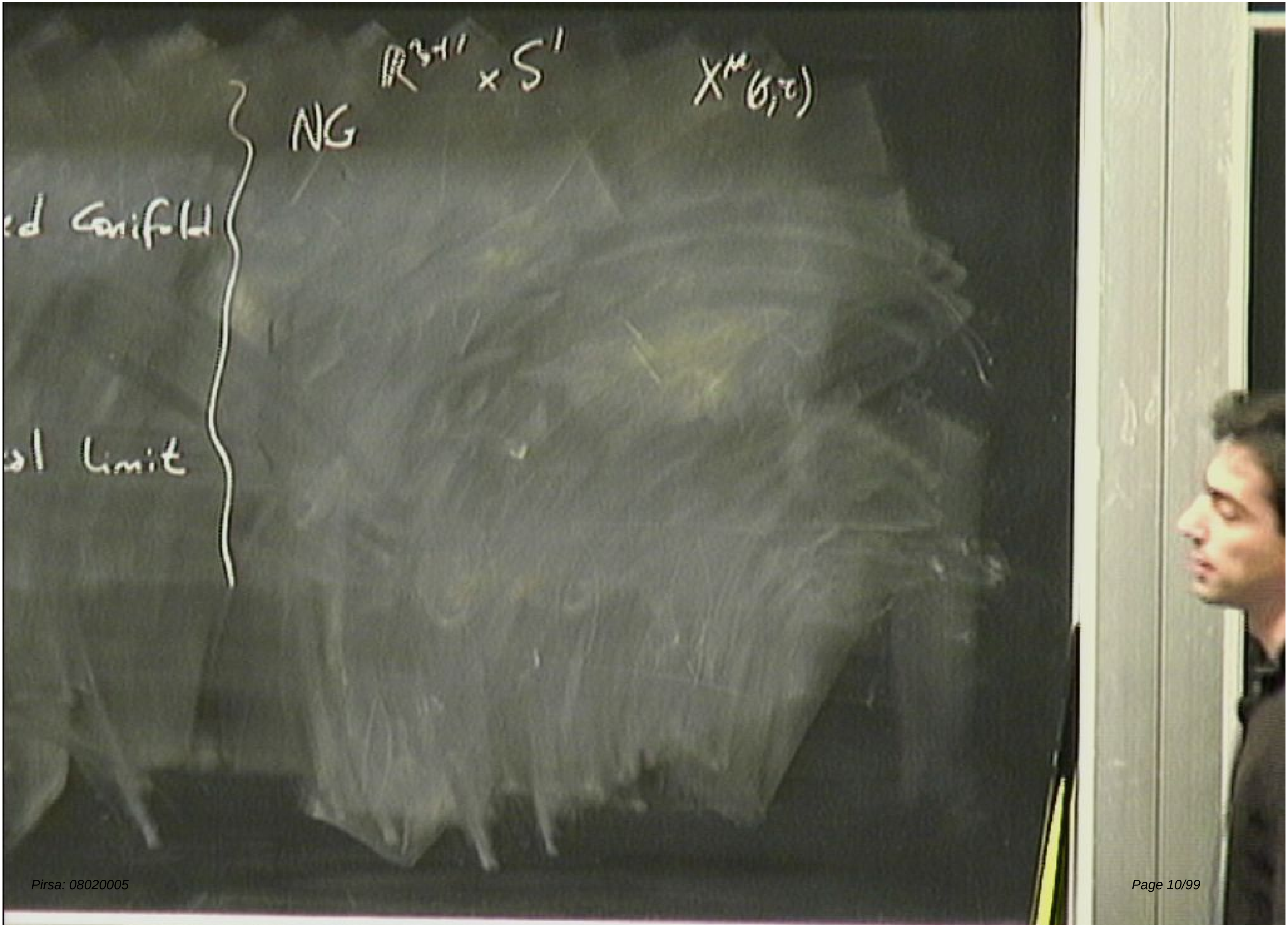
Plasmid Strings

- Classical
  - $\mathbb{R}^{3+1} \times S^1$
  - Warped Deformed Conifold
  - Plasmid


Plasmid Strings
Classical
$\mathbb{R}^{3+1} \times S^1$
Warped Deformed Conifold
Plasmid
Quantum → Semiclassical Limit


Plasmid Strings
. Classical . $\mathbb{R}^{3+1} \times S^1$
. Warped Deformed Conifold
. Plasmid
Quantum → Semiclassical Limit
Degeneracies
Dipole Black Rings


NG
$\mathbb{R}^{3+1} \times S^1$
X^μ
ed Conifold
al Limit


$\mathbb{R}^{3+1} \times S^1$
$X^\mu(\sigma,\tau)$
NG
Conifold
limit

$\mathbb{R}^{3+1} \times S^1$

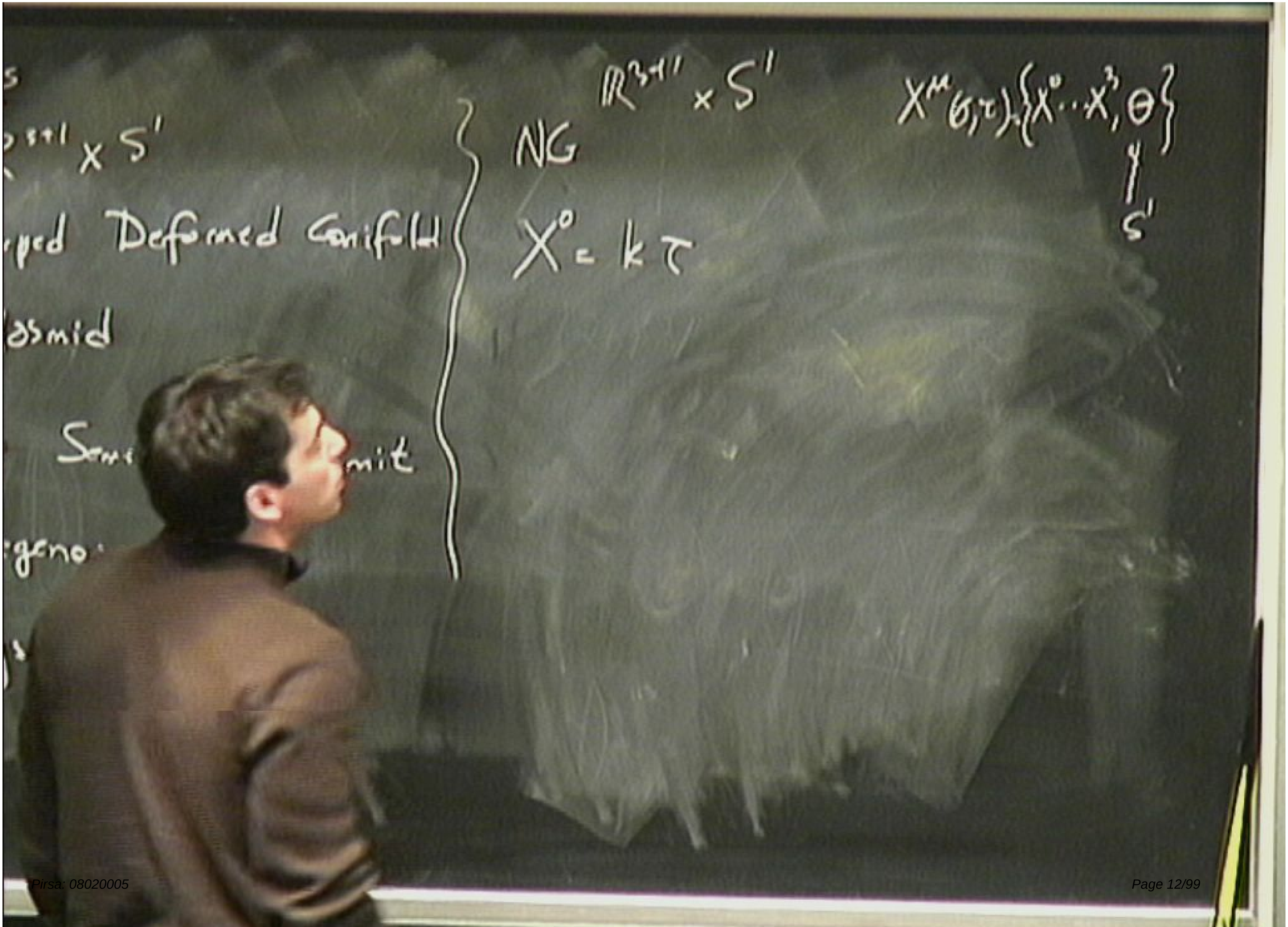
$X^\mu(\sigma,\tau) \to \{X^0 \cdots X^3, \theta\}$

$\theta \in S^1$

NG

ed Conifold

al Limit


$\mathbb{R}^{3+1} \times S^1$
$\times S^1$
Deformed Conifold
osmid
mit
NG
$X^0 = k\tau$
$X^\mu(\sigma,\tau) \cdot \{X^0 \cdots X^3, \Theta\}$
S^1

$\mathbb{R}^{3+1} \times S^1$

$X^\mu(\sigma,\tau) = \{X^0 \cdots X^3, \theta\}$

$\theta \in S^1$

Conif. ld

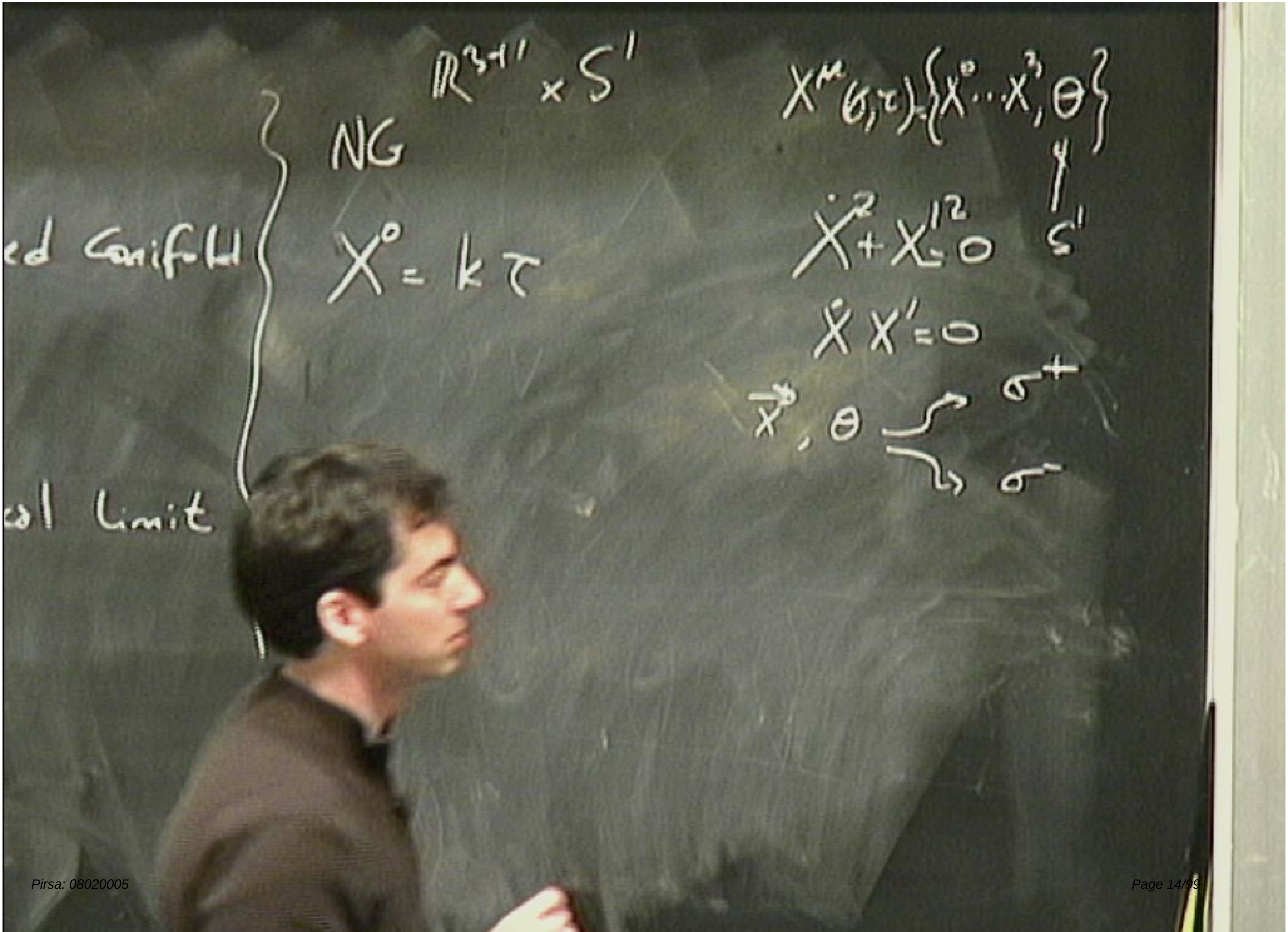
NG

$X^0 = k\tau$

$\dot{X}^2 + X'^2 = 0$

$\dot{X} X' = 0$

Limit



$\mathbb{R}^{3+1} \times S^1$
NG
$X^0 = k\tau$
ed Conifold
cal Limit
$X^\mu(\sigma,\tau) = \{X^0 \cdots X^3, \theta\}$
S^1
$\dot{X}^2 + X'^2 = 0$
$\dot{X} X' = 0$
$\vec{X}, \theta$
σ^+
σ^-

$\mathbb{R}^{3+1} \times S^1$

$X^\mu(\sigma,\tau) = \{X^0 \cdots X^3, \Theta\}$

S^1

ed Conifold

NG

$X^0 = k\tau$

$\dot{X}^2 + X'^2 = 0$

$\dot{X} X' = 0$

$\vec{x}, \theta \rightarrow \sigma^+$

$\rightarrow \sigma^-$

al Limit

S^1

Deformed Conifold

Classical Limit

$\mathbb{R}^{3+1} \times S^1$

NG

$X^\mu(\sigma,\tau) \to \{X^0 \cdots X^3, \theta\}$

θ: S^1

$X^0 = k\tau$

$\vec{X} = \vec{a}(\sigma^+)$

$\dot{X}^2 + X'^2 = 0$

$\dot{X} X' = 0$

$\vec{x}, \theta \to \sigma^+, \sigma^-$

S^1

Deformed Conifold

classical limit

ies

$\mathbb{R}^{3+1} \times S^1$

NG

$X^0 = k\tau$

$\vec{X} = \vec{a}(\sigma^+)$

$\theta =$

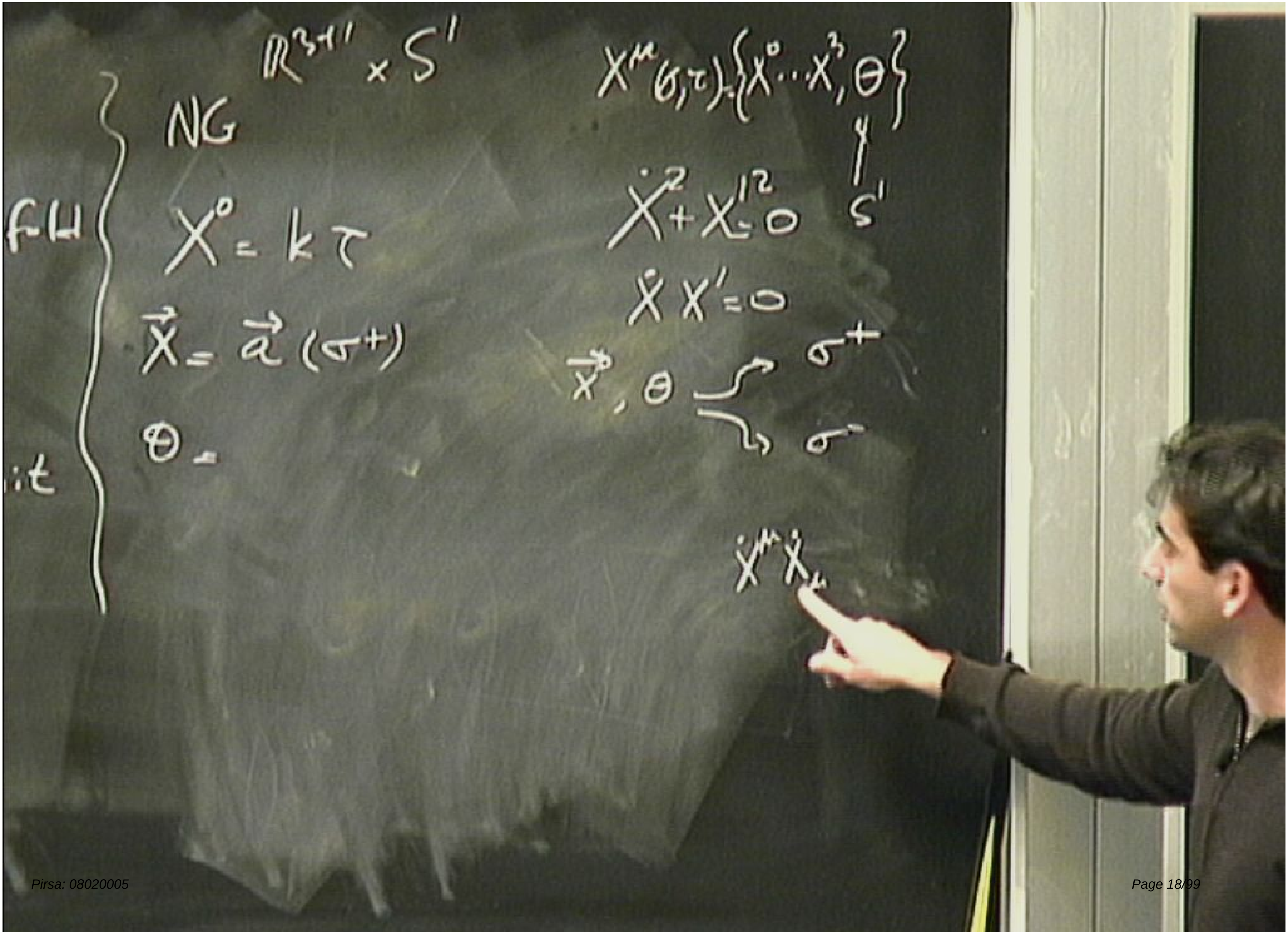
$X^\mu(\sigma,\tau) = \{X^0 \cdots X^3, \theta\}$

S^1

$\dot{X}^2 + X'^2 = 0$

$\dot{X} X' = 0$

$\vec{x}, \theta \to \sigma^+, \sigma^-$


$\mathbb{R}^{3+1} \times S^1$
NG
$X^0 = k\tau$
$\vec{X} = \vec{a}(\sigma^+)$
$\Theta =$
$X^\mu(\sigma,\tau) = \{X^0 \ldots X^3, \Theta\}$
S^1
$\dot{X}^2 + X'^2 = 0$
$\dot{X} X' = 0$
$\vec{x}, \theta$
σ^+
σ^-
$\dot{X}^\mu \dot{X}_\mu$

$\times S^1$

Deformed Conifold

d

ical Limit

$\mathbb{R}^{3+1} \times S^1$

NG

$X^0 = k\tau$

$\vec{X} = \vec{a}(\sigma^+)$

$\theta = k\tau$

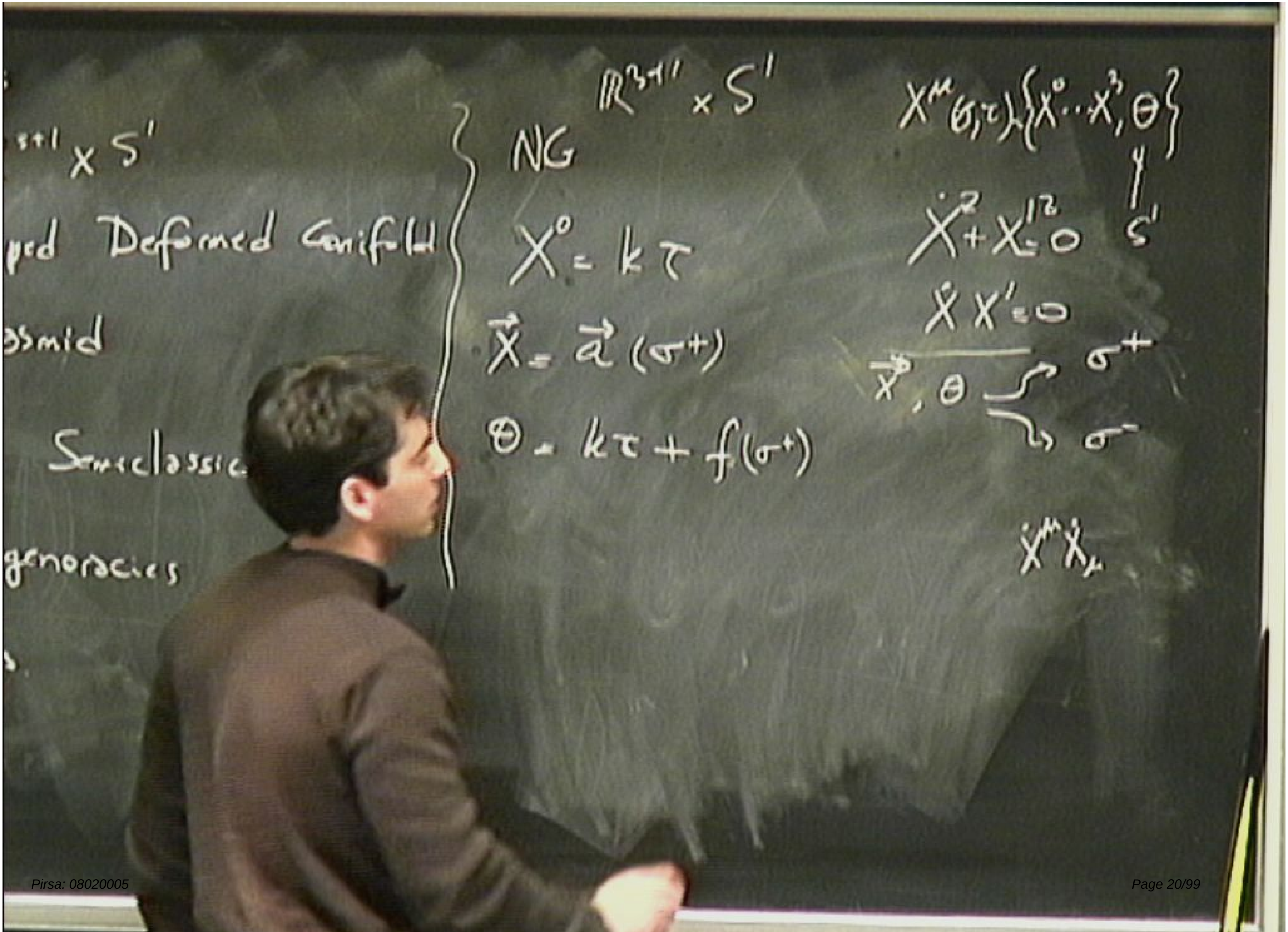
$X^\mu(\sigma,\tau) = \{X^0 \cdots X^3, \underbrace{\theta}_{S^1}\}$

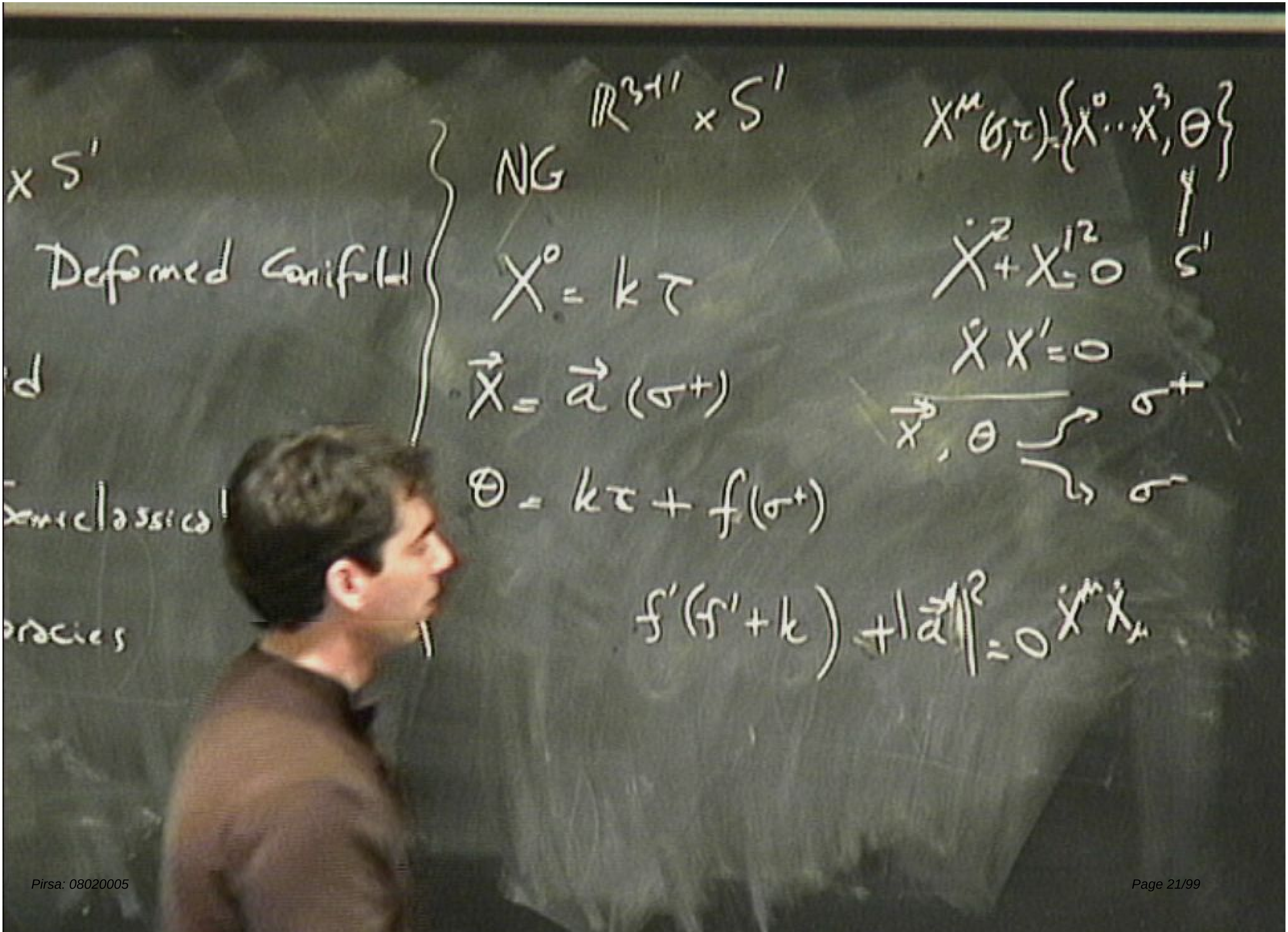
$\dot{X}^2 + X'^2 = 0$

$\dot{X} X' = 0$

$\vec{x}, \theta \rightarrow \sigma^+, \sigma^-$

$\dot{X}^\mu \dot{X}_\mu$


$\times S^1$
Deformed Conifold
NG
$\mathbb{R}^{3+1} \times S^1$
$X^\mu(\sigma,\tau) \{X^0 \ldots X^3, \theta\}$
S^1
$X^0 = k\tau$
$\vec{X} = \vec{a}(\sigma^+)$
$\Theta = k\tau + f(\sigma^+)$
$\dot{X}^2 + X'^2 = 0$
$\dot{X} X' = 0$
$\vec{x}, \theta$
σ^+
σ^-
$\dot{X}^\mu \dot{X}_\mu$


× S'
Deformed Conifold
Semiclassical
NG
$\mathbb{R}^{3+1} \times S^1$
$X^0 = k\tau$
$\vec{X} = \vec{a}(\sigma^+)$
$\Theta = k\tau + f(\sigma^+)$
$f'(f'+k) + |\vec{a}'|^2 = 0$
$X^\mu(\sigma,\tau) = \{X^0 \cdots X^3, \Theta\}$
$\dot{X}^2 + X'^2 = 0$
$\dot{X} X' = 0$
$\dot{X}^\mu \dot{X}_\mu$
$\vec{X}, \Theta$
σ^+
σ^-
S^1

$\times S^1$

Deformed Conifold

...d

Semiclassical Limit

...racies

$$\mathbb{R}^{3+1} \times S^1 \qquad X^\mu(\sigma,\tau) = \{X^0 \dots X^3, \theta\}$$

NG

$$\theta \in S^1$$

$$X^0 = k\tau \qquad \dot{X}^2 + X'^2 = 0$$

$$\dot{X} X' = 0$$

$$\vec{X} = \vec{a}(\sigma^+)$$

$$\vec{x}, \theta \to \sigma^+, \sigma^-$$

$$\theta = k\tau + f(\sigma^+)$$

$$f'(f' + k) + |\vec{a}'|^2 = 0 \qquad \dot{X}^\mu \dot{X}_\mu$$

ings

$\mathbb{R}^{3+1} \times S^1$

Warped Deformed Conifold

Plasmid

$\rightarrow$ Semiclassical Limit

Degeneracies

ings

$\mathbb{R}^{3+1} \times S^1$

$X^\mu(\sigma,\tau) = \{X^0 \cdots X^3, \theta\}$

$\theta \rightarrow S^1$

NG

$\dot{X}^2 + X'^2 = 0$

$\dot{X} X' = 0$

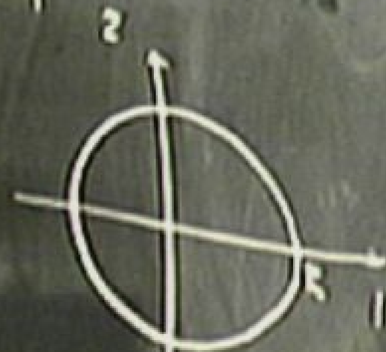
$X^0 = k\tau$

$\vec{X} = \vec{a}(\sigma^+)$

$\vec{X}, \theta \rightarrow \sigma^+, \sigma^-$

$\theta = k\tau + f(\sigma^+)$

$$f'(f'+k) + |\vec{a}'|^2 = 0$$



formed Conifold

lassical Limit

s

$\mathbb{R}^{3+1} \times S^1$

$X^\mu(\sigma,\tau) = \{X^0 \cdots X^3, \theta\}$

$\theta \in S^1$

NG

$\dot{X}^2 + X'^2 = 0$

$X^0 = k\tau$

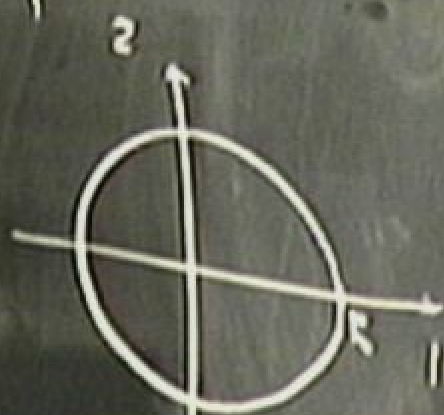
$\dot{X} X' = 0$

$\vec{X} = \vec{a}(\sigma^+)$

$\vec{x}, \theta \to \sigma^+, \ \sigma^-$

$\theta = k\tau + f(\sigma^+)$

$$f'(f'+k) + |\vec{a}'|^2 = 0$$



$$f' = b\sigma^+$$

. Warped Deformed Conifold

. Plasmid

...m → Semiclassical Limit

Degeneracies

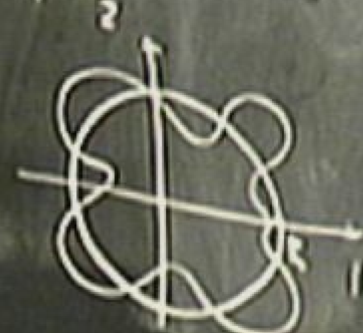
$X^0 = k\tau$

$\vec{X} = \vec{a}(\sigma^+)$

$\theta = k\tau + f(\sigma^+)$

$f'(f'+k) + |\vec{a}'|^2 = 0$

$f' = b\sigma^+$



$\dot{X} + X' = 0$

$\dot{X} X' = 0$

$\vec{x}, \theta \to \sigma^+$

$\to \sigma^-$

Warped Deformed Conifold

Plasmid

→ Semiclassical Limit

Degeneracies

Rings

$X^0 = k\tau$

$\vec{X} = \vec{a}(\sigma^+)$

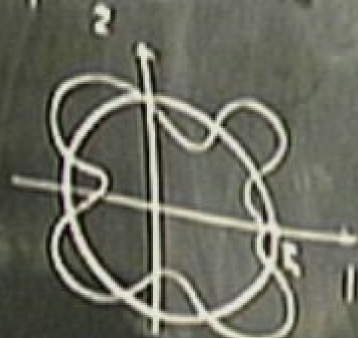
$\Theta = k\tau + f(\sigma^+)$

$f'(f'+k) + |\vec{a}'|^2 = 0$

$\dot{X} + X' = 0 \quad S'$

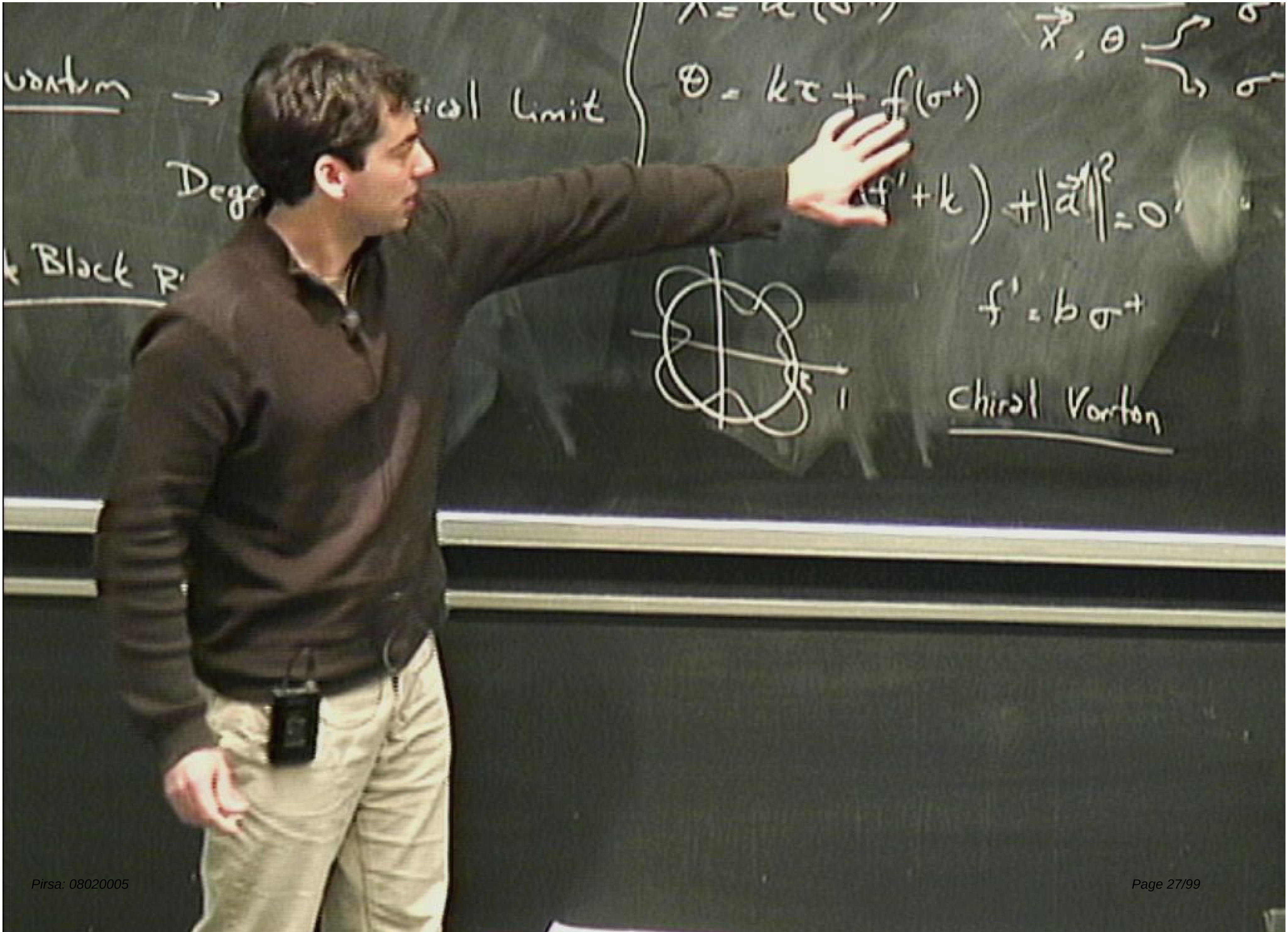
$\dot{X} X' = 0$

$\vec{x}, \theta \to \sigma^+, \sigma^-$



$f' = b\sigma^+$

Chiral Vorton


Limit
Black
Θ = kτ + f(σ+)
f' = b σ+
Chiral Vorton

Strings

$\mathbb{R}^{3+1} \times S^1$

Warped Deformed Conifold

Plasmid

$\rightarrow$ Semiclassical Limit

Degeneracies

Rings $\partial_\sigma \theta$

$\mathbb{R}^{3+1} \times S^1$

NG

$X^0 = k\tau$

$\vec{X} = \vec{a}(\sigma^+)$

$\theta = k\tau + f(\sigma^+)$

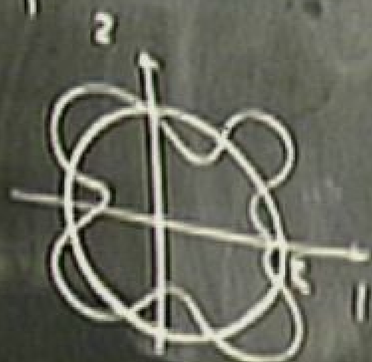
$f'(f'+k) + |\vec{a}'|^2 = 0$

$X^\mu(\sigma,\tau)\{X^0 \cdots X^3, \theta\}$ (θ: S^1)

$\dot{X}^2 + X'^2 = 0$

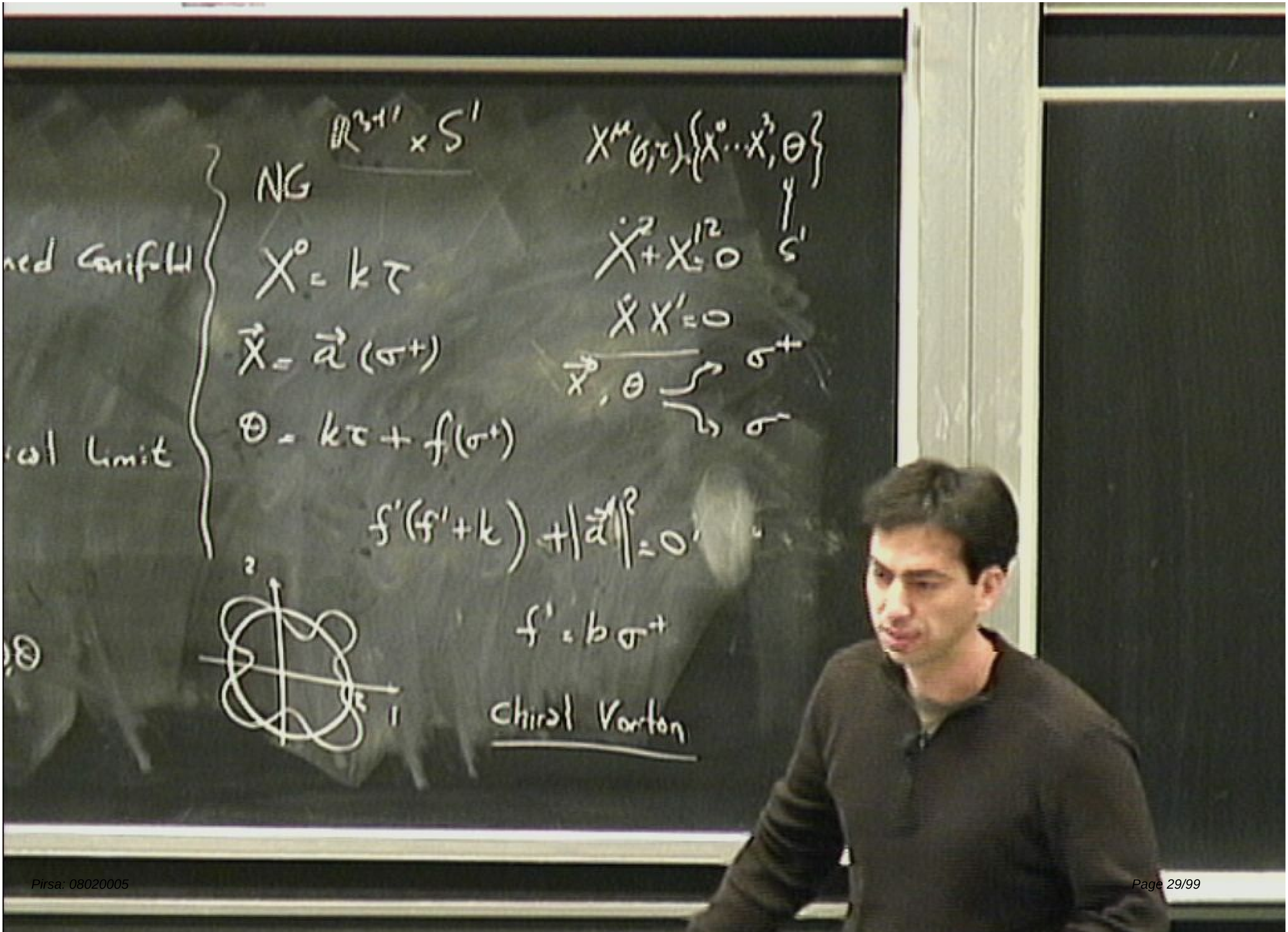
$\dot{X} X' = 0$

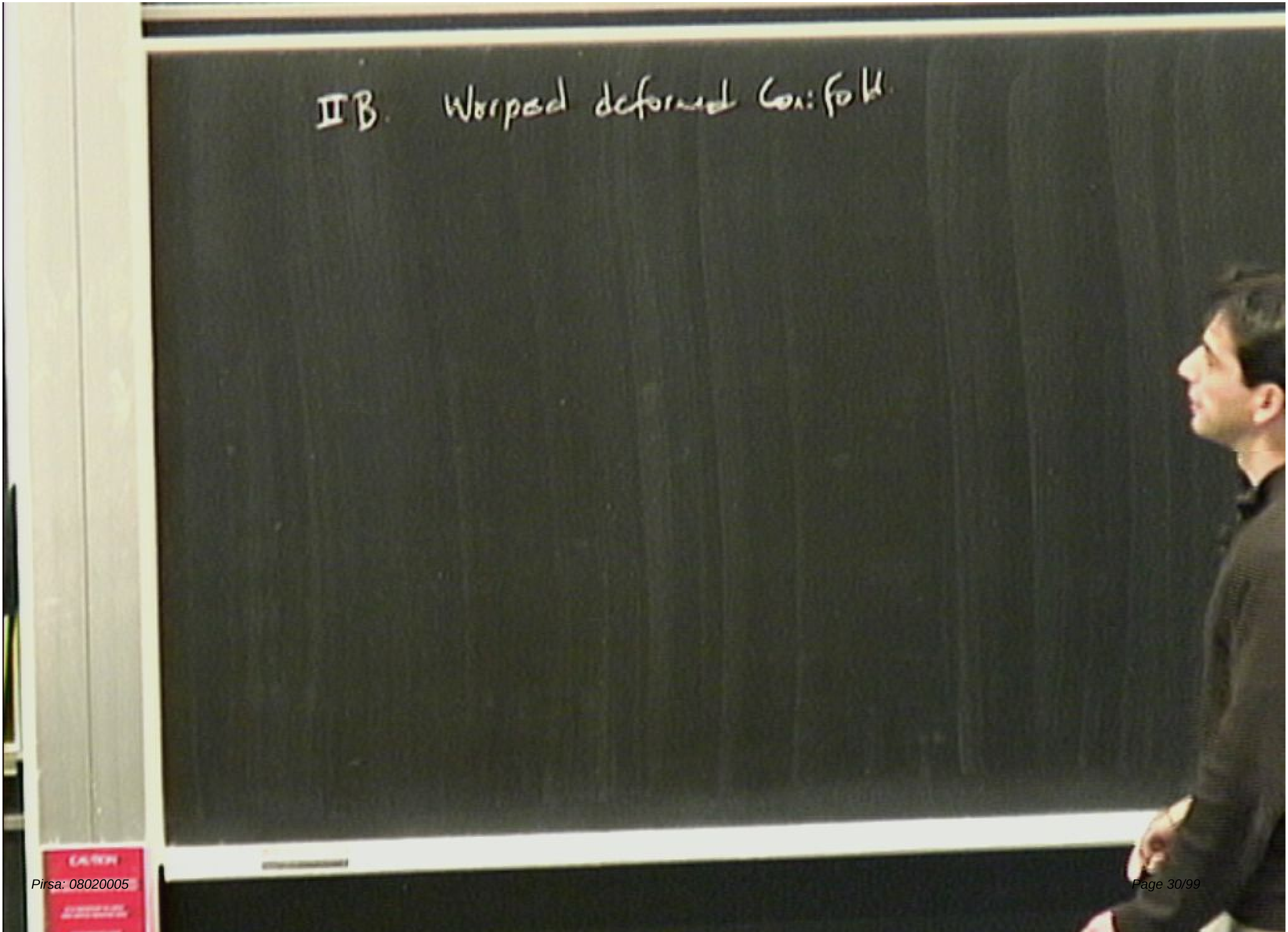
$\vec{X}, \theta \to \sigma^+, \sigma^-$



$f' = b\sigma^+$

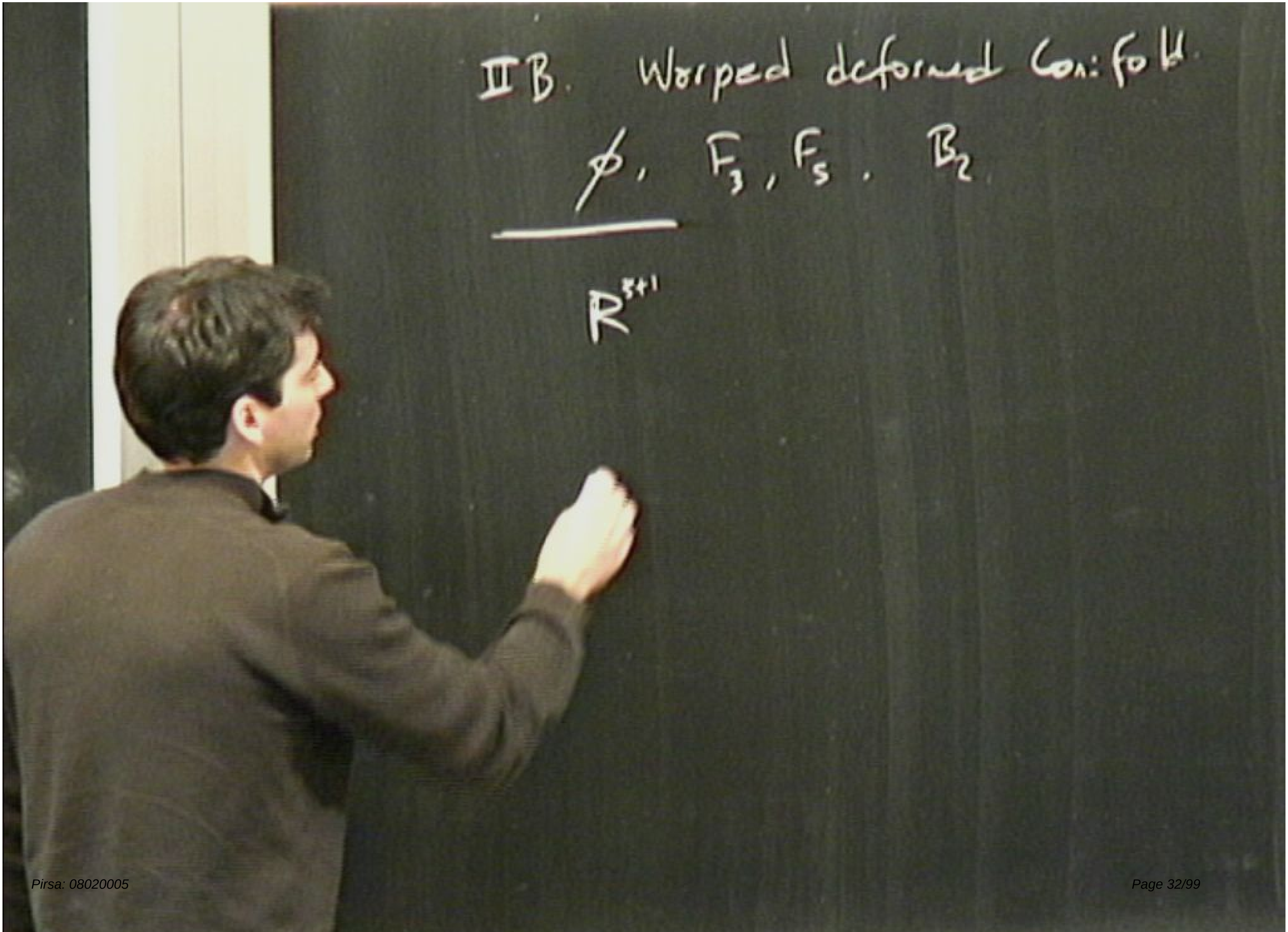
Chiral Vorton

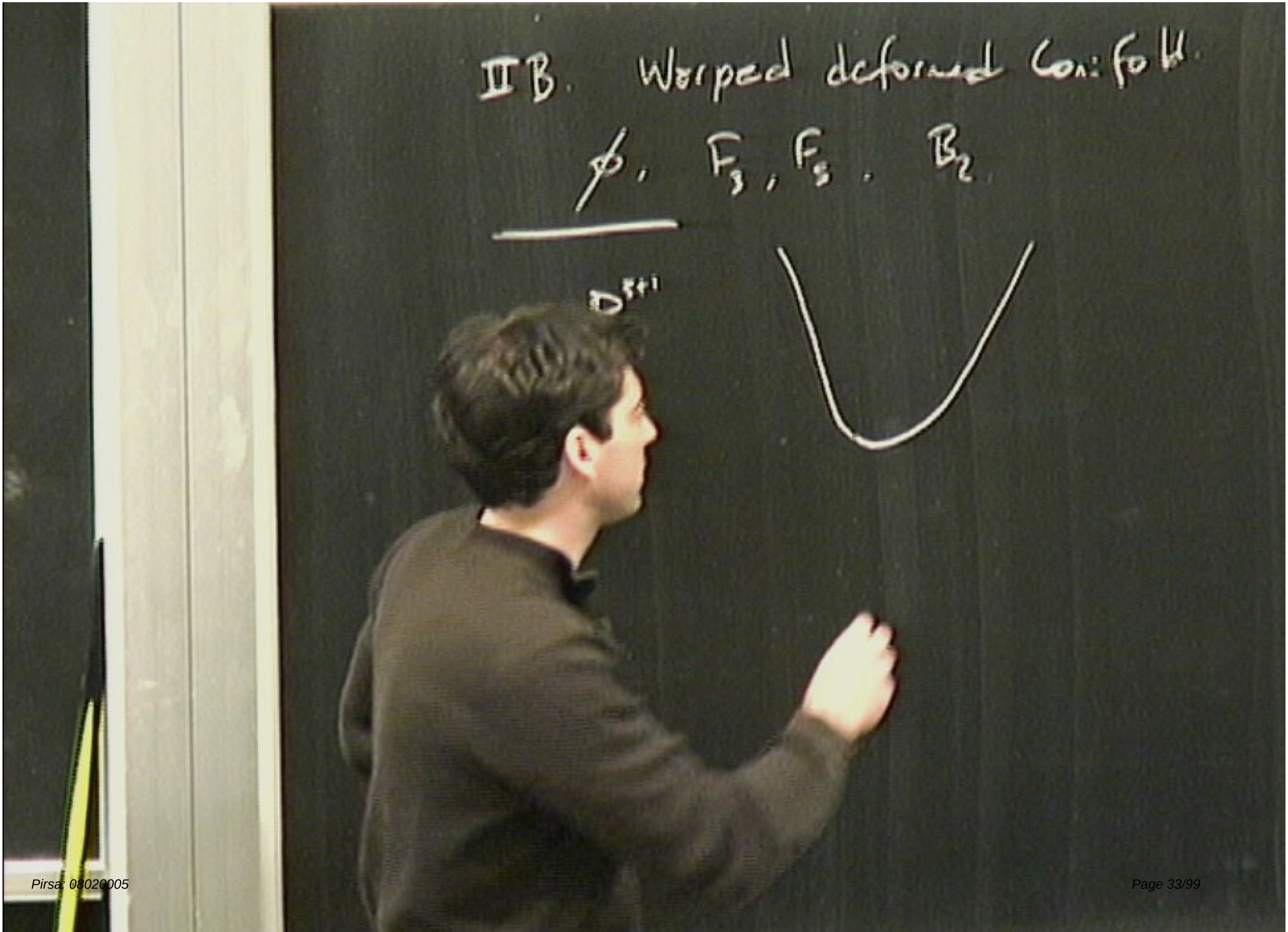

R^{3+1} × S^1
X^μ(σ,τ) → {X^0 ... X^3, θ}
S^1
NG
ned Conifold
X^0 = kτ
Ẋ² + X'² = 0
Ẋ X' = 0
X⃗ = a⃗(σ+)
X⃗, θ
σ+
σ−
θ = kτ + f(σ+)
cal Limit
f'(f'+k) + |a⃗'|² = 0
f' = bσ+
Chiral Vorton

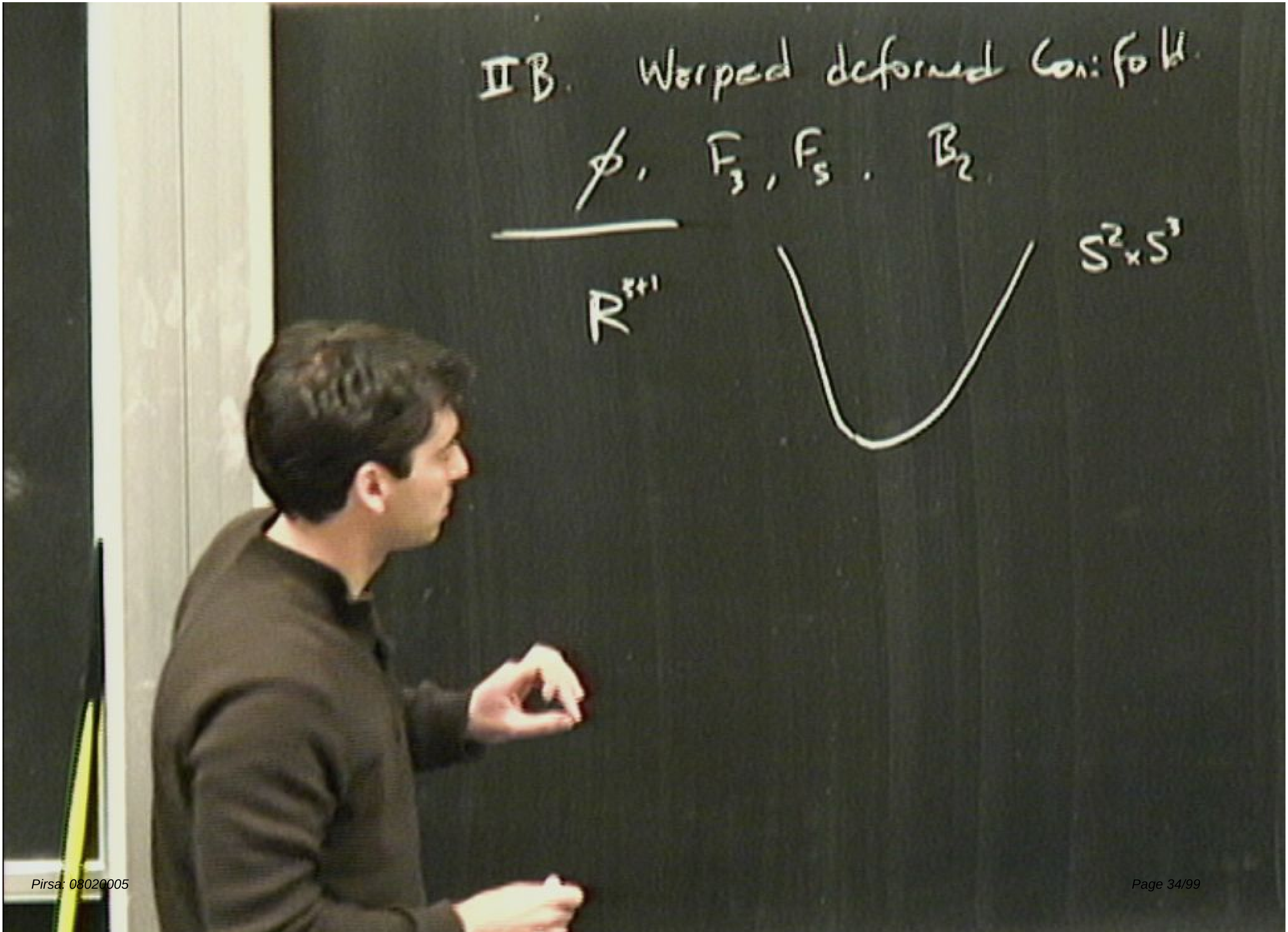

IIB. Warped deformed Conifold

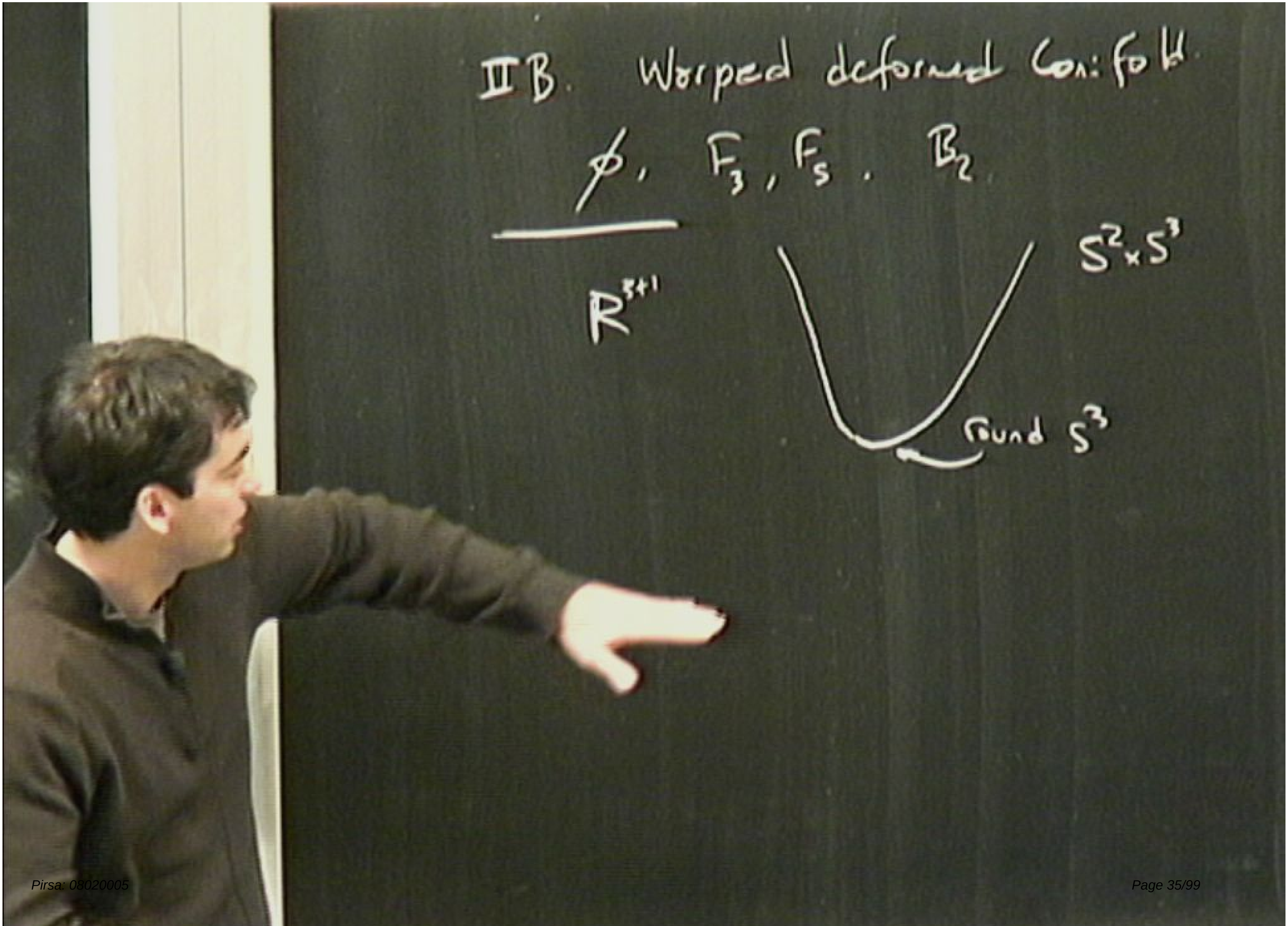
IIB. Warped deformed Conifold

ϕ, F_3, F_5, B_2


IIB. Warped deformed Conifold
ϕ, F_3, F_5, B_2
R^{3+1}


IIB. Warped deformed Conifold
φ, F3, F5, B2
D3+1

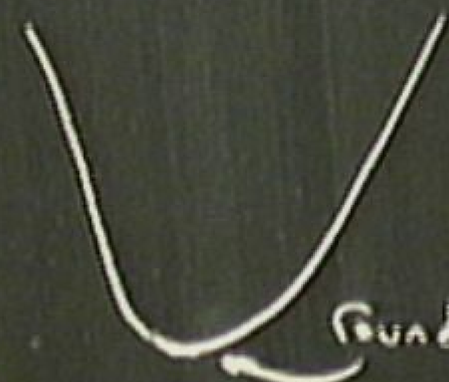

IIB. Warped deformed Conifold
ϕ, F_3, F_5. B_2
R^{3+1}
$S^2 \times S^3$


IIB. Warped deformed Conifold
ϕ, F_3, F_5. B_2
R^{3+1}
$S^2 \times S^3$
round S^3

IIB. Warped deformed Conifold

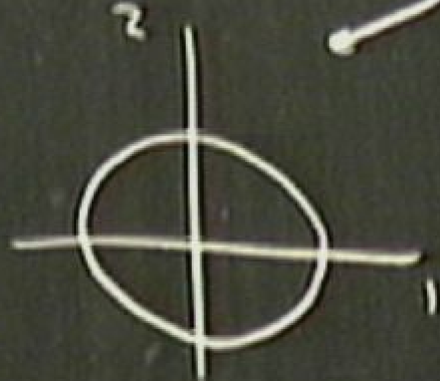
ϕ, F_3, F_5, B_2

R^{3+1}



$S^2 \times S^3$

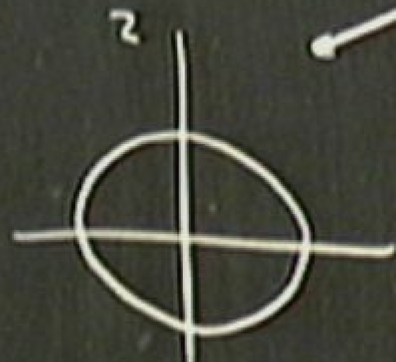
round S^3

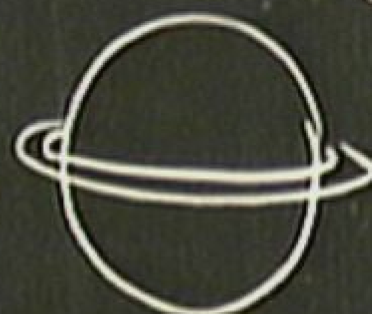


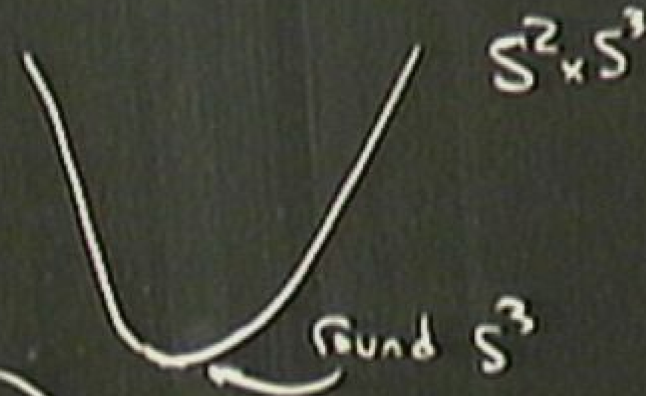
II B. Warped deformed Conifold

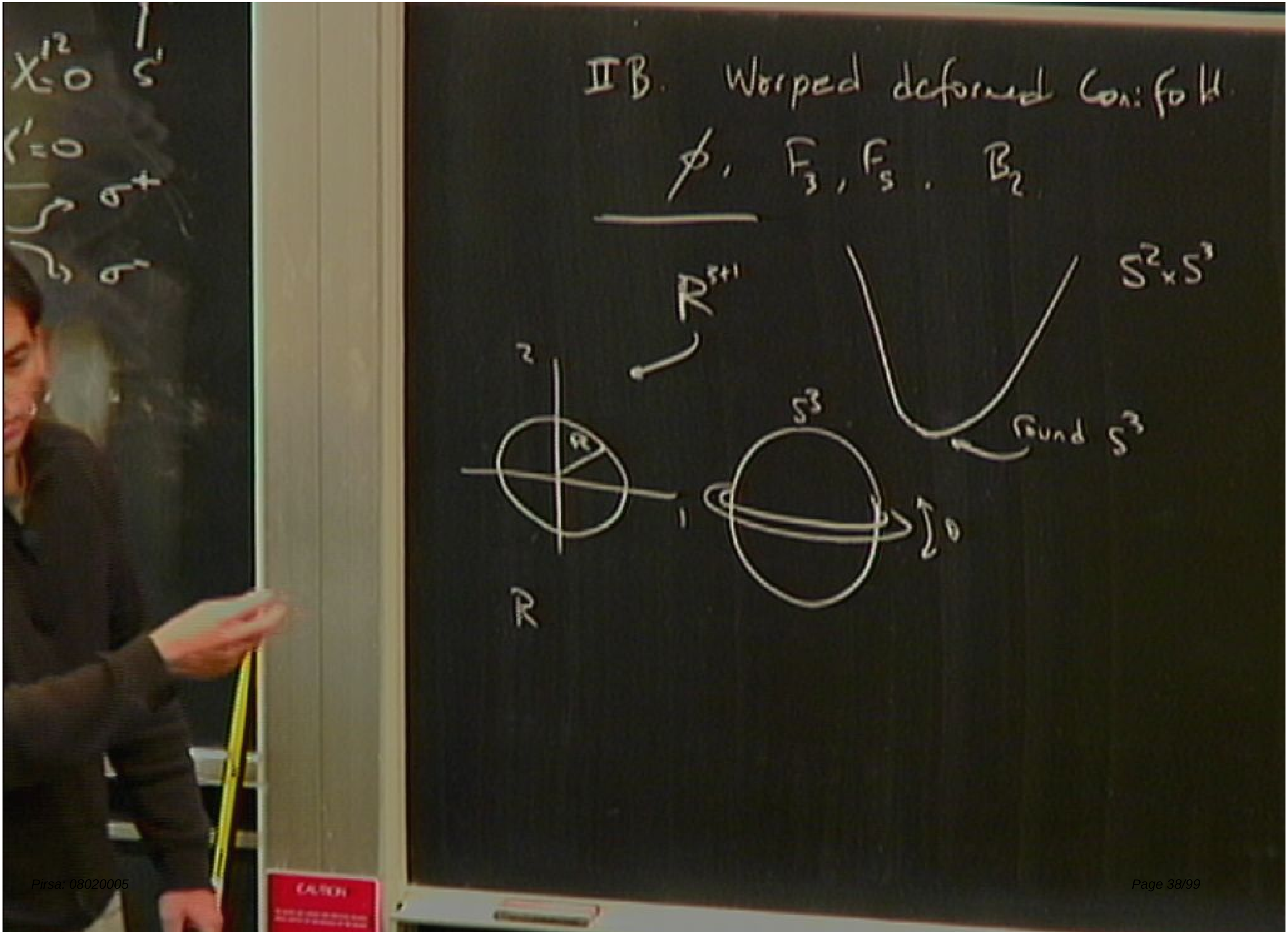
ϕ, F_3, F_5. B_2

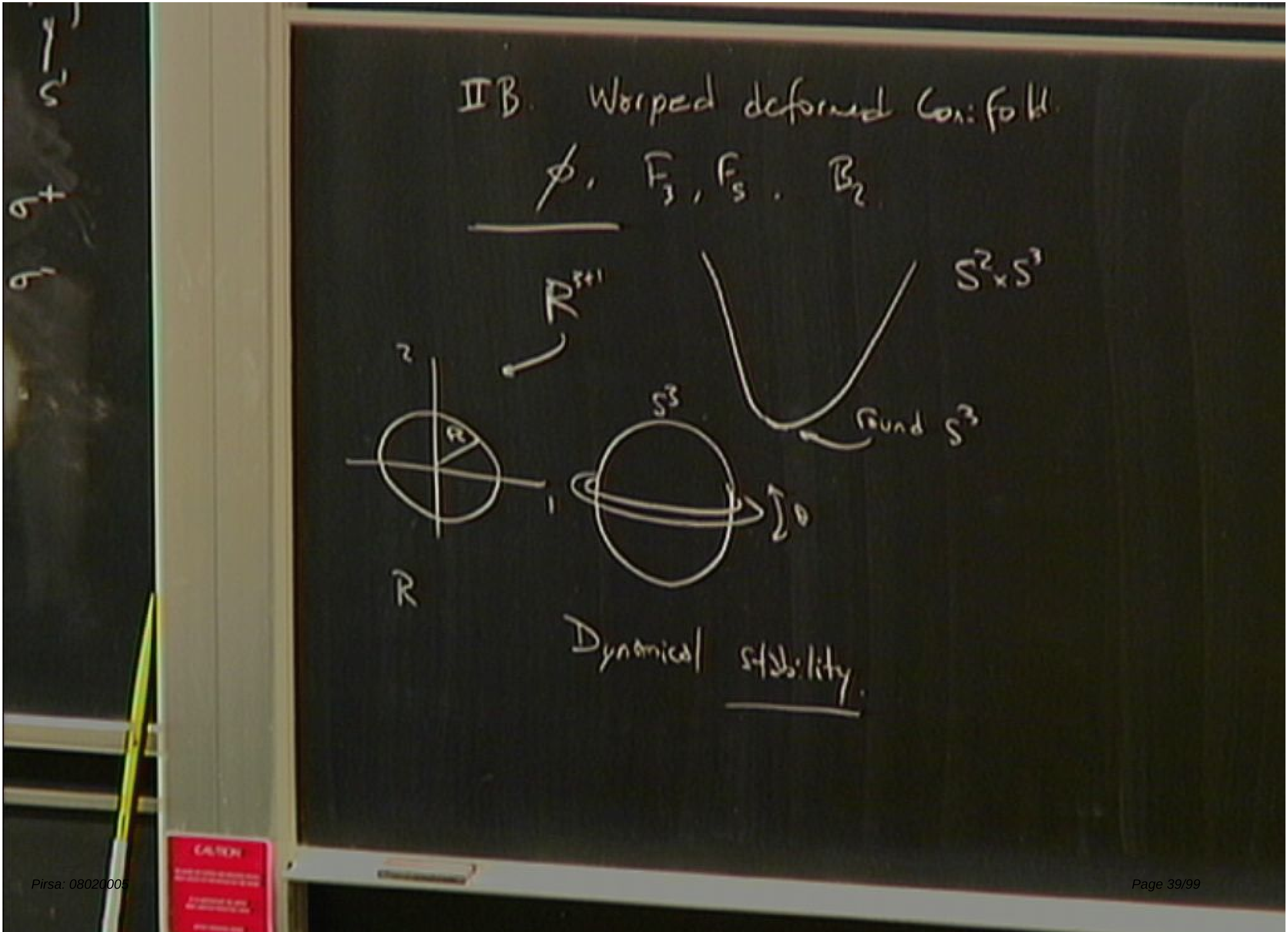
$\mathbb{R}^{3+1}$





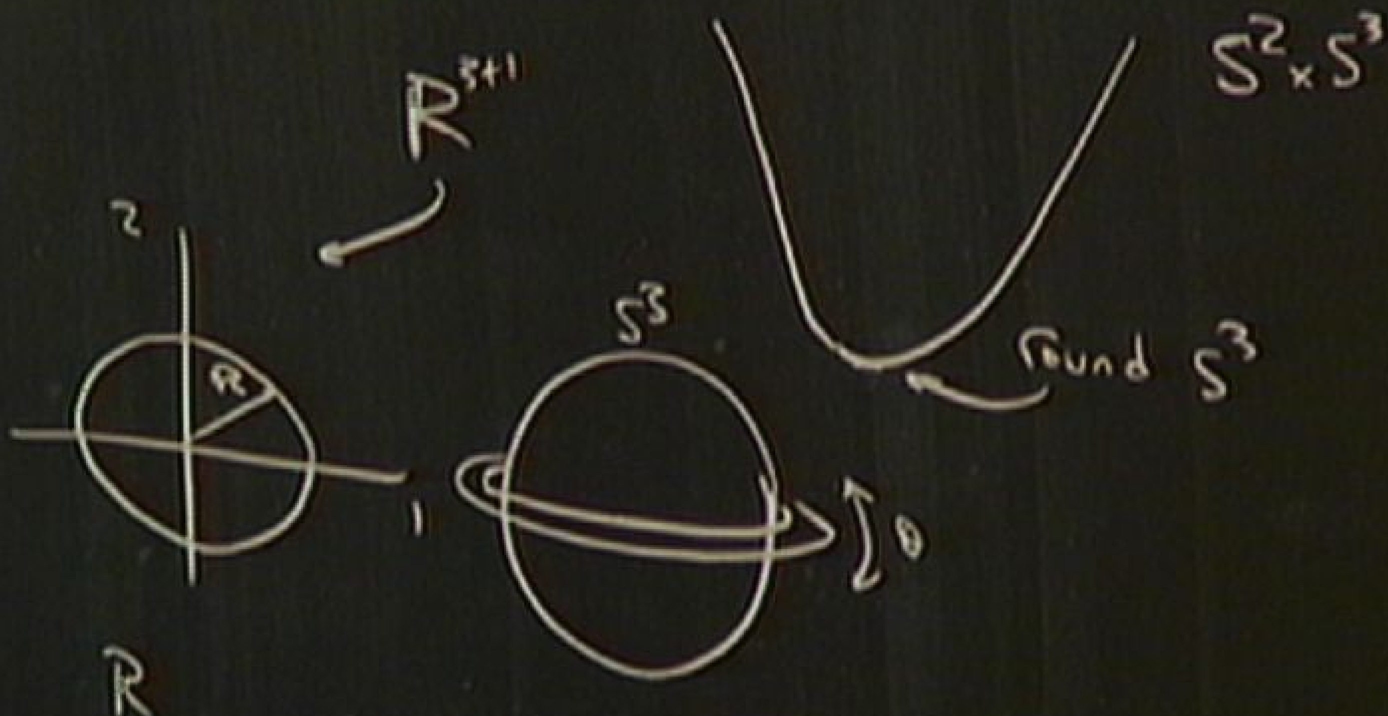



IIB. Warped deformed Conifold
φ, F3, F5, B2
R^5+1
S^2 × S^3
S^3
round S^3
R
CAUTION

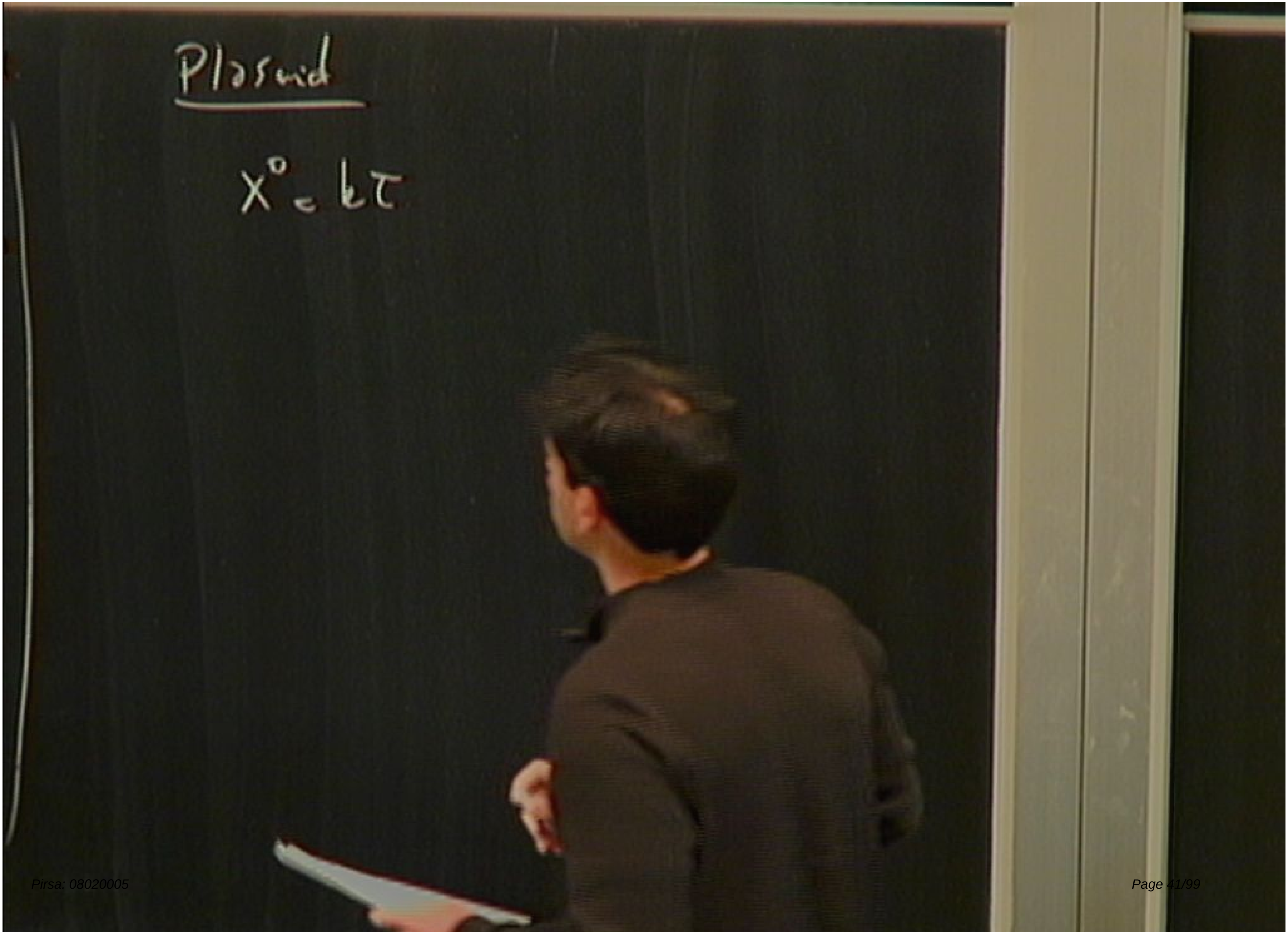

IIB Warped deformed Conifold
φ, F3, F5, B2
R^5+1
S^3
θ
S^2×S^3
round S^3
R
Dynamical stability

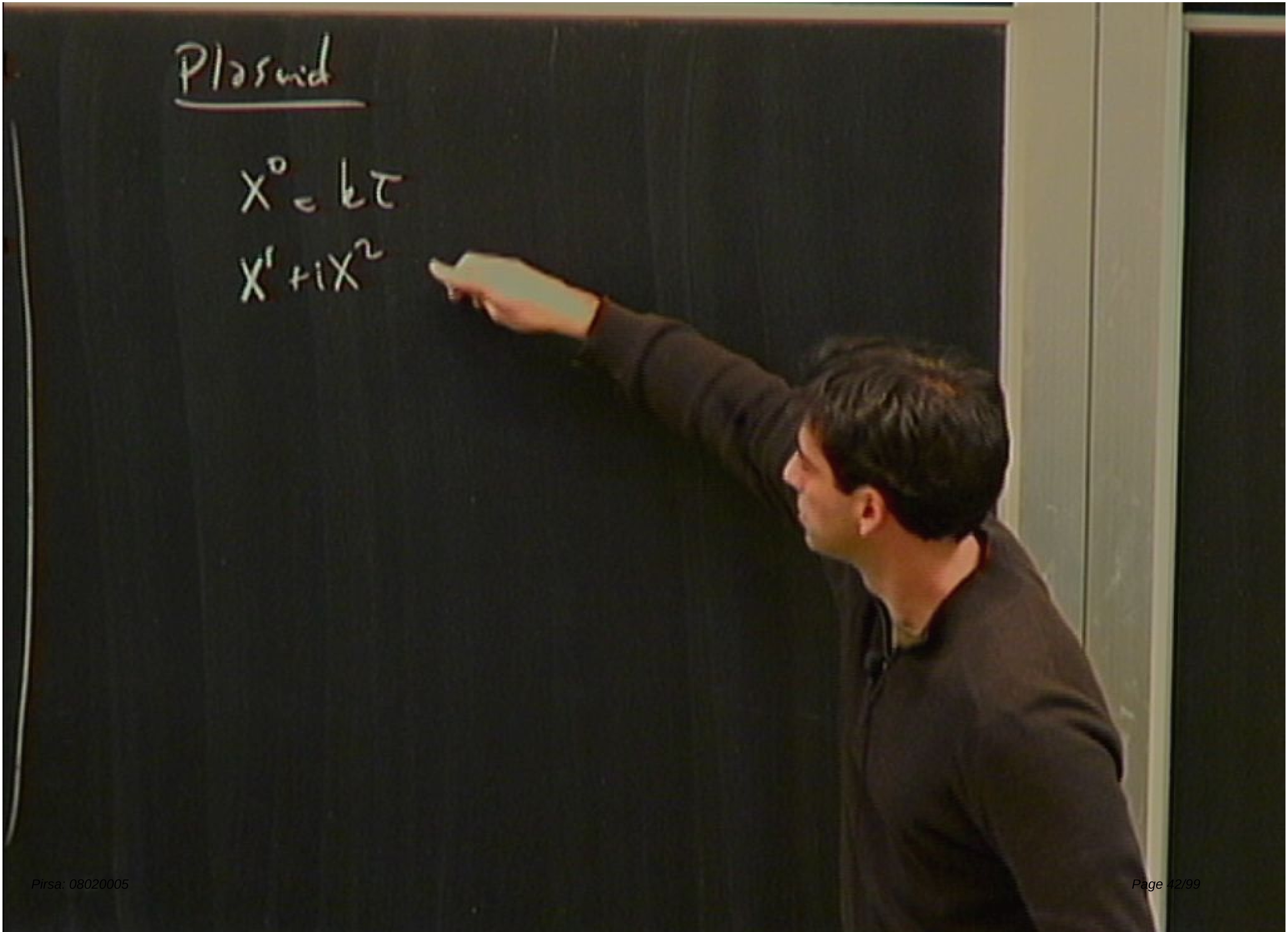
IIB. Warped deformed Conifold.

$\cancel{\phi}$, F_3, F_5. B_2



Dynamical stability.


Plasmid
$X^0 = k\tau$


Plasmid
$X^0 = k\tau$
$X^1 + iX^2$

...ed Conifold

B_2

$S^2 \times S^3$

round S^3

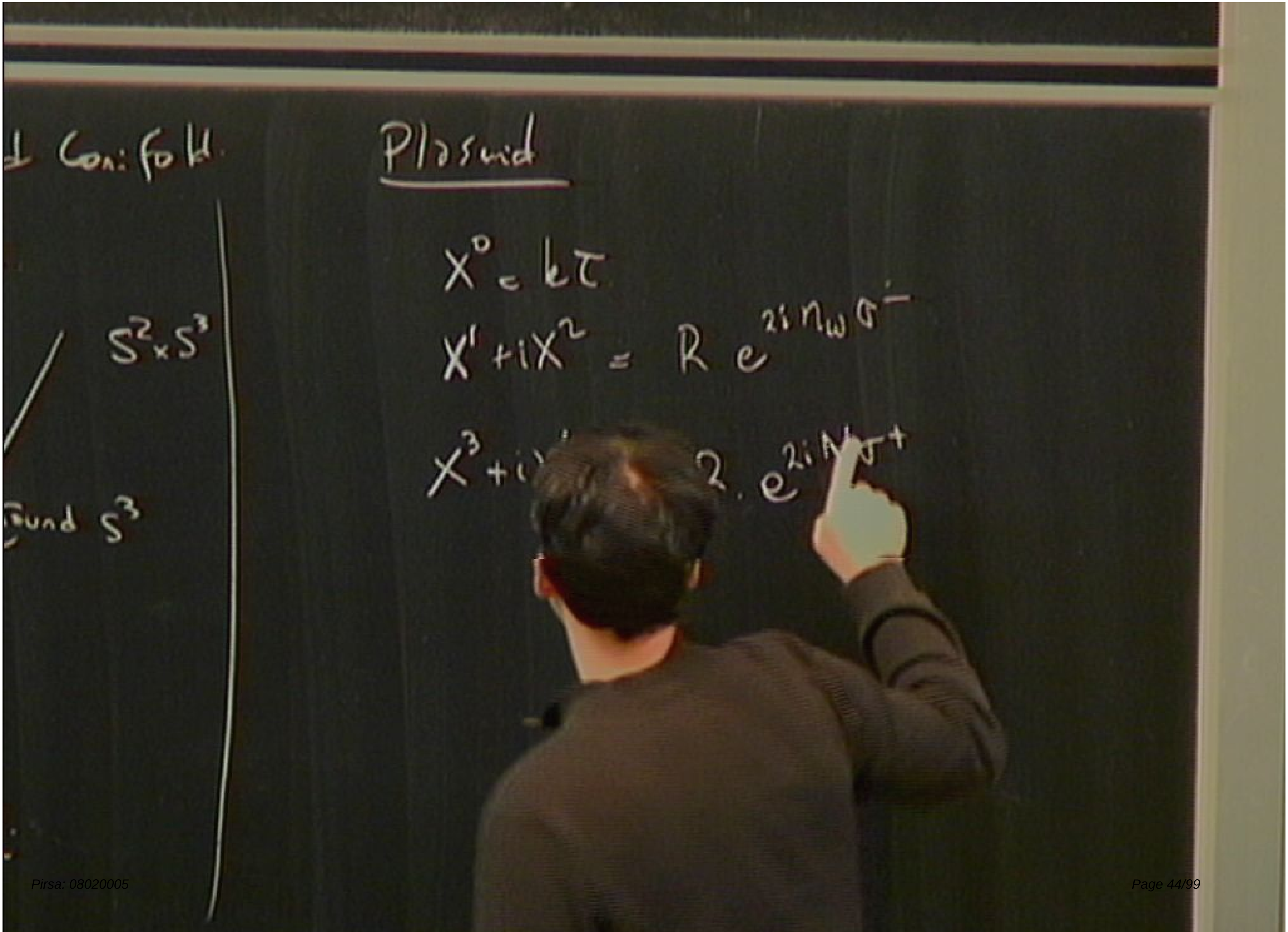
...ity.

Plasmid

$X^0 = k\tau$

$X^1 + iX^2 = R\, e^{2i n_w \sigma^-}$

$X^3 + iX^4 =$


Conifold
Plasmid
$X^0 = k\tau$
$X^1 + iX^2 = R\, e^{2i n_w \sigma^-}$
$S^2 \times S^3$

...d Conifold

Plasmid

$$X^0 = k\tau$$

$$X^1 + iX^2 = R\, e^{2i n_w \sigma^-}$$

$$X^3 + iX^4 = \frac{n_w R}{N}\, e^{2iN\sigma^+}$$

$S^2 \times S^3$

...ound S^3

d Conifold

$S^2 \times S^3$

ound S^3

Plasmid

$$X^0 = k\tau$$

$$X^1 + iX^2 = R\, e^{2i n_w \sigma^-}$$

$$X^3 + iX^4 = \frac{n_w R}{N} \cdot e^{2i N \sigma^+}$$

d Conifold

$S^2 \times S^3$

ound S^3

Plasmid

$$X^0 = k\tau$$

$$X^1 + iX^2 = R\, e^{2i n_w \sigma^-}$$

$$X^3 + iX^4 = \frac{n_w R}{N}\, e^{2iN\sigma^+}$$

d Conifold

$S^2 \times S^3$

round S^3

Plasmid

$X^0 = k\tau$

$X^1 + iX^2 = R\, e^{2i n_w \sigma^-}$ $\quad n_w \ll N$

$X^3 + iX^4 = \frac{n_w R}{N} \cdot e^{2i N \sigma^+}$

Conifold

$S^2 \times S^3$

nd S^3

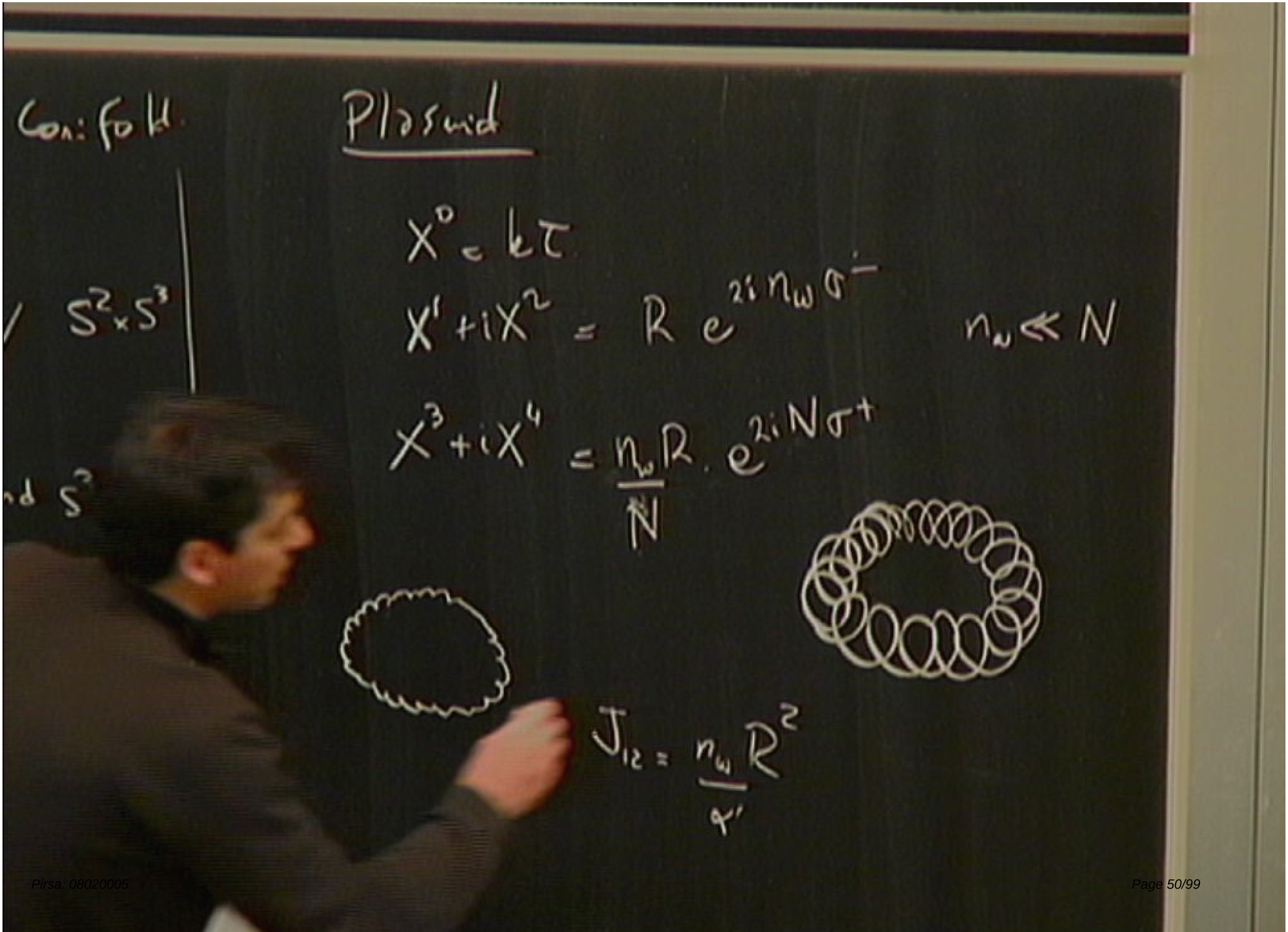
Plasmid

$$X^0 = k\tau$$

$$X^1 + iX^2 = R\, e^{2i n_w \sigma^-} \qquad n_w \ll N$$

$$X^3 + iX^4 = \frac{n_w R}{N}\, e^{2i N \sigma^+}$$

$$J_{12} = \frac{n_w R}{\alpha'}$$


Conifold
$S^2 \times S^3$
S^3
Plasmid
$X^0 = k\tau$
$X^1 + iX^2 = R\, e^{2i n_w \sigma^-}$
$n_w \ll N$
$X^3 + iX^4 = \frac{n_w R}{N} e^{2iN\sigma^+}$
$J_{12} = \frac{n_w}{\alpha'} R^2$

Conifold

$S^2 \times S^3$

nd S^3

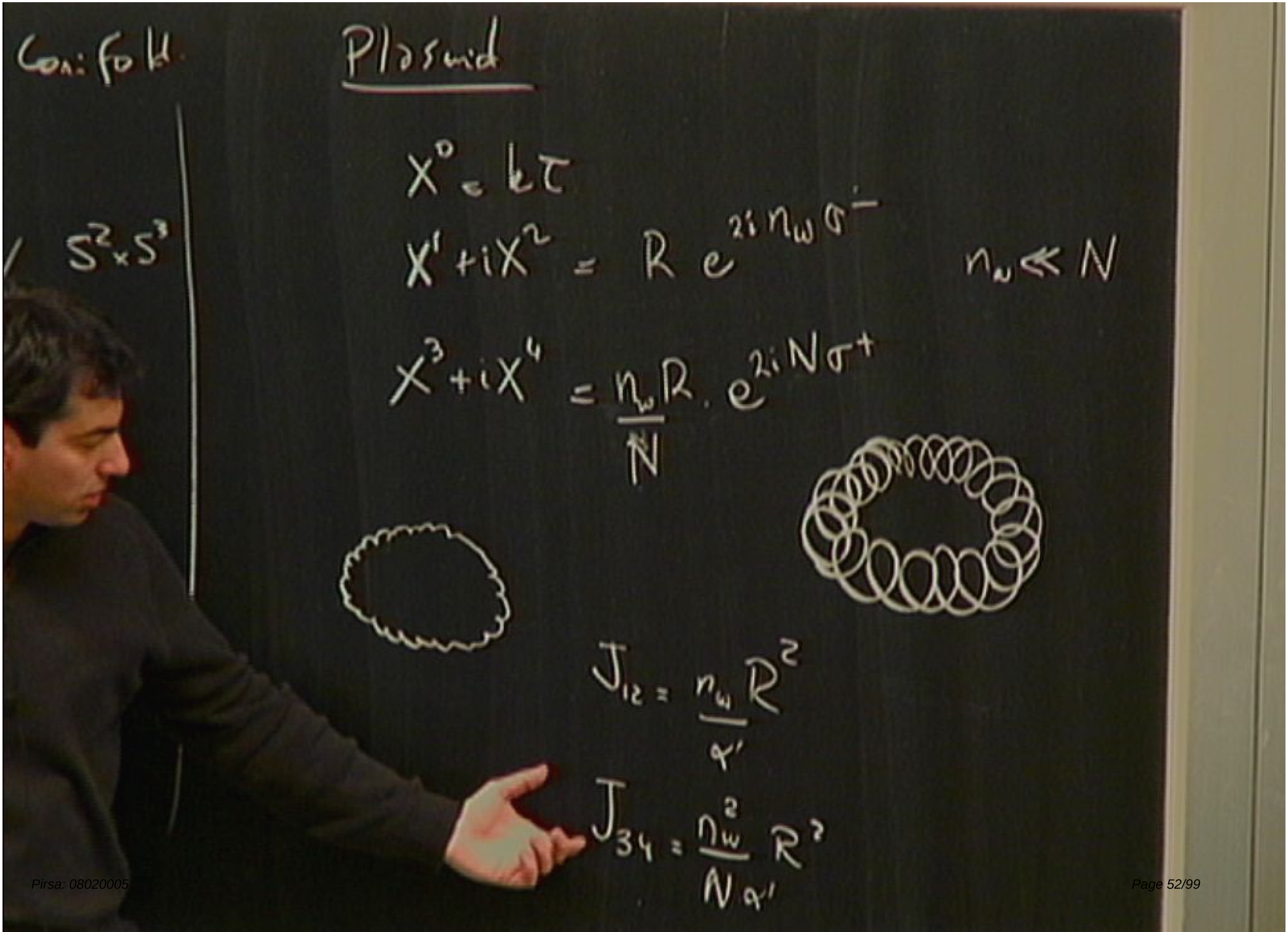
Plasmid

$$X^0 = k\tau$$

$$X^1 + iX^2 = R\, e^{2i n_w \sigma^-} \qquad n_w \ll N$$

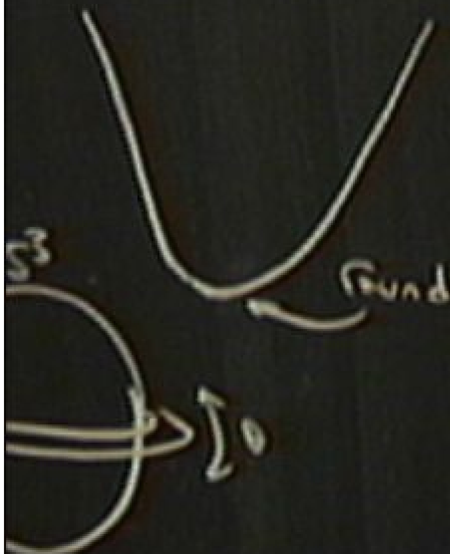
$$X^3 + iX^4 = \frac{n_w R}{N}\, e^{2i N \sigma^+}$$

$$J_{12} = \frac{n_w}{\alpha'} R^2$$


Conifold
$S^2 \times S^3$
Plasmid
$X^0 = k\tau$
$X^1 + iX^2 = R\, e^{2i n_w \sigma^-}$
$n_w \ll N$
$X^3 + iX^4 = \frac{n_w R}{N} \cdot e^{2iN\sigma^+}$
$J_{12} = \frac{n_w}{\alpha'} R^2$
$J_{34} = \frac{n_w^2}{N\alpha'} R^2$

...ed deformed Conifold

F_3, F_5, B_2



...nical stability

Plasmid

$$X^0 = k\tau$$

$$X^1 + iX^2 = R\, e^{2i n_w \sigma^-} \qquad n_w \ll N$$

$$X^3 + iX^4 = \frac{n_w R}{N}\, e^{2iN\sigma^+}$$

$$M = 2\frac{n_w}{\alpha'} R$$

$$J_{12} = \frac{n_w}{\alpha'} R^2$$

$$J_{34} = \frac{n_w^2}{N\alpha'} R^2$$

d Conifold

$S^2 \times S^3$

ound S^3

Plasmid

$$X^0 = k\tau$$

$$X^1 + iX^2 = R\, e^{2i n_w \sigma^-} \qquad n_w \ll N$$

$$X^3 + iX^4 = \frac{n_w R}{N}\, e^{2i N \sigma^+}$$

$$M = 2\frac{n_w}{\alpha'} R$$

$$J_{12} = \frac{n_w}{\alpha'} R^2$$

$$J_{34} = \frac{n_w^2}{N\alpha'} R^2$$

fold

$S^2 \times S^3$

Plasmid

$X^0 = k\tau$

$X^1 + iX^2 = R\, e^{2i n_w \sigma^-}$ $n_w \ll N$

$X^3 + iX^4 = \frac{n_w R}{N} \cdot e^{2iN\sigma^+}$

$M = 2\frac{n_w}{\alpha'} R$

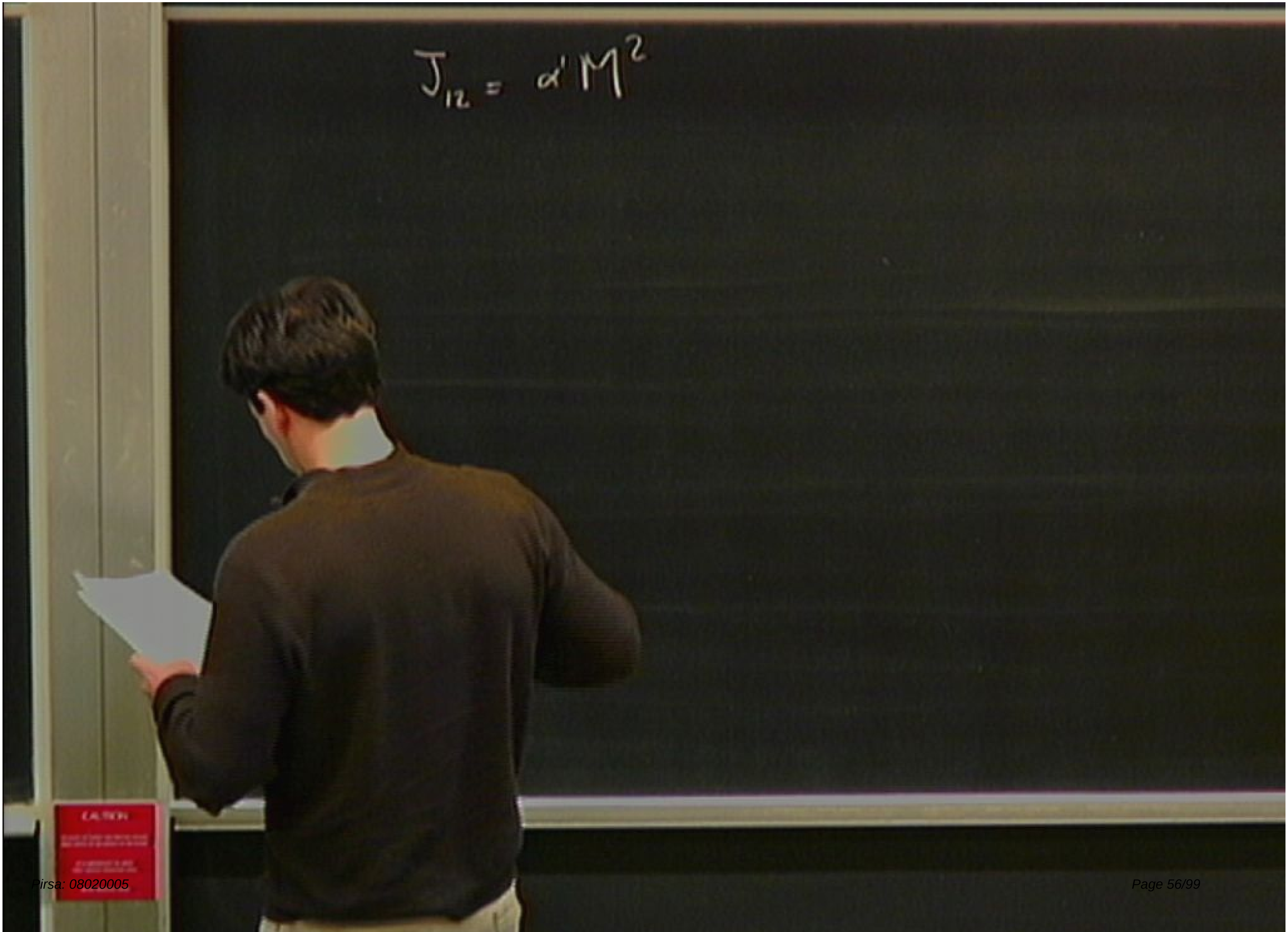
$J_{12} = \frac{n_w}{\alpha'} R^2$

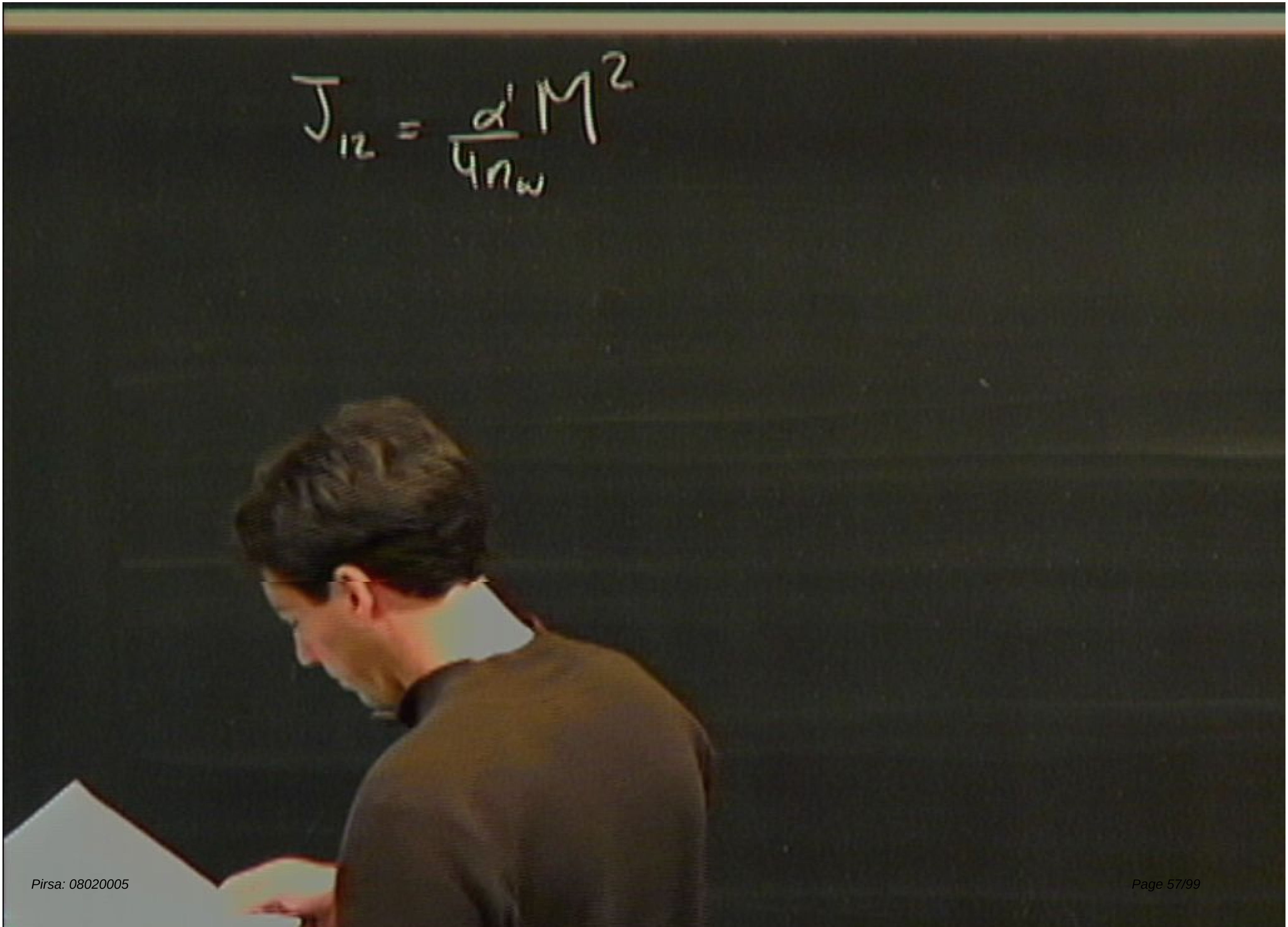
$J_{34} = \frac{n_w^2}{N\alpha'} R^2$

Wider class

$\downarrow$

degeneracy.


$J_{12} = \alpha' M^2$
CAUTION


$J_{12} = \frac{\alpha'}{4 n_w} M^2$

$$J_{12} = \frac{\alpha'}{4n_w} M^2$$

$$E = \frac{n_p}{R} + \frac{n_w}{\alpha'} R$$

$$J_{12} = \frac{\alpha'}{4 n_w} M^2$$

$$E = \frac{n_p}{R} + \frac{n_w}{\alpha'} R$$

$$n_p = \frac{n_w}{\alpha'} R^2$$

$$J_{12} = \frac{\alpha'}{4 n_w} M^2$$

$$E = \frac{n_p}{R} + \frac{n_w R}{\alpha'}$$

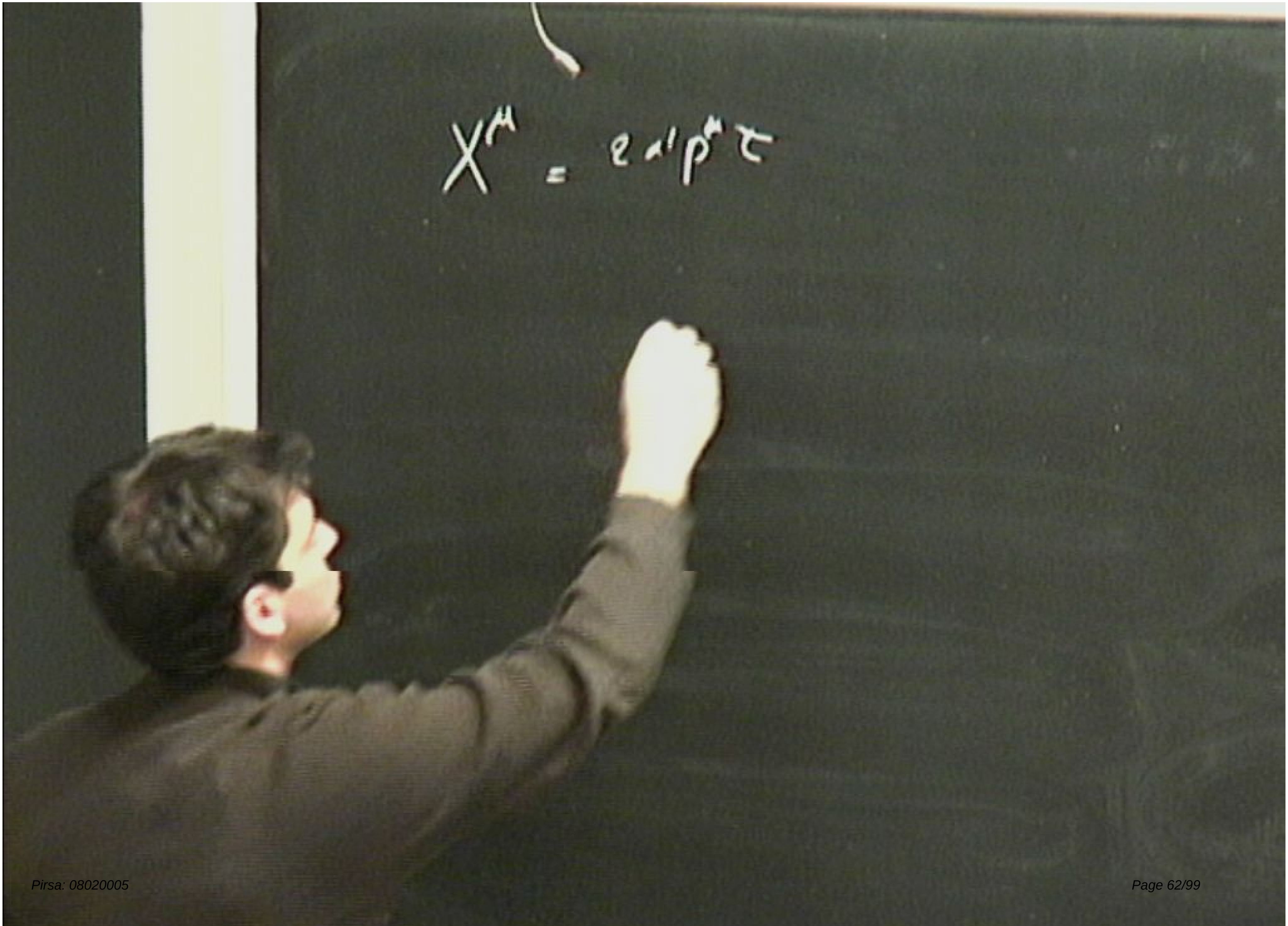
$$n_p = \frac{n_w}{\alpha'} R^2$$

$$J_{12} = \frac{\alpha'}{4 n_w} M^2$$

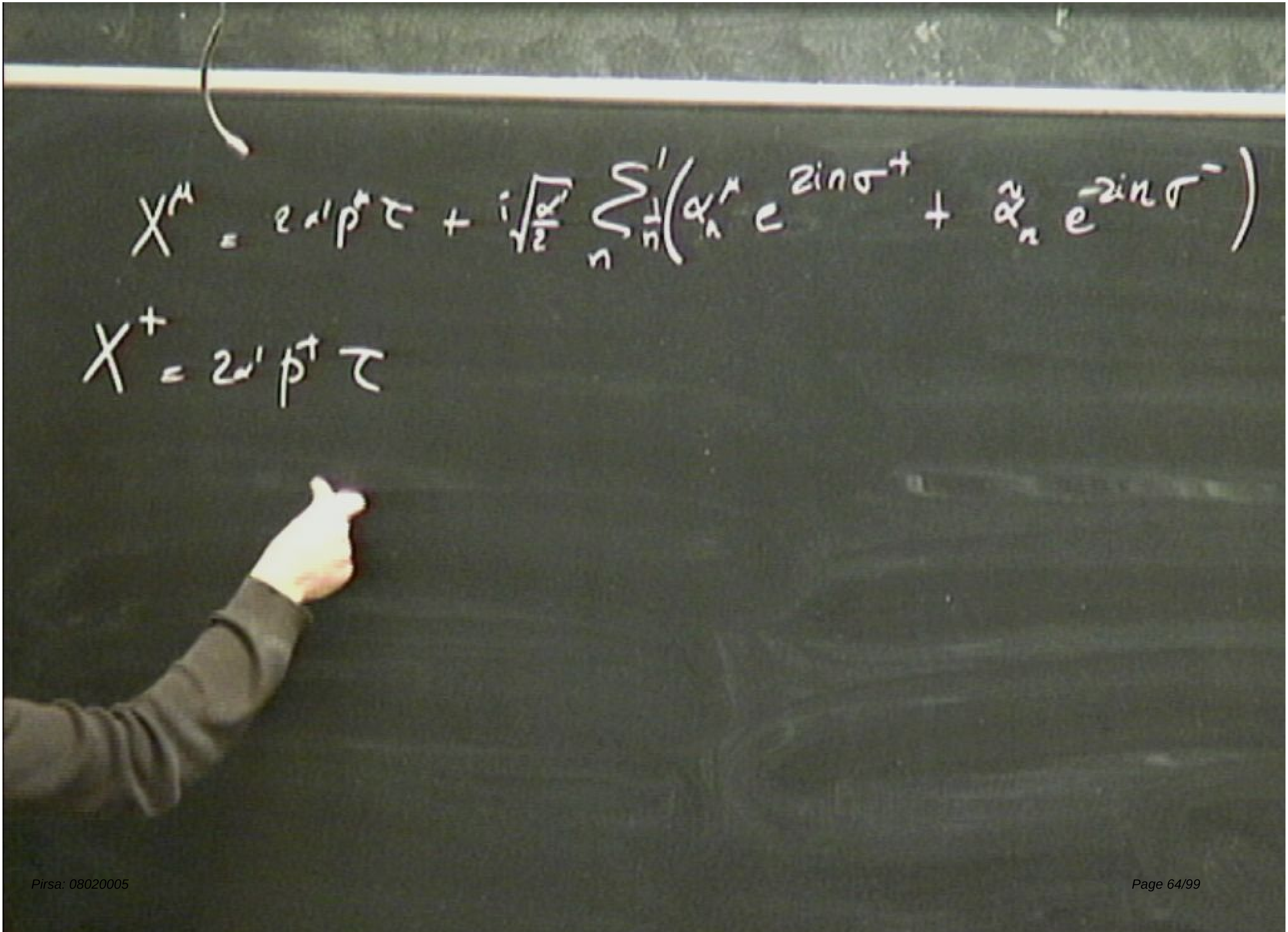
$$E = \frac{n_p}{R} + \frac{n_w R}{\alpha'}$$

$$n_p = \frac{n_w}{\alpha'} R^2$$

$$n_p \rightarrow J_{12}$$


$X^\mu = 2\alpha' p^\mu \tau$

$$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n{}' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$$


$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$
$X^+ = 2\alpha' p^+ \tau$

$$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n{}' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$$

$$X^+ = 2\alpha' p^+ \tau$$

α^-

$$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n{}' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$$

$$X^+ = 2\alpha' p^+ \tau$$

Solve Constraints for α_n^-, $\tilde{\alpha}_n^-$

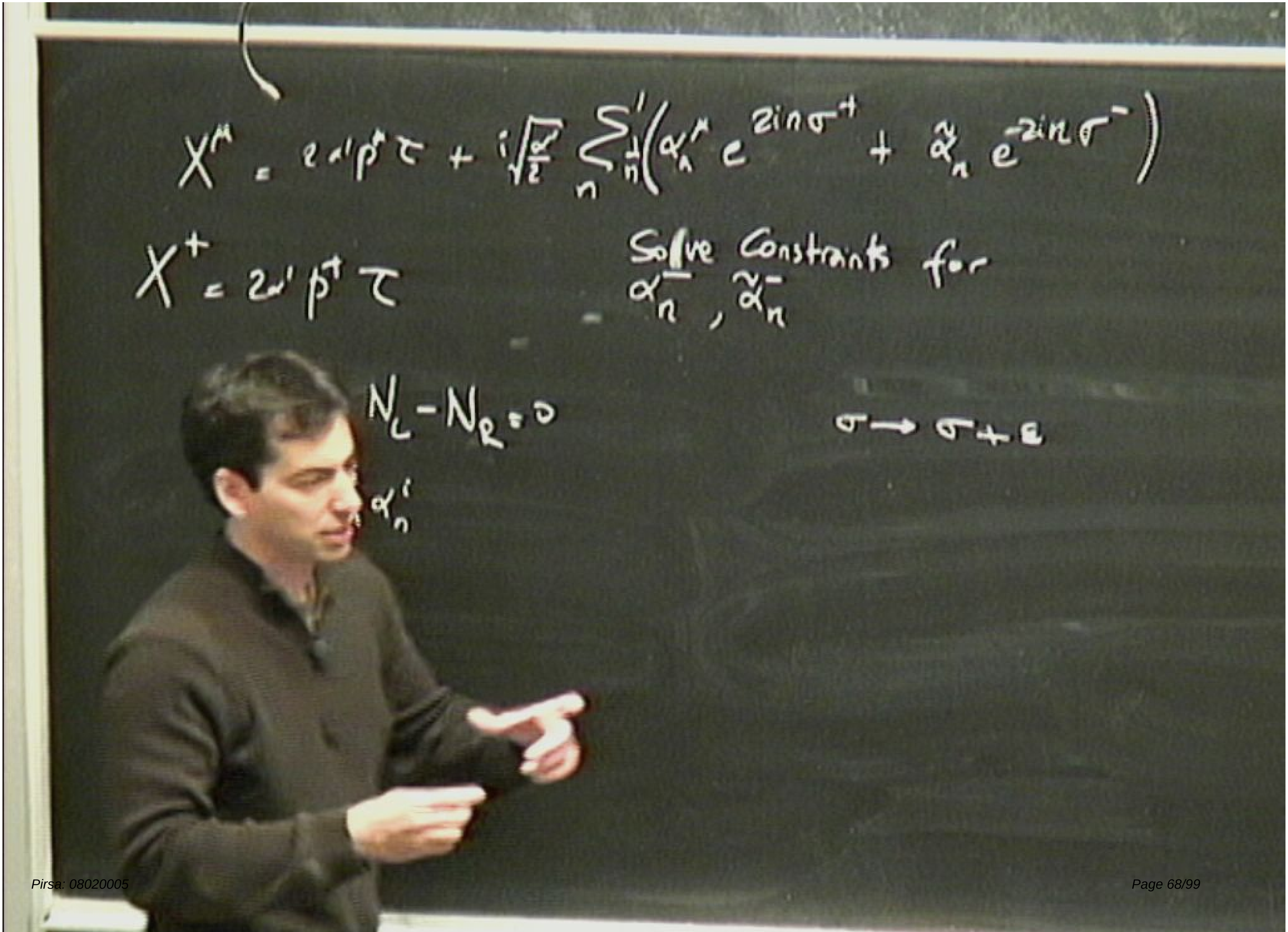
$$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n{}' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$$

$$X^+ = 2\alpha' p^+ \tau$$

Solve Constraints for α_n^-, $\tilde{\alpha}_n^-$

$$N_L - N_R = 0$$

$$\alpha_{-n}^i \alpha_n^i$$


$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n{}' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$
$X^+ = 2\alpha' p^+ \tau$
Solve Constraints for
α_n^-, $\tilde{\alpha}_n^-$
$N_L - N_R = 0$
$\sigma \to \sigma + \epsilon$
α_n^i

$$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n{}' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$$

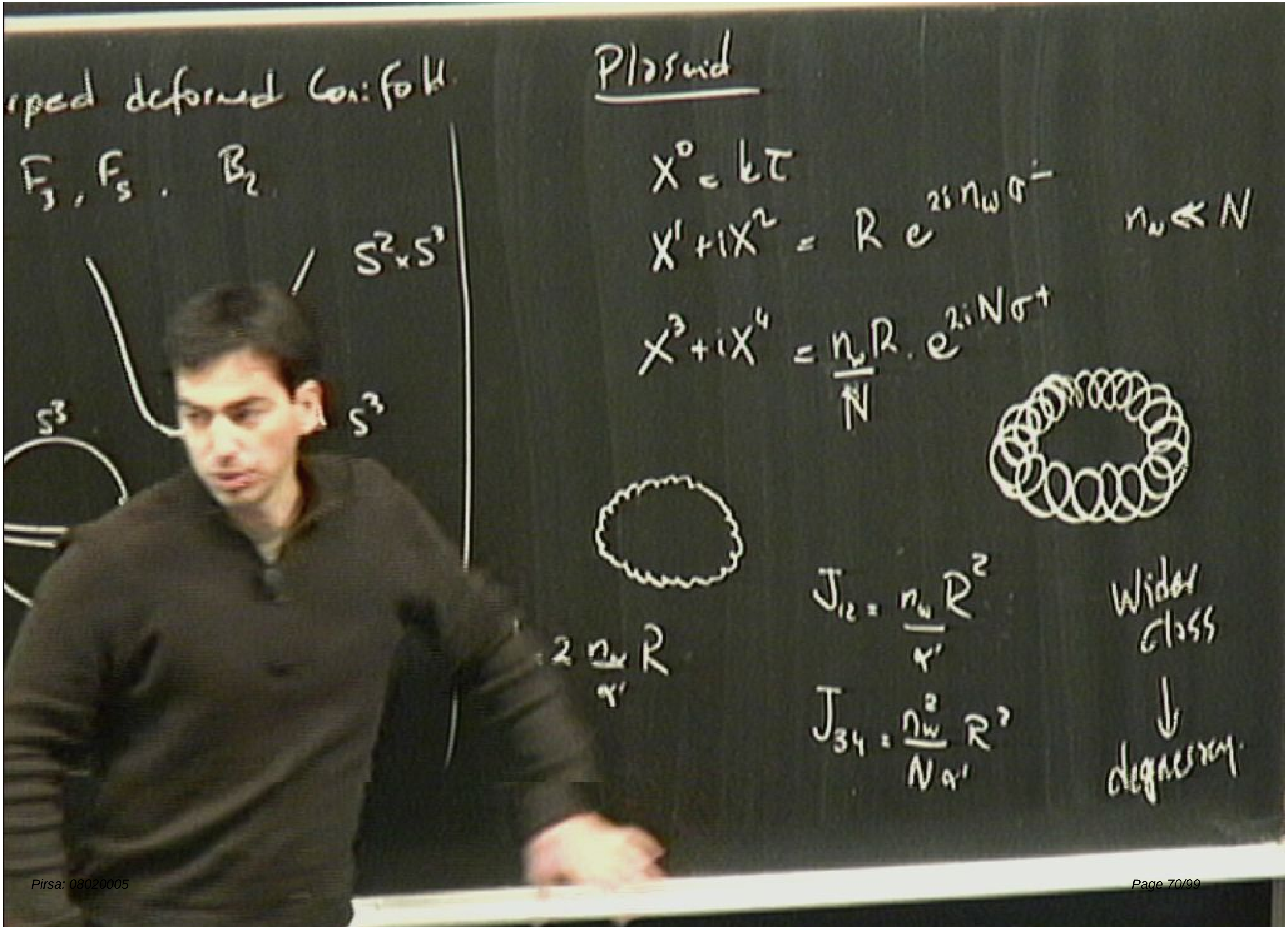
$$X^+ = 2\alpha' p^+ \tau$$

Solve Constraints for α_n^-, $\tilde{\alpha}_n^-$

$$N_L - N_R = 0$$

$$\sigma \to \sigma + \epsilon$$

$$\alpha_{-n}^i \alpha_n^i$$



...rped deformed Conifold
F3, F5, B2
S2×S3
S3
S3
Plasmid
X0 = kτ
X1 + iX2 = R e^{2i nw σ-}
nw ≪ N
X3 + iX4 = (nw/N) R e^{2i N σ+}
J12 = (nw/α') R^2
J34 = (nw^2/(N α')) R^2
= 2 (nw/α') R
Wider class
degeneracy

$$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n{}' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$$

$$X^+ = 2\alpha' p^+ \tau$$

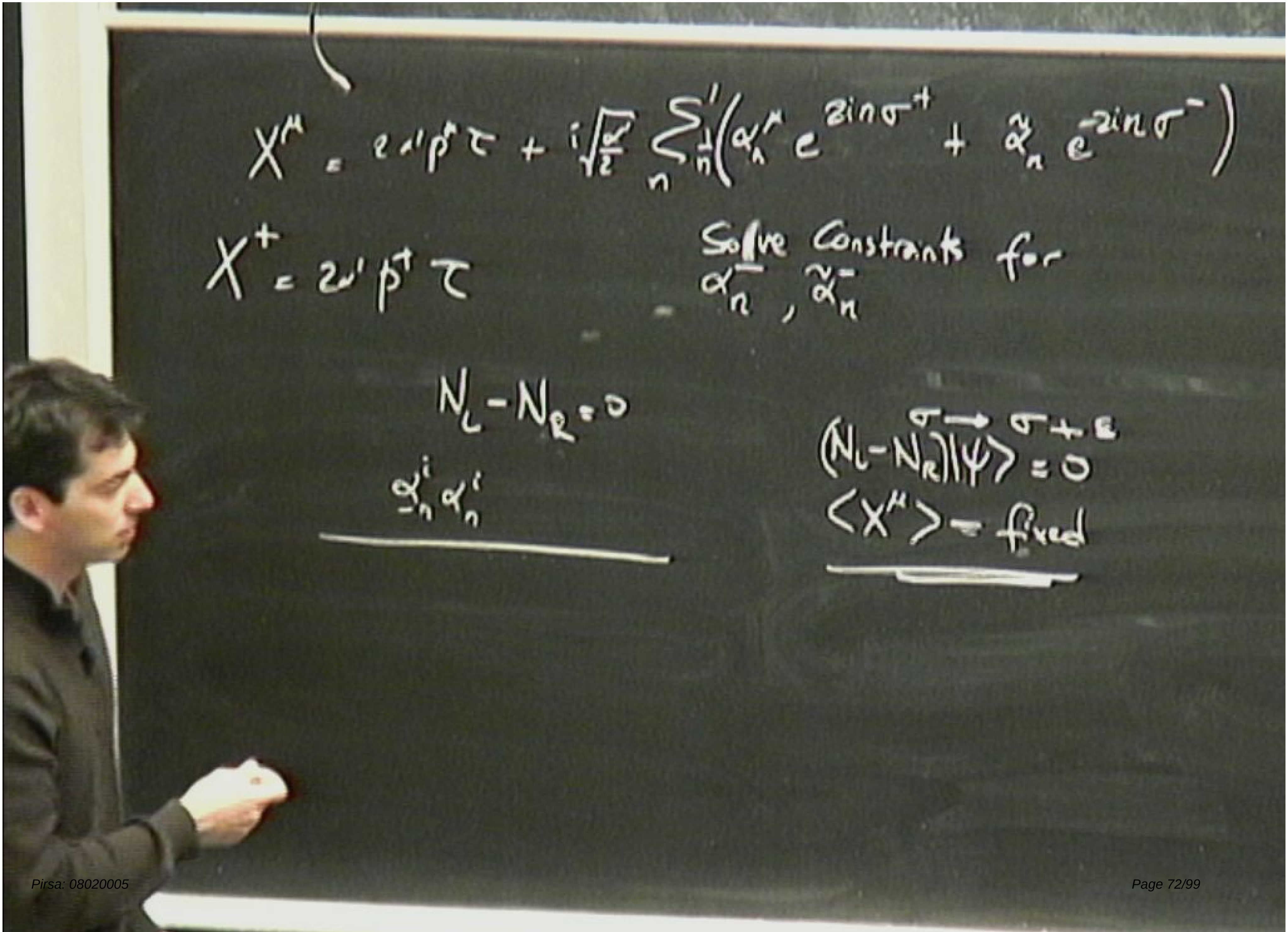
Solve Constraints for α_n^-, $\tilde{\alpha}_n^-$

$$N_L - N_R = 0$$

$$\sigma \to \sigma + \epsilon$$

$$\alpha_{-n}^i \alpha_n^i$$

$$\langle X^\mu \rangle = \text{fixed}$$


$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n{}' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$
$X^+ = 2\alpha' p^+ \tau$
Solve Constraints for
α_n^-, $\tilde{\alpha}_n^-$
$N_L - N_R = 0$
$\alpha_{-n}^i \alpha_n^i$
$\sigma \to \sigma + \epsilon$
$(N_L - N_R)|\psi\rangle = 0$
$\langle X^\mu \rangle =$ fixed

$$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n{}' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$$

$$X^+ = 2\alpha' p^+ \tau$$

Solve Constraints for α_n^-, $\tilde{\alpha}_n^-$

$$N_L - N_R = 0$$

$$\alpha_{-n}^i \alpha_n^i$$

$\sigma \to \sigma + \varepsilon$

$$(N_L - N_R)|\psi\rangle = 0$$

$$\langle X^\mu \rangle = \text{fixed}$$

Alternative. Fix symm.

$$\alpha_{n_w} \sim R$$

$$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n{}' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$$

$$X^+ = 2\alpha' p^+ \tau$$

Solve constraints for α_n^-, $\tilde{\alpha}_n^-$

$$N_L - N_R = 0$$

$$\alpha_{-n}^i \alpha_n^i$$

$\sigma \to \sigma + \varepsilon$

$$(N_L - N_R)|\psi\rangle = 0$$

$$\langle X^\mu \rangle = \text{fixed}$$

Alternative. Fix symm.

Fix. $\alpha_{n_\omega}^2 \sim R$

Solve constr. $\alpha_{-n_\omega}^2$

$$\langle X^1 + iX^2 \rangle =$$

$$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n{}' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$$

$$X^+ = 2\alpha' p^+ \tau$$

Solve Constraints for α_n^-, $\tilde{\alpha}_n^-$

$$N_L - N_R = 0$$

$$\alpha_{-n}^i \alpha_n^i$$

$\sigma \to \sigma + \epsilon$

$(N_L - N_R)|\psi\rangle = 0$

$\langle X^\mu \rangle$ = fixed

Alternative. Fix symm.

Fix. $\alpha^2_{n_w} \sim R$

Solve constr. $\alpha^2_{-n_w}$

$$\langle X^1 + i X^2 \rangle =$$

$$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n{}' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$$

$$X^+ = 2\alpha' p^+ \tau$$

Solve Constraints for α_n^-, $\tilde{\alpha}_n^-$

$$N_L - N_R = 0$$

$$\alpha_{-n}^i \alpha_n^i$$

$\sigma \to \sigma + \epsilon$

$$(N_L - N_R)|\psi\rangle = 0$$

$$\langle X^\mu \rangle = \text{fixed}$$

Alternative. fix symm.

Fix. $\alpha^2_{n_w} \sim R$

Solve constr. $\alpha^2_{-n_w}$

$$\langle X^1 + iX^2 \rangle =$$

$$|\emptyset\rangle = e^{iRn_w \alpha^1_{-n}}|0\rangle$$

$$X^\mu = 2\alpha' p^\mu \tau + i\sqrt{\frac{\alpha'}{2}} \sum_n{}' \frac{1}{n}\left(\alpha_n^\mu e^{2in\sigma^+} + \tilde{\alpha}_n e^{-2in\sigma^-}\right)$$

$$X^+ = 2\alpha' p^+ \tau$$

Solve Constraints for α_n^-, $\tilde{\alpha}_n^-$

$$N_L - N_R = 0$$

$$\alpha_{-n}^i \alpha_n^i$$

$\sigma \to \sigma + \epsilon$

$$(N_L - N_R)|\psi\rangle = 0$$

$$\langle X^\mu \rangle = \text{fixed}$$

Alternative. Fix symm.

Fix. $\alpha_{n_w}^2 \sim R$

Solve constr. $\alpha_{-n_w}^2$

$$\langle X^1 + iX^2 \rangle =$$

$$|\emptyset\rangle = e^{iRn_w \alpha_{-n_w}^2}|0\rangle$$

$\alpha_n \,,\, \tilde{\alpha}_n$

$N_R = 0$

$\sigma \to \sigma + \varepsilon$

$(N_L - N_R)|\psi\rangle = 0$

$\langle X^\mu \rangle = \text{fixed}$

Symm.:

$\sim R$

$\langle X^1 + i X^2 \rangle =$

$\alpha^2_{-n_w}$

$|\phi\rangle = e^{iRn_w\alpha^1_{-n_w}}|0\rangle \otimes |N_R\rangle$

Solve constraints for
α^-_n , $\tilde{\alpha}^-_n$

$\sigma \to \sigma + \varepsilon$

$(N_L - N_R)|\psi\rangle = 0$

$\langle X^\mu \rangle = \text{fixed}$

R

n_w

$n_w^2 \frac{R^2}{\alpha'}$

$\langle X^1 + i X^2 \rangle =$

$|\emptyset\rangle = e^{iRn_w \alpha_{-n_w}^1}|0\rangle \otimes |N_R\rangle$

$= 0$

$m:$

R

$\alpha^2_{-n_w}$

$$\sigma \to \sigma + \varepsilon$$

$$(N_L - N_R)|\psi\rangle = 0$$

$$\langle X^\mu \rangle = \text{fixed}$$

$$\langle X^3 + iX^4 \rangle = \frac{n_w}{N} R e^{2in_w\sigma^-}$$

$$\langle X^1 + iX^2 \rangle = R e^{2in_w\sigma^+} \quad n_w^2 \frac{R^2}{\alpha'}$$

$$|\phi\rangle = e^{iRn_w\alpha^1_{-n_w}}|0\rangle \otimes |N_R\rangle$$

$= 0$

$m:$

R

$X^2_{-n_w}$

$\sigma \to \sigma + \epsilon$

$(N_L - N_R)|\psi\rangle = 0$

$\langle X^\mu \rangle =$ fixed

$\langle X^3 + iX^4 \rangle = \frac{n_w}{N} R e^{2iN\sigma + t}$

$\langle X^1 + iX^2 \rangle = R e^{2in_w\sigma^+} \sim n_w^2 \frac{R^2}{\alpha'}$

$|\phi\rangle = e^{iRn_w\alpha^1_{-n_w}}|0\rangle \otimes |N_R\rangle$

ive constraints for

$\tilde{\alpha}_n$

$\sigma \to \sigma + \epsilon$

$(N_L - N_R)|\psi\rangle = 0$

$\langle X^\mu \rangle = \text{fixed}$

$\langle X^3 + iX^4 \rangle = \frac{n_w}{N} R e^{2iN\sigma t}$

$\langle X^1 + iX^2 \rangle = R e^{2in_w\sigma}$

$|\emptyset\rangle = e^{iRn_w x_m^1}|0\rangle \otimes |N_R\rangle$

$n_w^2 \frac{R^2}{\alpha'}$

$\frac{\ }{N\alpha'}$

Degeneracy. - # of ways to fill with rightmovers up to $N_R = \frac{n_w^2 R^2}{\alpha'}$

<u>Degeneracy</u>: # of ways to fill with rightmovers up to $N_R = \frac{n_w^2 R^2}{\alpha'}$

$$d_{N_R} \sim e^{\# \sqrt{\quad}}$$

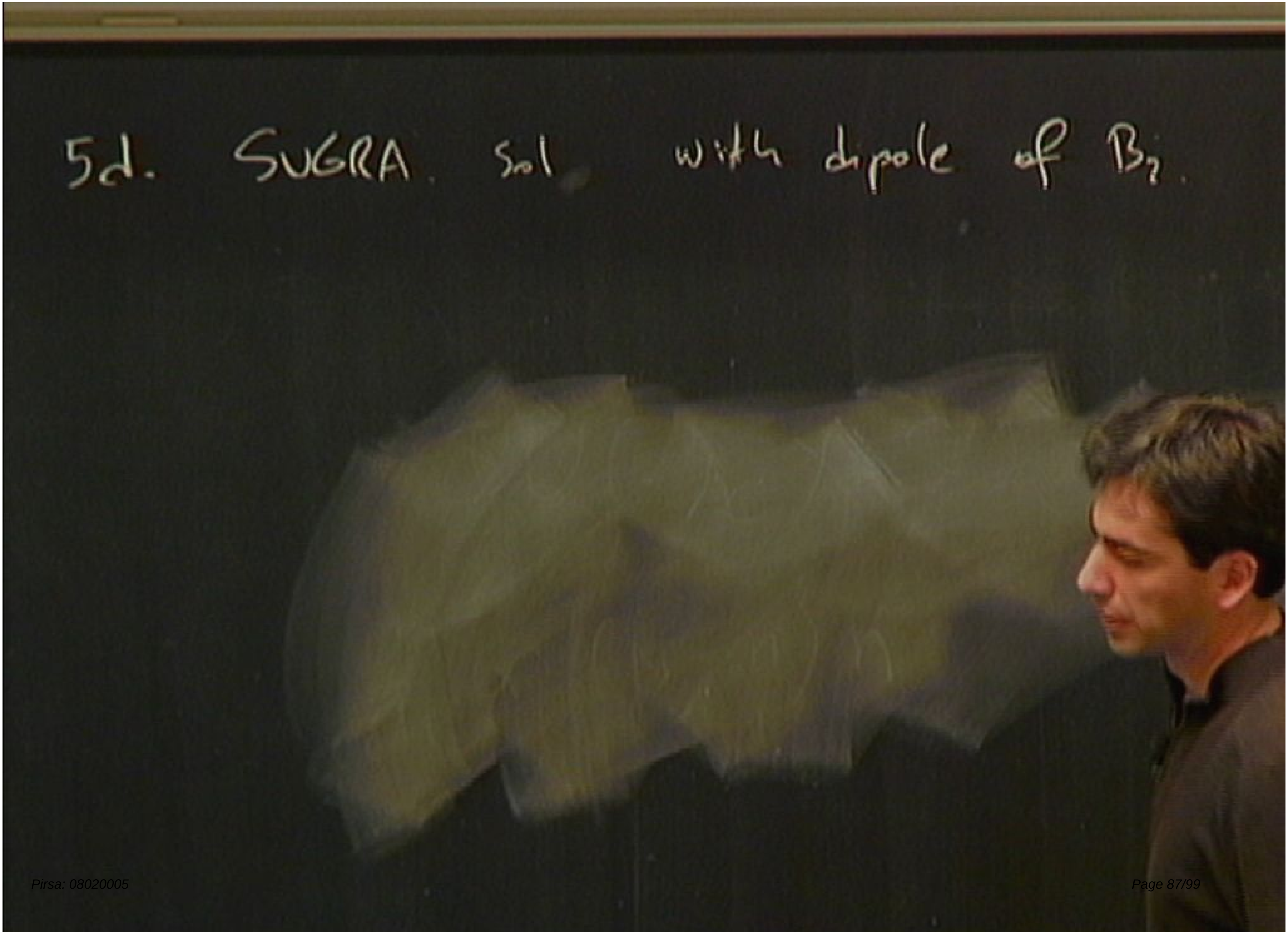
Degeneracy: # of ways to fill with rightmovers up to $N_R = \frac{n_w^2 R^2}{\alpha'}$

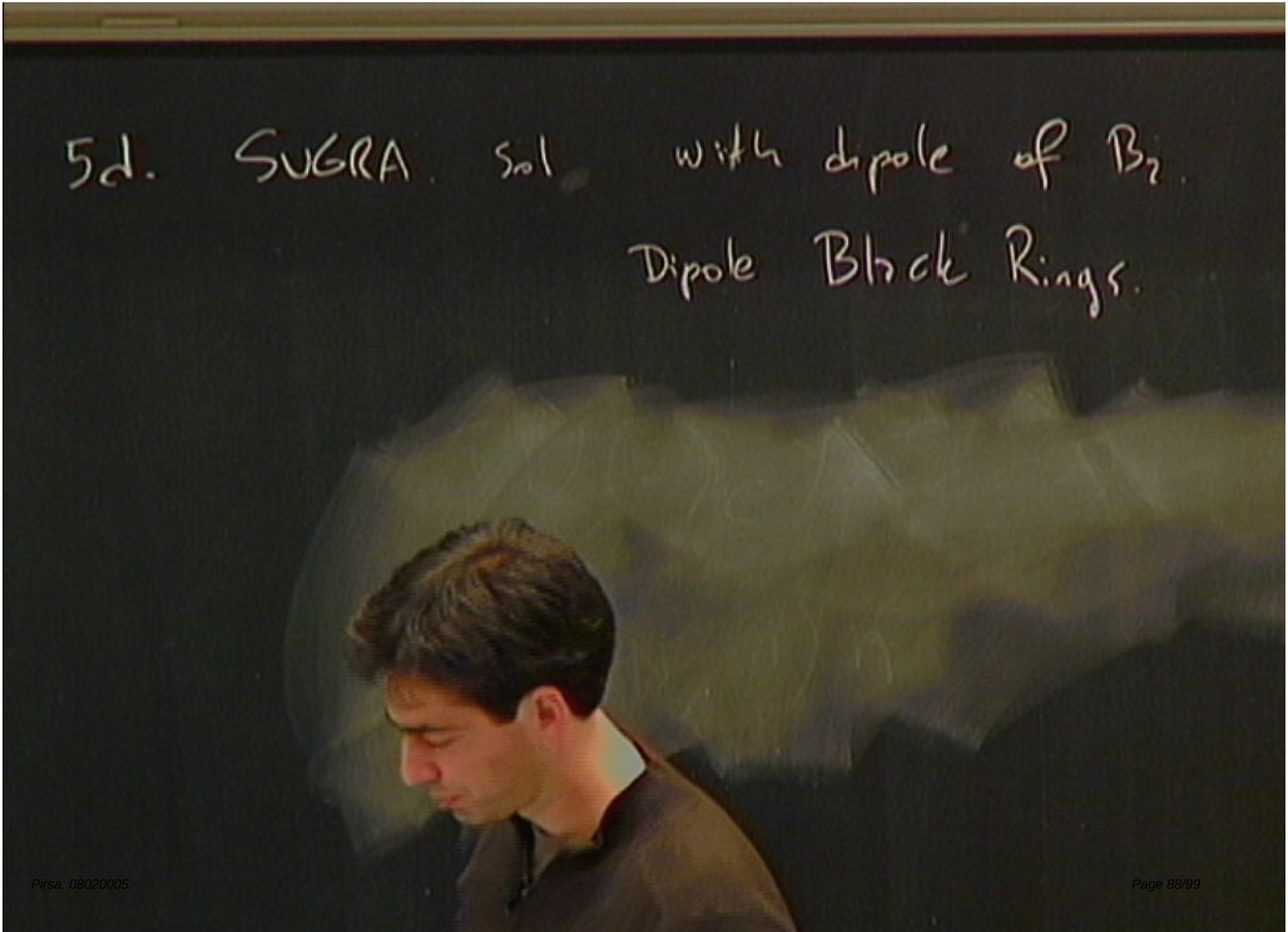
$$d_{N_R} \sim e^{\# \sqrt{N_R}}$$

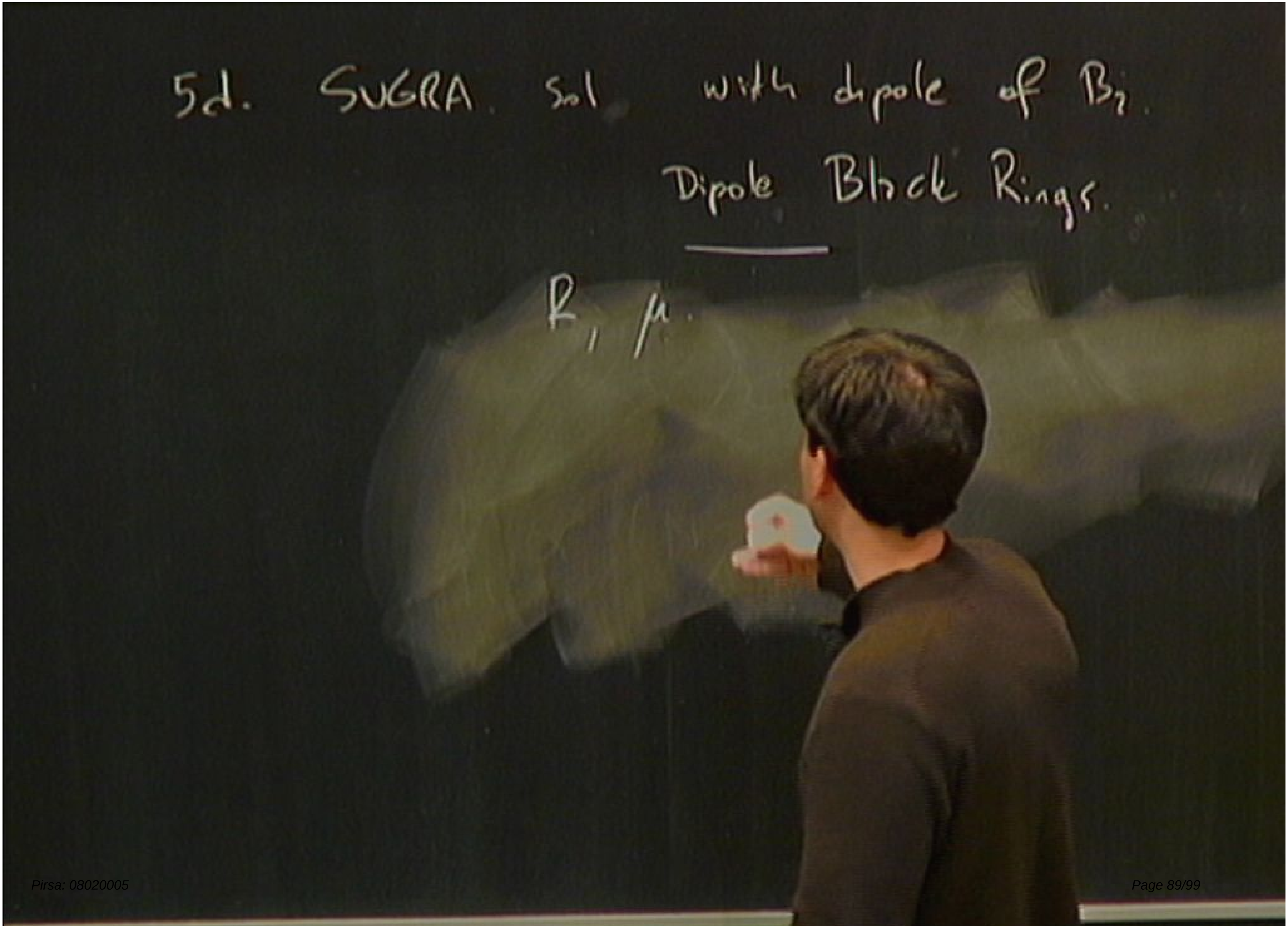
Degeneracy: # of ways to fill with rightmovers up to $N_R = \frac{n_w^2 R^2}{\alpha'}$

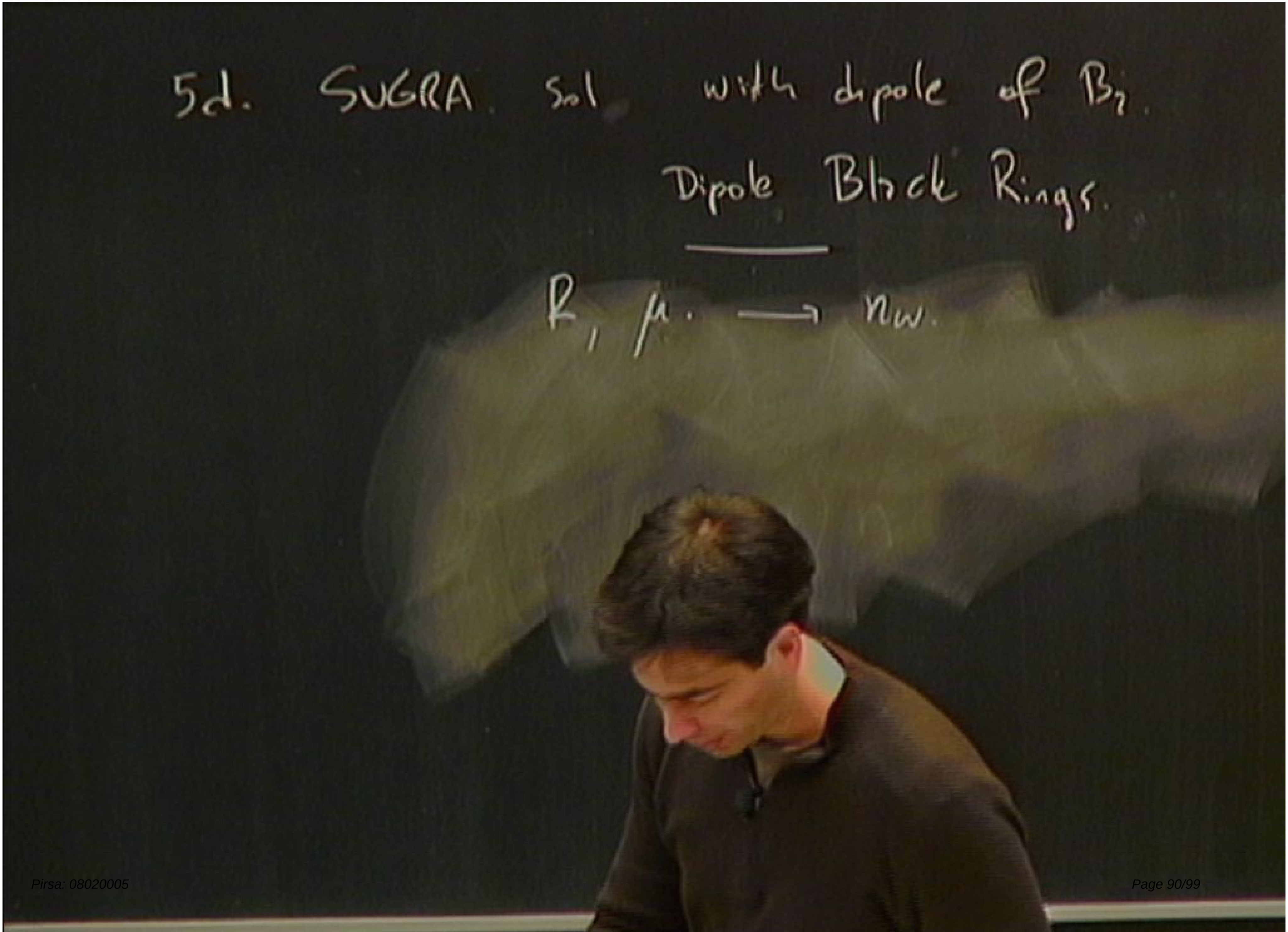
$$d_{N_R} \sim e^{\# \sqrt{N_R}}$$

$$S \sim \sqrt{n_w J_{12}}$$


5d. SUGRA sol with dipole of B2


5d. SUGRA Sol with dipole of B_2.
Dipole Black Rings.


5d. SUGRA sol with dipole of B_2.
Dipole Black Rings.
R, μ.


5d. SUGRA sol with dipole of B2.
Dipole Black Rings.
R, μ. → nw.

5d. SUGRA sol with dipole of B_2

Dipole Black Rings.

$$R, \mu \longrightarrow n_w$$

ADM mass. $M = \frac{2R\, n_w}{\alpha'} \left(1 + G\, n_w \ldots \right)$

$$J_{12} = \frac{R^2 n_w}{\alpha'} \left(1 + \frac{2G\, n_w}{\pi \alpha' R} \right)$$

5d. SUGRA Sol with dipole of B_2.

Dipole Black Rings.

$$R, \mu. \longrightarrow n_w.$$

ADM mass. $$M = \frac{2R n_w}{\alpha'} \left(1 + \frac{G n_w}{\pi \alpha' R} \right)$$

$$J_{12} = \frac{R^2 n_w}{\alpha'} \left(1 + \frac{2G n_w}{\pi \alpha' R} \right)$$

5d. SUGRA sol with dipole of B_2.

Dipole Black Rings.

$R, \mu. \longrightarrow n_w.$

ADM mass. $M = \frac{2R n_w}{\alpha'}\left(1 + \frac{G n_w}{\pi\alpha' R}\right)$ $\ll 1$

$J_{12} = \frac{R^2 n_w}{\alpha'}\left(1 + \frac{2G n_w}{\pi\alpha' R}\right)$

Thin ring Approx.

5d. SUGRA Sol with dipole of B_2.

Dipole Black Rings.

$R,\ \mu \longrightarrow n_w$

ADM mass. $M = \frac{2R\,n_w}{\alpha'}\left(1 + \frac{G\,n_w}{\pi\alpha' R}\right)$ $\ll 1$

$J_{12} = \frac{R^2 n_w}{\alpha'}\left(1 + \frac{2G\,n_w}{\pi\alpha' R}\right)$

Thin ring Approx.

5d. SUGRA Sol with dipole of B_2.

Dipole Black Rings.

$$R, \mu \longrightarrow n_w.$$

ADM mass. $$M = \frac{2R n_w}{\alpha'}\left(1 + \frac{G n_w}{\pi \alpha' R}\right)$$

$$\frac{G n_w}{\pi \alpha' R} \ll 1$$

$$J_{12} = \frac{R^2 n_w}{\alpha'}\left(1 + \frac{2G n_w}{\pi \alpha' R}\right)$$

Thin ring Approx.

F P strings.

5d. SUGRA Sol with dipole of B_2.

Dipole Black Rings.

$R, \mu. \longrightarrow n_w.$

ADM mass. $M = \frac{2R n_w}{\alpha'} \left(1 + \frac{G n_w}{\pi \alpha' R} \right)$ $\ll 1$

$J_{12} = \frac{R^2 n_w}{\alpha'} \left(1 + \frac{2G n_w}{\pi \alpha' R} \right)$

Thin ring Approx.

FP strings. $\longrightarrow$ Add higher deriv

5d. SUGRA Sol with dipole of B_2.

Dipole Black Rings.

$R, \mu \longrightarrow n_w$

ADM mass. $M = \frac{2R n_w}{\alpha'}\left(1 + \frac{G n_w}{\pi \alpha' R}\right)$ $\ll 1$

$J_{12} = \frac{R^2 n_w}{\alpha'}\left(1 + \frac{2G n_w}{\pi \alpha' R}\right)$

Thin ring Approx.

FP strings. $\longrightarrow$ Add higher derv. terms.

Higher D $S \sim \sqrt{n_p n_w}$

5d. SUGRA Sol with dipole of B_2.

Dipole Black Rings.

$R, \mu \longrightarrow n_w$.

ADM mass. $M = \frac{2R n_w}{\alpha'}\left(1 + \frac{G n_w}{\pi \alpha' R}\right)$

$\ll 1$

$J_{12} = \frac{R^2 n_w}{\alpha'}\left(1 + \frac{2G n_w}{\pi \alpha' R}\right)$

Thin ring Approx.

FP strings. $\longrightarrow$ Add higher derv. terms.

Higher D $S \sim \sqrt{n_f n_w}$

5d. SUGRA Sol with dipole of B_2.

Dipole Black Rings.

$R, \mu \longrightarrow n_w$

ADM mass. $M = \frac{2R n_w}{\alpha'}\left(1 + \frac{G n_w}{\pi \alpha' R}\right)$ $\ll 1$

$J_{12} = \frac{R^2 n_w}{\alpha'}\left(1 + \frac{2G n_w}{\pi \alpha' R}\right)$

Thin ring Approx.

F P strings. $\longrightarrow$ Add higher derv terms.

Higher D $S \sim \sqrt{n_p n_w}$