

Title: Superstring Cosmology Mini-course: Part 2

Date: Jan 31, 2006 11:00 AM

URL: <http://pirsa.org/06010022>

Abstract: From Monday, January 30th to Thursday, February 2nd, Senarath (Shanta) de Alwis will give a four lecture mini-course on 'Potentials for light moduli in N=1 supergravity and string theory'. In these lectures, Shanta will be describing some of the technical ingredients used in recent constructions of inflation in string theory. The lectures will be given at a level appropriate for advanced graduate students and will be held in the Bob Room at 11:00am each day.

The topics to be covered include:

Derivation of the potential for chiral scalars in N=1 supergravity;

Weyl anomalies and the generation of non-perturbative terms in the superpotential;

Derivation of moduli potentials from fluxes in type IIB and heterotic string theory;

Derivation of potentials for light moduli by integrating out heavy moduli.

Shanta is a faculty member in the Physics Department at the University of Colorado, Boulder who is spending his sabbatical year here at Perimeter.

$n=1$

$$S = -3 \int d^3z E e^{-K/3} + \int d^3z \frac{E}{R}$$

P_{no}
 K_{no}

P

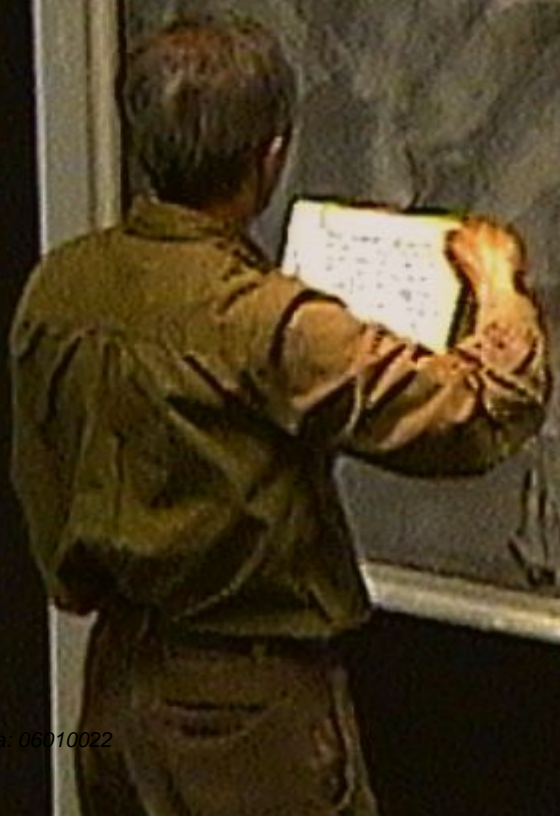


1.1

$$S = -3 \int d^3z E e + \int d^3z \left(\frac{E}{R} W(\phi) + h.c \right)$$

Per 1.1.10
K-1.1.10

$$= -3 \int d^3z \phi^3$$



$k=1$

ii. $-k/3$

$$S = -3 \int d^3z E e^{-k/3} + \int d^3z \left(\frac{E}{R} W(\phi) + h.c \right)$$

Per. 11/10
k=1, 2, 3

$$= -3 \int d^3z \left(-\frac{1}{4} \nabla^2 \phi^2 \right) e^{-k/3}$$



12.1

$$S = -3 \int d^3z E e^{-K/3} + \int d^3z \left(\frac{E}{R} W(\phi) + h.c \right)$$

$$= -3 \int d^3z \phi^2 \left(-\frac{1}{4} \nabla^2 - \mu^2 \right) e^{-K/3}$$

12.1.10
12.1.11

P



1.1.1

1.1.1.1

$$S = -3 \int d^3z E e + \int d^3z \left(\frac{E}{R} W(\Phi) + h.c \right)$$

1.1.1.2

$$= -3 \int d^3z \varphi^3 \left(-\frac{1}{4} \nabla^2 - \mu^2 \right) e^{-k/4} + \int d^3z \varphi^3 W(\Phi)$$



1.1

$$S = -3 \int d^3x \mathbf{E} \cdot \mathbf{e} + \int d^3x \left(\frac{E}{R} W(\Phi) + h.c \right)$$

1.1. -K/3
 1.1.1.1.1
 1.1.1.1.1
 $= -3 \int d^3x \varphi^3 \left(-\frac{1}{4} \nabla^2 - \mu^2 \right) e^{-K/3} + \left(\int d^3x \varphi^3 W(\Phi) + h.c \right)$

$k=1$

$$S = -3 \int d^2 z E \bar{t} t e^{-k/3} + \int d^2 z \left(\frac{E}{R} \phi^3 W(\Phi) + h.c \right)$$

\int_{Fermions}
 $\int_{\text{Bosons}} \rightarrow \int d^2 z \phi^3 \left(-\frac{1}{4} \nabla^2 - gR \right) e^{-k/3} + \left(\int d^2 z \phi^3 W(\Phi) + h.c \right)$



$$S = -3 \int d^2 z E \bar{t} t \quad + \int d^2 z \left(\frac{E}{R} \phi^3 W(\Phi) + h.c \right)$$

$$= -3 \int d^2 z \phi^3 \left(-\frac{1}{4} \bar{\nabla}^2 - 8R \right) \bar{t} t \quad + \left(\int d^2 z \phi^3 W(\Phi) + h.c \right)$$

$$\tau : \bar{\nabla}_\mu t = 0, \quad \Phi \rightarrow \bar{\Phi} \quad \phi \rightarrow e^{-2\sigma} \phi \quad \psi \rightarrow e^{2\sigma} \psi$$



$k=1$

$$S = -3 \int d^3z E \bar{\psi} \psi - K/3 + \int d^3z \left(\frac{E}{R} \Phi^3 W(\Phi) + h.c \right)$$

$$= -3 \int d^3z \psi^\dagger \left(-\frac{1}{4} \nabla^2 - g \tau \right) \psi + \left(\int d^3z \Phi^3 W(\Phi) + h.c \right)$$

$$\tau : \bar{\nabla}_\mu \tau = 0, \quad \Phi \rightarrow \Phi \quad \psi \rightarrow e^{-i\tau} \psi \quad \bar{\psi} \rightarrow e^{i\tau} \bar{\psi}$$

$k=1$

$$S = -3 \int d^3z E \dot{\bar{\tau}} \tau + \int d^3z \left(\frac{E}{R} \Phi^3 W(\Phi) + h.c \right)$$

Field
Kinetic

$$\rightarrow \int d^6z \Phi^3 \left(-\frac{1}{4} \nabla^2 - 8\tau \right) \bar{\tau} \tau + \left(\int d^6z \Phi^3 W(\Phi) + h.c \right)$$

$$\tau \quad \bar{\nabla}_2 \tau = 0 \quad \Phi \rightarrow \bar{\Phi}$$

$$\rightarrow e^{(\tau - \bar{\tau})} \left(E_M^{\alpha} \right)$$

$$\Phi \rightarrow e^{-2\tau} \Phi \quad \Psi \rightarrow e^{2\tau} \Psi$$

$$E_M^{\alpha} \rightarrow e^{(\tau + \bar{\tau})} \left(E_M^{\alpha} \right)$$

11.1

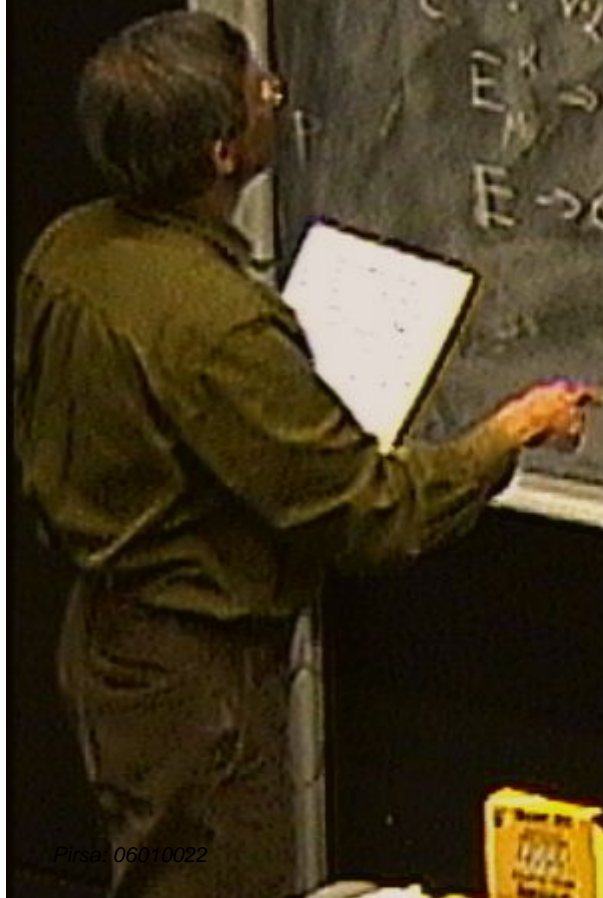
$$S = -3 \int d^3z E \dot{\Phi} \dot{\Phi} + \int d^3z \left(\frac{E}{R} \Phi^3 W(\Phi) + h.c. \right)$$

$$= -3 \int d^3z \left(-\frac{1}{4} \vec{\nabla}^2 \Phi \right) \dot{\Phi} + \left(\int d^3z \Phi^3 W(\Phi) + h.c. \right)$$

$\tau : \vec{\nabla}_i \tau = 0, \quad \Phi \rightarrow \Phi$

$E_M^K \rightarrow e^{(K\tau - \tau)} (E_M^K)$ $E_M^K \rightarrow e^{(K\tau + \tau)} (E_M^K)$

$\Phi \rightarrow e^{-2\tau} \Phi$ $\Phi \rightarrow e^{2\tau} \Phi$



$$S = -3 \int d^2 z E_{ij} \dot{\tau}^i \dot{\tau}^j + \int d^2 z \left(\frac{E}{R} \Phi^3 W(\Phi) + h.c \right)$$

$$= -3 \int d^2 z \Phi^3 \left(-\frac{1}{4} \nabla^2 - \gamma \tau \right) \bar{\tau} e^{-K/3} + \left(\int d^2 z \Phi^3 W(\Phi) + h.c \right)$$

$$\tau : \bar{\nabla}_i \tau = 0 \quad \Phi \rightarrow \bar{\Phi} \quad \psi \rightarrow e^{-\gamma \tau} \psi \quad \varphi \rightarrow e^{\gamma \tau} \varphi$$

$$E_M^A \rightarrow e^{(\gamma \tau - \bar{\tau})} (E_M^A) \quad E_M^A \rightarrow e^{(\tau + \bar{\tau})} (E_M^A)$$



11. -K/3

$$S = -3 \int d^2 z E \bar{t} t e + \int d^2 z \left(\frac{E}{R} \Phi^3 W(\Phi) + h.c \right)$$

$$= -3 \int d^2 z \varphi^3 \left(-\frac{1}{4} \bar{\nabla}^2 - \frac{1}{2} \bar{\nabla} \cdot \nabla \right) \bar{t} e^{-K/3} + \left(\int d^2 z \varphi^3 W(\Phi) + h.c \right)$$

$\tau : \bar{\nabla}_\mu \tau = 0 \quad \Phi \rightarrow \bar{\Phi} \quad \varphi \rightarrow e^{-2\tau} \varphi \quad \psi \rightarrow e^{2\tau} \psi$

$E_M^N \rightarrow e^{(\tau - \bar{\tau})} (E_M^N)$ $E_M^N \rightarrow e^{(\tau + \bar{\tau})} (E_M^N)$

$\nabla_M \rightarrow e^{(\tau - \bar{\tau})} (\nabla_M)$ $\nabla_M \rightarrow e^{(\tau + \bar{\tau})} (\nabla_M)$

Kähler-Transf.



Kähler-transf.

$K \rightarrow K + S + S$

Kähler transf

$$K \rightarrow K + \text{light} \rightarrow \text{light}$$

Kähler-transf.

$$K \rightarrow K + \frac{1}{2} \text{Ric} \rightarrow \mathbb{R} \\ W \rightarrow$$

Kähler-Transf.

$$K \rightarrow K + \sqrt{-1} \partial \bar{\partial} \psi$$

$$W \rightarrow$$

$$S^1 \times B^2 \times K$$



Kähler-Transf.

$K \rightarrow k + \text{sur} \rightarrow \text{S}(\mathbb{C})$

$W \rightarrow e^{-s} W$

Sob. K



Kähler-transf.

Solb. k

$$K \rightarrow k + \text{Sist} \rightarrow \text{Sist}$$
$$W \rightarrow e^{-s} W + e^{s/3} \phi$$

Kähler-transf.

$$K \rightarrow K + \frac{1}{2} \text{tr} \rightarrow \mathbb{C} \mathbb{P}^1$$
$$W \rightarrow e^{-s} W \quad t \rightarrow e^{s/3} \phi$$

earlier $t = 1$

$d^2 b \cdot k$

Wahl 2008



Kähler transfⁿ

$\int d^4x K$

$K \rightarrow K + \frac{1}{2}(\psi + \bar{\psi}) + \frac{1}{2}(\psi - \bar{\psi})$

$W \rightarrow e^{-S} W + e^{S/3} \phi$

Wahl gauge

earlier

$\psi \rightarrow 1$

Alternatingly

$\phi \rightarrow 1$



Kähler transp^m

$\int d^4x$

Wahl gauge

$$K \rightarrow K + \delta K \rightarrow \bar{K}$$

$$W \rightarrow e^{-S} W \quad t \rightarrow e^{S/3} \phi$$

earlier

$$t \rightarrow 1$$

Alternativly,

$$\phi \rightarrow 1$$

To calculate the \int

To calculate the potential
can ignore connections / curvature pieces

Kähler transf

$\int d^4x K$

Wahl gauge

$$K \rightarrow K + \frac{1}{2}(\psi + \bar{\psi})$$

$$W \rightarrow e^{-\psi} W + e^{\psi/3} \phi$$

$$t \rightarrow 1$$

$$\varphi \rightarrow 1$$

earlier
finly



$$S = -3 \int d^3x E_{ij} \dot{E}^i E^j + \int d^3x \left(\frac{E^2}{R} + W(\Phi) + h.c. \right)$$

$$= -\int d^3x \varphi^2 \left(-\frac{1}{4} \nabla^2 - \gamma \right) \dot{\varphi} e^{-K\varphi} + \left(\int d^3x \varphi^3 + W(\Phi) + h.c. \right)$$

$\tau : \bar{\nabla}_\mu c = 0, \quad \Phi \rightarrow \bar{\Phi} \quad t \rightarrow e^{-\tau t} t \quad \varphi \rightarrow e^{\tau \varphi} \varphi$
 $E_M^X \rightarrow e^{(s\tau - z)} (E_M^X) \quad E_M^X \rightarrow e^{(s + \tau z)} (E_M^X)$
 $E \rightarrow e^{s(\tau + z)} \quad \nabla_X \rightarrow e^{(s - \tau z)} (\nabla_X)$

Kähler transf

$$K \rightarrow K + \gamma \ln |t| \rightarrow (K)$$

$$W \rightarrow e^{-S} W \quad t \rightarrow e^{s/3} \phi$$

Alternative
 $\phi \rightarrow 1$
 $\phi \rightarrow 1$

Kähler transf^m

$$K \rightarrow K + \frac{1}{2} \bar{\partial} \bar{\partial} \bar{\partial} \bar{\partial}$$

$$W \rightarrow e^{-\bar{\partial}} W \quad \bar{\partial} \rightarrow e^{\bar{\partial}/3} \bar{\partial}$$

$$\int d\bar{\partial} K$$

Wahlgesetz

earlier

$$\bar{\partial} \rightarrow 1$$

Alternating

$$\bar{\partial} \rightarrow 1$$

To calculate the potential

can ignore connection / curvature. fine as

$$E \rightarrow 4\pi \int d^3z$$

To calculate the potential

can ignore connection / curvature piece as

$$\vec{E} \rightarrow \nabla \phi \quad \int dz \phi \phi e^{-k|z|}$$

To calculate the potential

can ignore connection / curvature piece as

$$E \rightarrow \int d^8z \bar{\phi} \phi e^{-k/3} + \left[\int d^6z \phi^3 W(\Phi) + \text{h.c.} \right]$$

SSC
Chp 30
To calculate the potential

Can ignore connection / curvature piece as

$$E \rightarrow \phi \bar{\phi} \int d^8 z \phi \bar{\phi} e^{-K/3} + \left[\int d^6 z \phi^3 W(\Phi) + h.c \right]$$

Sec. 11
Chp 8
To calculate the potential

can ignore connection / curvature piece as

$$\bar{E} \rightarrow \phi \bar{\phi} \quad \int d^8 z \phi \bar{\phi} e^{-K/3} + \left[\int d^6 z \phi^3 W(\Phi) + h.c. \right]$$

$$\nabla_a \rightarrow D_x$$

Ex. 11
Ch 10
To calculate the potential

can ignore connection / curvature piece as

$$\bar{E} \rightarrow \psi \bar{\psi}$$

$$\int d^8 z \psi \bar{\psi} e^{-k/3} + \left[\int d^6 z \psi^3 W(\Phi) + h.c \right]$$

$$\nabla_a \rightarrow D_a \quad \delta d$$

Kähler transf

$$K \rightarrow K + \sqrt{-1} \bar{\partial} \bar{\partial} \bar{\partial}$$
$$W \rightarrow e^{-s} W \quad \text{to } e^{s/3} \phi$$

SDBK

Wahl gauge

earlier

$$\phi \rightarrow 1$$

R_q

Alternating

$$\phi \rightarrow 1$$

SSC
Chp 8
To calculate the potential

can ignore connection / curvature piece as

$$E \rightarrow \phi \bar{\psi}$$

$$\int d^6 z \phi \bar{\phi} e^{-k/3} + \left[\int d^6 z \phi^3 W(\Phi) + h.c. \right]$$

$$\nabla_a \rightarrow D_a$$



SSC 13
Ch 8
To calculate the potential

Can ignore connection / curvature. fine as

$$E \rightarrow \psi \bar{\psi}$$

$$\int d^6 z \left(\frac{1}{4} \right) \bar{\psi} \psi e^{-k/3} + \left[\int d^6 z \psi^3 W(\Phi) + h.c. \right]$$

$$\nabla_a \rightarrow D_a \quad \delta d$$

6.6.13
 ch 8
 To calculate the potential

can ignore connection / curvature piece as

$$E \rightarrow \int d^6z \left(\frac{1}{4} \bar{\psi} \psi \right) + \left[\int d^6z \phi^3 W(\phi) \right]$$

$$\frac{\delta}{\delta \phi} \left(\frac{1}{4} \bar{\psi} \psi \right) = \phi^2 W + h.c.$$

SSC-AS
Chp 8
To calculate the potential

Can ignore connection / curvature ... fine as

$$E \rightarrow \psi \bar{\psi}$$

$$\nabla_\mu \rightarrow D_\mu \quad \delta \psi$$

$$\int d^4x \frac{1}{4} \bar{\psi} \not{\partial} \psi e^{-ik_1 x} + \left[\int d^4x \psi^\dagger W(\psi) \right]$$

$$- \frac{1}{4} \bar{\psi} \not{\partial} (\bar{\psi} e^{-k_1 x}) - \psi^\dagger W + h.c.$$

$$- \frac{1}{4} \bar{\psi} \not{\partial} (\psi e^{-k_1 x})$$

SSC 13
Ch 8
To calculate the potential

can ignore connection / curvature piece as

$$E \rightarrow \phi \bar{\psi}$$

$$\int d^6z \frac{1}{4} \bar{\psi} \psi e^{-K/3} + \left[\int d^6z \phi^3 W(\Phi) \right]$$

$$\nabla_a \rightarrow D_a \quad \delta \phi$$

$$-\frac{1}{4} \bar{D}^2 (\bar{\psi} e^{-K/3}) = \phi^2 W + h.c.$$

$$\psi \rightarrow \xi \psi \quad \delta \bar{\psi}$$

$$-\frac{1}{4} \bar{D}^2 (\phi \bar{\psi} e^{-K/3} k_i) = -\phi^3 W_i$$

S.C. 13
Ch 8
To calculate the potential

can ignore connection / curvature. give us

$$E \rightarrow \psi \bar{\psi}$$

$$\int d^6z \left(\frac{1}{4} \bar{D}^2 \right) \bar{\psi} e^{-k/3} + \left[\int d^6z \psi^3 W(\Phi) \right]$$

$$\nabla_a \rightarrow D_a \quad \delta \psi$$

$$-\frac{1}{4} \bar{D}^2 (\bar{\psi} e^{-k/3}) = \psi^2 W + h.c.$$

$$\psi \bar{\psi} \quad \delta \bar{\psi}$$

$$-\frac{1}{4} \bar{D}^2 (\psi \bar{\psi} e^{-k/3} k_i) = -\psi^3 W_i$$

any fermions

To calculate the potential

can ignore connection / curvature piece as

$E \rightarrow \psi \bar{\psi}$

$$\int d^4x (\bar{\psi} \not{D} \psi) e^{-K/3} + \left[\int d^4x \psi^3 W(\Phi) \right]$$

$\nabla_\mu \rightarrow \partial_\mu$

$$-\frac{1}{4} \bar{D}^2 (\bar{\psi} e^{-K/3}) = \psi^2 W + h.c$$

$\psi \rightarrow \psi \bar{\psi}$

$$-\frac{1}{4} \bar{D}^2 (\psi \bar{\psi} e^{-K/3}) = -\psi^3 W_c$$

To calculate the potential

can ignore connection / curvature piece as

$E \rightarrow \phi \bar{\psi}$

$$\int d^6z \frac{1}{(4\pi)^3} \bar{\phi} e^{-K/3} + \left[\int d^6z \phi^3 W(\Phi) \right]$$

$\nabla_a \rightarrow D_a \quad \delta\phi$

$$-\frac{1}{4} \bar{D}^2 (\bar{\phi} e^{-K/3}) = \phi^2 W + h.c.$$

$\psi \rightarrow \xi \bar{\psi} \quad \delta\bar{\psi}^i$

$$-\frac{1}{4} \bar{D}^2 (\phi \bar{\psi} e^{-K/3} k_i) = W_i$$

ignoring fermions

$$\bar{F}_\phi e^{-K/3} = \phi \frac{k_i}{3} \bar{F}^i = *$$



CCAS
Chp 8
To calculate the potential

can ignore connection / curvature piece as

$E \rightarrow \phi \bar{\psi}$

$$\int d^6z \left(\frac{1}{4} \bar{D}^2 \phi e^{-k/3} + \left[\int d^6z \phi^3 W(\Phi) \right] \right)$$

$$-\frac{1}{4} \bar{D}^2 (\bar{\psi} e^{-k/3}) = \phi^2 W + h.c$$

$$-\frac{1}{4} \bar{D}^2 (\phi \bar{\psi} e^{-k/3} k_i) = -\phi^3 W_i$$

$$\bar{F}_\phi e^{-k/3} \left| -\phi \frac{k_i}{3} \bar{F}_i e^{-k/3} + \phi \bar{\psi} e^{-k/3} k_{ij} \bar{F}_j \right| = -\phi^3 W_i$$

Δ
 \bar{D}
 $\delta \phi$
 $\delta \bar{\psi}$
if
minias

6.5.18
 ch 8
 To calculate the potential

can ignore connection / curvature piece

$$E \rightarrow \phi \bar{\psi}$$

$$\int d^6z \left(\frac{1}{4} \bar{D}^2 \phi \right) \bar{\psi} e^{-K/3} + \left[\int d^6z \phi^3 W(\Phi) \right]$$

$$\nabla_a \rightarrow D_a \quad \delta \phi$$

$$-\frac{1}{4} \bar{D}^2 (\bar{\psi} e^{-K/3}) = \phi^2 W + h.c.$$

$$\psi \rightarrow \xi \bar{\psi} \quad \delta \bar{\psi}^i$$

$$-\frac{1}{4} \bar{D}^2 (\phi \bar{\psi} e^{-K/3} k_i) = -\phi^3 W_i$$

ignoring fermions

$$\bar{F}_i e^{-K/3} \Big|_{\frac{1}{3}} = \frac{1}{3} \bar{F}_i e^{-K/3} + \phi \bar{\psi} e^{-K/3} k_i \bar{F}_i$$

$$4 \left[-\frac{1}{4} \bar{D}^2 (\bar{\psi} e^{-K/3} k_i) \right] = -\phi^3 W_i$$

Ex. 13.1
 ch. 8
 To calculate the potential

can ignore connection / curvature. piece

$$E \rightarrow \psi \bar{\psi}$$

$$\int d^6z \left(\frac{1}{4} \bar{D}^2 \psi \right) \bar{\psi} e^{-k/3} + \left[\int d^6z \psi^3 W(\Phi) \right]$$

$$\bar{D}_\alpha \rightarrow \bar{D}_\alpha \quad \delta \psi$$

$$-\frac{1}{4} \bar{D}^2 (\bar{\psi} e^{-k/3}) = \psi^2 W + h.c.$$

$$\psi \rightarrow \xi \psi \quad \delta \bar{\psi}$$

$$-\frac{1}{4} \bar{D}^2 (\psi \bar{\psi} e^{-k/3}) = -\psi^3 W_c$$

ignoring fermions

$$e^{-k/3} \left| -\psi \frac{\delta}{\delta \psi} \bar{\psi} e^{-k/3} \right| = \psi^2 |W|$$

$$\psi \cdot \bar{D}^2 (\bar{\psi} e^{-k/3}) \left| \frac{\delta}{\delta \psi} \right| +$$

To calculate the potential

Ex. 8
Ch. 8

can ignore connection / curvature piece

$$E \rightarrow \psi \bar{\psi}$$

$$\int d^6 z \left(\frac{1}{4} \bar{\psi} \not{D} \psi \right) e^{-K/3} + \left[\int d^6 z \psi^3 W(\Phi) \right]$$

$$\nabla_a \rightarrow D_a \quad \delta \psi$$

$$-\frac{1}{4} \bar{D}^2 (\bar{\psi} e^{-K/3}) = \psi^2 W + h.c.$$

$$\psi \rightarrow \psi + \delta \psi$$

$$-\frac{1}{4} \bar{D}^2 (\psi \bar{\psi} e^{-K/3} k_i) = -\psi^3 W_i$$

fluctuation formulas

$$\bar{F}_i e^{-K/3} - \frac{1}{3} k_i \bar{F} e^{-K/3} = \psi^2 W_i$$

$$\psi \left[-\frac{1}{4} \bar{D}^2 (\psi \bar{\psi} e^{-K/3} k_i) \right] + \psi \bar{\psi} e^{-K/3} k_i \bar{F} = -\psi^3 W_i$$

Ex 11
Ch 8
To calculate the potential

can ignore connection / curvature piece

$$E \rightarrow \phi \bar{\phi}$$

$$\int d^6z \left(\frac{1}{4} \bar{D}^2 \right) \phi \bar{\phi} e^{-K/3} + \left[\int d^6z \phi^3 W(\phi) \right]$$

$$\nabla_a \rightarrow D_a \quad \delta \phi$$

$$-\frac{1}{4} \bar{D}^2 (\bar{\phi} e^{-K/3}) = \phi^2 W + h.c.$$

$$\phi \rightarrow \xi \bar{\phi} \quad \delta \bar{\phi}$$

$$-\frac{1}{4} \bar{D}^2 (\phi \bar{\phi} e^{-K/3} k_c) = -\phi^3 W_c$$

ignoring fermions

$$\bar{F}_\phi e^{-K/3} = \frac{1}{3} k_c \bar{F}^c e^{-K/3} = \phi^2 W_c$$

$$\phi \left[-\frac{1}{4} \bar{D}^2 (\bar{\phi} e^{-K/3}) \right] k_c + \phi \bar{\phi} e^{-K/3} k_c \bar{F}^c = -\phi^3 W_c$$

$$\nabla \left[-\frac{1}{4} \bar{D}^2 (\psi e^{-K/3}) \right] \bar{K}_i + 4\psi e^{-K/3} \bar{K}_{i,j} F^j = -\psi^2 W$$

$$\frac{1}{2} \bar{D}^2 \psi$$



$$\psi \left[-\frac{1}{4} D^2 \left(\psi e^{-K/3} \right) \right] K_1 + 4\psi e^{-K/3} K_1 \psi = -\psi^2 W$$

$$\frac{\psi}{\psi} = e^{K/3} \psi^2 W + \frac{1}{3} \psi K_1$$

$$4 \left[-\frac{1}{4} \bar{D}^2 (\bar{\psi} e^{-K/3}) \right] \bar{K}_c + 4\psi e^{-K/3} \bar{K}_{1,2} \bar{F} = -\psi^2 W$$

$$\bar{F}_{1,2} = e^{K/3} \psi^2 W + \frac{1}{3} \bar{\psi} \bar{K}_c \bar{F}$$

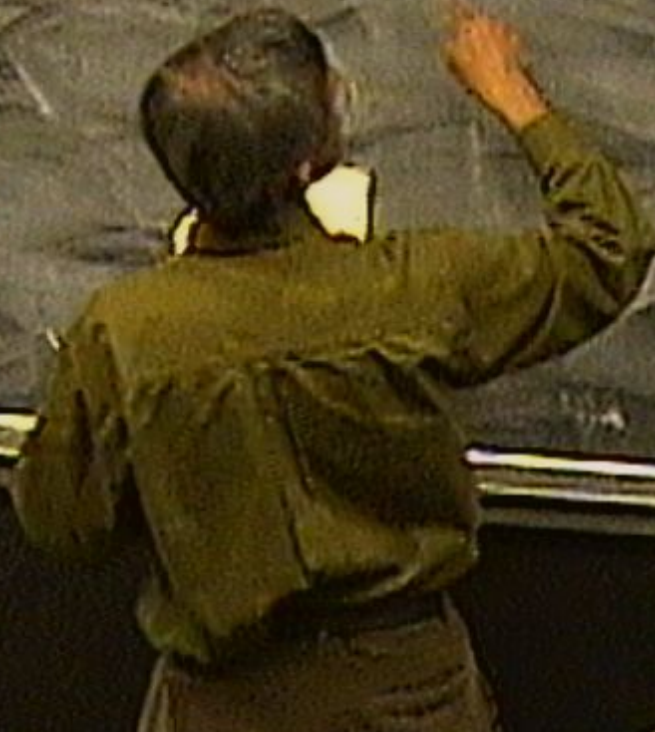
$$\bar{F}_{1,2} = -\psi^3 W$$



$$\psi \left[-\frac{1}{4} \bar{D}^2 (\psi e^{-K/3}) \right] \bar{K}_i + 4\psi e^{-K/3} K_{i\bar{j}} F^{\bar{j}} = -\psi^3 W$$

$$\frac{\bar{F}^{\bar{i}}}{\psi} = e^{K/3} \psi^3 W + \frac{1}{3} \psi K_{i\bar{j}} F^{\bar{j}}$$

$$\bar{F}^{\bar{i}} = -\psi^3 W K_{i\bar{j}} K^{i\bar{k}} e^{K/3} - \frac{\psi^3}{4\psi} W_0 K^{i\bar{j}} e^{K/3}$$



$$4 \left[-\frac{1}{4} D (4 e^{-K/3}) \right] K_1 + 44e \quad K_{1,2} F = -4W$$

$$\bar{F}_7 = e^{K/3} 4^2 W + \frac{1}{3} 4 K_2 F^2$$

$$\bar{F}^2 = -4^3 W K_2 K^{1,2} e^{K/3} - \frac{4^3}{4^2} W_0 K^{1,2} e^{K/3}$$

$$D W = 2 W + K_1$$

$$\psi \left[-\frac{1}{4} \bar{D}^2 (\psi e^{-K/3}) \right] \bar{K}_c + 4\psi e^{-K/3} \bar{K}_{1,1} \bar{F} = -\psi^2 W$$

$$\bar{F}_4 = e^{K/3} \psi^2 W + \frac{1}{3} \psi \bar{K}_c \bar{F}^2$$

$$\bar{F}^2 = -\psi^3 W \bar{K}_c \bar{K}^{1,1} e^{K/3}$$

$$\frac{\bar{F}_4}{\psi^4} = \frac{\psi^3}{\psi^4} W_c \bar{K}^{1,1} e^{K/3}$$

$$D\psi = \partial_c \psi + \bar{K}_c \psi$$

$$4 \left[-\frac{1}{4} D \left(4 e^{-K/3} \right) \right] K_i + 44e \quad K_{i-1} F = -\varphi^2 W$$

$$\bar{F}_7 = e^{K/3} \varphi^2 W + \frac{1}{3} \varphi K_i F_i$$

$$\bar{F}_i = -\varphi^3 W K_i K^{i-1} e^{K/3} - \frac{\varphi^3}{4\varphi} W_i K^{i-1} e^{K/3}$$

$$DW = \partial_i W K_i W$$

$$= -\frac{\varphi^3}{4\varphi} e^{K/3} K^{i-1} D_i W$$

$$-V = \int d^3x \phi^3$$

$$-V = \int d^3\phi \phi^3 W|_{\text{barrier}}$$

$$-V = -\frac{1}{4}D^2(\phi^3 W)|_{\text{barrier}}$$

$$\phi \left[-\frac{1}{4} \bar{D}^2 (\bar{\phi} e^{K/3}) \right] \bar{K}_c + \phi \bar{\phi} \bar{e}^{K/3} K_{i\bar{j}} \bar{F}^i = -\phi^3 W$$

$$\bar{F}_{\bar{j}} = e^{K/3} \phi^2 W + \frac{1}{3} \bar{\phi} K_{\bar{j}} \bar{F}^i$$

$$\bar{F}^i = -\phi^3 W K_c K^{i\bar{j}} e^{K/3} - \frac{\phi^3}{4\bar{\phi}} W_c K^{i\bar{j}} e^{K/3}$$

$$D_c W = \partial_c W + K_c W$$

$$-\frac{\phi^3}{4\bar{\phi}} e^{K/3} K^{i\bar{j}} D_c W$$

$$-V = -\frac{1}{4} \vec{D}^2 (\phi^3 W) \Big|_{\text{brane}}$$



$$\begin{aligned} -V &= -\frac{1}{4} \bar{D}^2 (\phi^3 W) \Big|_{\text{bosonic}} \\ &= 3\phi^2 \cdot F_{\phi} W + \phi^3 W_{\phi} F_{\phi} \end{aligned}$$

To calculate the potential -
 can ignore constant / curvature pieces
 $E \rightarrow \psi$
 $\int d^4x (\bar{\psi} \not{\partial} \psi) + e^{-K/3} \left[\int d^3x \psi^3 W(\Phi) \right]$
 $\nabla_\mu \rightarrow D_\mu$ $\delta \psi$ $-\frac{1}{4} \bar{D}^2 (\bar{\psi} e^{-K/3}) = \psi^3 W + h.c$
 $\delta \bar{\psi}$ $-\frac{1}{4} \bar{D}^2 (\psi \bar{D} e^{-K/3} k_c) = -\psi^3 W_c$
 Hermitian form $\bar{F}_4 e^{K/3} = -\frac{1}{3} k_c \bar{F} e^{-K/3} = F^2 |W|$
 $4 \left[-\frac{1}{4} \bar{D}^2 (\bar{\psi} e^{-K/3}) \right] k_c + 4 \bar{\psi} e^{-K/3} k_c \bar{F} = -\psi^3 W_c$

$$\bar{F}_4 = e^{K/3} \psi^3 W + \frac{1}{3} \bar{\psi} k_c \bar{F}$$

$$\bar{F} = -\psi^3 W k_c k^{ij} e^{K/3}$$

$$\frac{1}{3} \bar{\psi} k_c \bar{F} = \frac{\psi^3}{3} W k^{ij} e^{K/3}$$

$$D_i W = \frac{1}{3} k^{ij} D_j W$$

$$\begin{aligned}
 -V &= -\frac{1}{4} \bar{D}^2 (\phi^3 W) \Big|_{\text{bosonic}} \\
 &= 3\phi^2 \bar{F}_\phi W + \phi^3 W_\mu F^\mu \\
 &= e^{-k/3} \phi^2 \bar{\phi}^2 (K^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - 3|W|^2)
 \end{aligned}$$



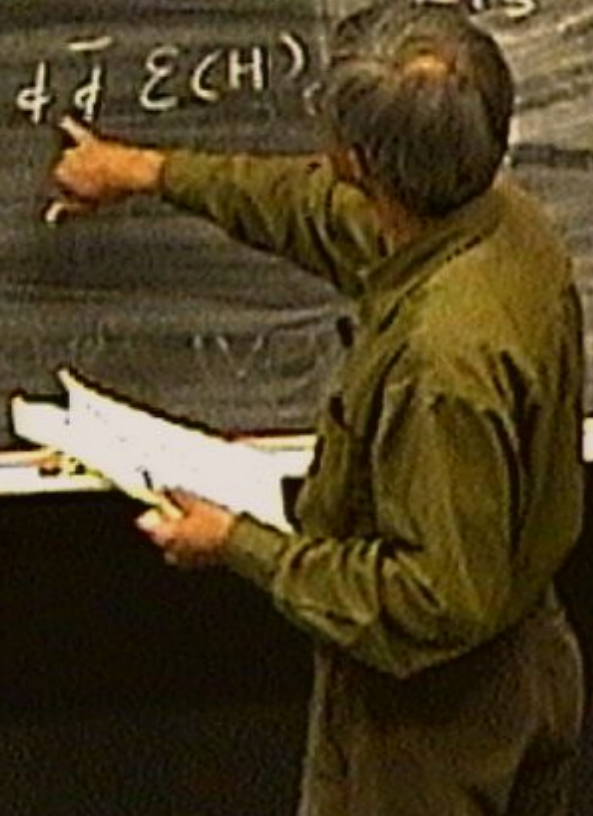
$$\begin{aligned}
 -V &= -\frac{1}{4} \bar{D}^2 (\phi^3 W) \Big|_{\text{barrier}} \\
 &= 3\phi^2 \cdot \bar{F}_\phi W + \phi^3 W_c F_c \\
 &= e^{-k/s} \phi^2 \bar{\phi}^2 (K^{ij} D_i W D_j \bar{W} - 3|W|^2)
 \end{aligned}$$

$$-V = -\frac{1}{4} \bar{D}^2 (\phi^3 W) \Big|_{\text{barrier}}$$

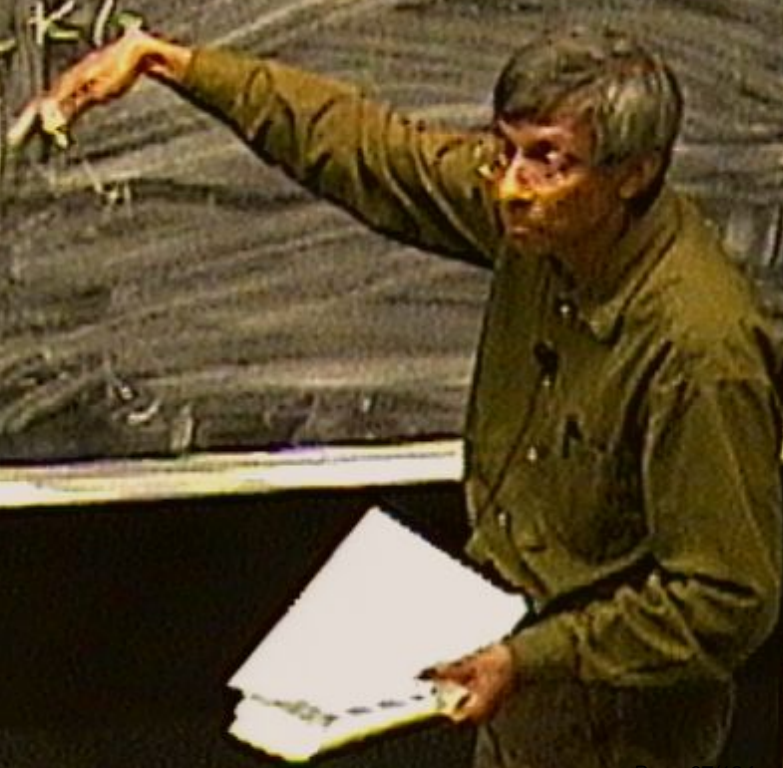
$$= 3\phi^2 \bar{F}_+ W + \phi^3 W_c F_c$$

$$\approx -e^{-k/3} \phi^2 \bar{\phi}^2 \left(K^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - 3|W|^2 \right)$$

$$-3 \int d^2 \phi \bar{\phi} \mathcal{E}(H)$$



$$\begin{aligned}
 -V &= -\frac{1}{4} \bar{D}^2 (\phi^3 W) \Big|_{\text{brane}} \\
 &= 3\phi^2 \bar{F}_+ W + \phi^2 W_+ F_- \\
 &\rightarrow -e^{-k/2} \phi^2 \bar{\phi}^2 (K^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - 3|W|^2) \\
 &- 3 \int d^2 \phi \bar{\phi} \mathcal{E}(H) e^{-k/2}
 \end{aligned}$$



$$\begin{aligned}
 -V &= \frac{1}{4} D^2 (\phi^3 W) \Big|_{\text{boundary}} \\
 &= 3\phi^2 F_\perp W + \phi^3 W_\perp F_\perp \\
 &= e^{-k/3} \phi^2 \bar{\phi}^2 \left(K^{ij} D_i W D_j \bar{W} - 3|W|^2 \right) \\
 &= 3 \int d^2x \phi \bar{\phi} \mathcal{E}(H) e^{-k/3} \phi |-\bar{\phi}|
 \end{aligned}$$



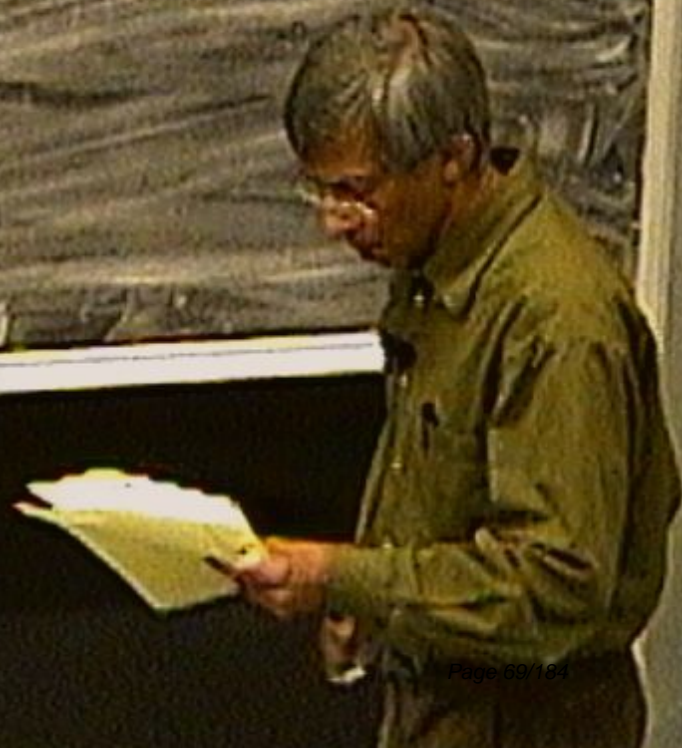
$$-V = -\frac{1}{4} \bar{D}^2 (\phi^3 W) \Big|_{\text{barric}}$$

$$= 3\phi^2 \bar{F}_\phi W + \phi^3 W_\phi F_\phi$$

$$\rightarrow -e^{-k/3} \phi^2 \bar{\phi}^2 \left(K^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - 3|W|^2 \right)$$

$$-3 \int d^2 \phi \bar{\phi} \mathcal{E}(H) e^{-k/3} \phi |-\bar{\phi}| = e^{k/6}$$

$$V =$$



$$-V = -\frac{1}{4} \bar{D}^2 (\phi^3 W) \Big|_{\text{barré}}$$

$$= 3\phi^2 \cdot \bar{F}_\phi W + \phi^3 W_\phi F_\phi$$

$$\rightarrow -e^{-k/3} \phi^2 \bar{\phi}^2 \left(K^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - 3|W|^2 \right)$$

$$-3 \int d^2 \phi \bar{\phi} \mathcal{E}(H) e^{-k/3}$$

$$V = e^K \left(D_i W D_{\bar{j}} \bar{W} K^{i\bar{j}} - 3|W|^2 \right)$$

$$g = K + \ln|W|^2$$

$$V = \frac{1}{4} \bar{D}^2 (\phi^3 W) \Big|_{\text{barrier}}$$

$$= 3\phi^2 \bar{F}_\phi W + \phi^3 W_\phi F_\phi$$

$$\rightarrow -e^{-k/15} \phi^2 \bar{\phi}^2 \left(K^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - 3|W|^2 \right)$$

$$- 3 \int d^2 z \phi \bar{\phi} \mathcal{E}(H) e^{-k/13} \phi |-\bar{\phi}| = e^{k/16}$$

$$V = e^k \left(D_i W D_{\bar{j}} \bar{W} K^{i\bar{j}} - 3|W|^2 \right)$$

$$= e^{\frac{k}{4}} (\partial_i \phi \partial_{\bar{j}} \bar{\phi} - 3)$$

$$g = k + \ln|W|^2$$

$$V = \frac{1}{4} \bar{D}^2 (\phi^3 W) |_{\text{barrier}}$$

$$= 3\phi^2 \bar{F}_\phi W + \phi^3 W_\phi F_\phi$$

$$\rightarrow -e^{-k/15} \phi^2 \bar{\phi}^2 \left(K^{ij} D_i W D_j \bar{W} - 3|W|^2 \right)$$

$$- 3 \int d^2 \phi \bar{\phi} \mathcal{E}(H) e^{-k/13} \phi | - \bar{\phi} | = e^{k/16}$$

$$V = e^K \left(D_i W D_j \bar{W} K^{ij} - 3|W|^2 \right)$$

$$= e^{\frac{k}{4}} (\partial_i \phi \partial_j \bar{\phi} - 3)$$

$$g = K + \ln|W|^2$$

$$-V = -\frac{1}{4} \overline{D}^2 (\phi^3 W) \Big|_{\text{barrier}}$$

$$= 3\phi^2 \overline{D}_+ W + \phi^3 W_i F^i$$

$$\rightarrow -e^{-k|z|} \phi^2 \overline{\phi}^2 (K^{i\bar{j}} D_i W D_{\bar{j}} \overline{W} - 3|W|^2)$$

$$-3 \int d^2z \phi \overline{\phi} \mathcal{E}(H) e^{-k|z|} \quad \phi | - \overline{\phi} | = e^{k|z|}$$

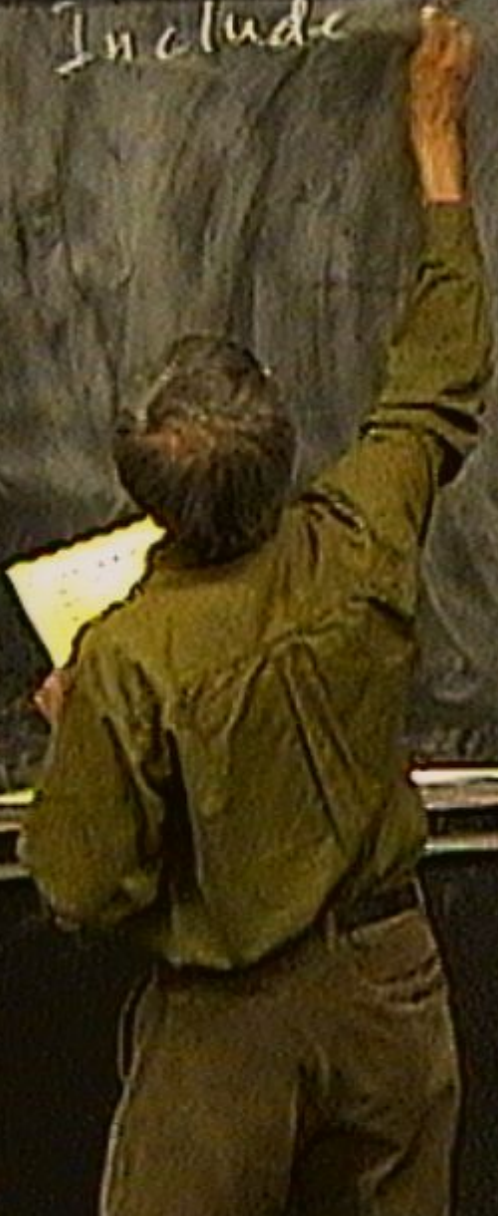
$$V = e^k (D_i W D_{\bar{j}} \overline{W} K^{i\bar{j}} - 3|W|^2)$$

$$= e^{\frac{k}{2}} (\partial_i \phi \partial_{\bar{j}} \overline{\phi} - 3)$$

$$g = k + \ln|W|^2$$

$$= e^{(0.04)(4)} = 1.1735$$

Include



$$= e^i (0, \gamma, 0, \gamma - \beta)$$

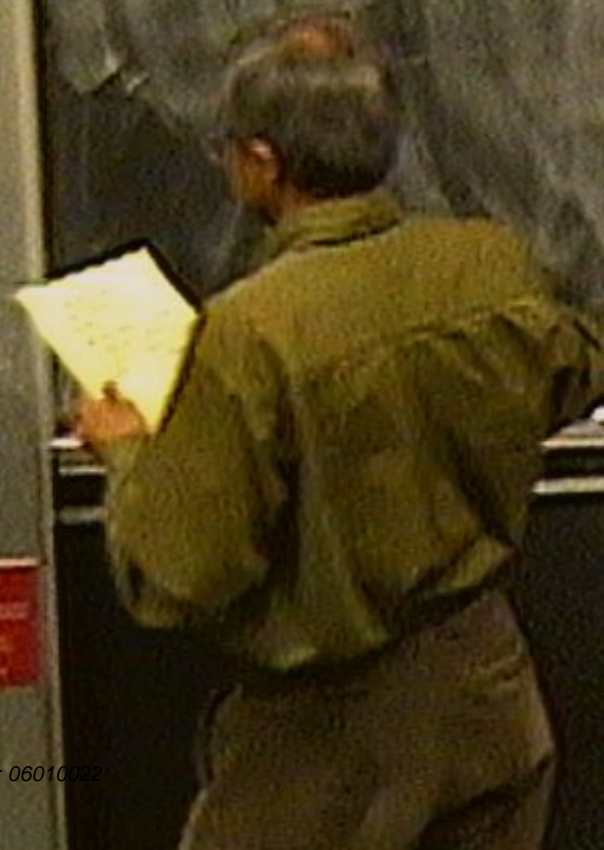
Include gauge fields



$$= \mathbb{R}^1 (0, 4, 0; 4, 2)$$

Include gauge fields

gauge isometries of K



$$= \mathcal{L}(\partial_\mu \psi, \psi, \mathcal{A}_\mu)$$

Include gauge fields

gauge isomorphisms
gauge prepotentials

$$V = V^T K$$

$$= e^i (0, 4, 0, 4, 3)$$

Include gauge fields

gauge isomorphisms \mathcal{K}
gauge prepotentials $V = V^T$

$$V = V^T$$

$$= e^i (0, 4, 0, 4 - 3)$$

Include gauge fields

Gauge isomorphisms

Gauge prepotential

Field strength

$$V = V^T K$$

$$V = V^a T^a$$

$$W_a = T^a W^a$$



$$= e^i (0, 4, 0, (4-3))$$

Include gauge fields

gauge isomorphisms $\mathcal{G} \rightarrow \mathcal{K}$
 gauge prepotential $V = V^T$
 Field strength $W_\alpha = T^a W_\alpha^a = -\left(\frac{1}{4} \bar{\nabla}^2 - 2R\right) \psi$
 $V = V^a T^a$



$$= e^i (0, 4, 0, 4, -3)$$

Include gauge fields

gauge isomorphisms $\mathfrak{g} = \mathfrak{V} + \mathfrak{K}$
 gauge potentials $V = V^a T^a$
 field strength $\mathcal{W}_\alpha = T^a \mathcal{W}_\alpha^a \rightarrow -\left(\frac{1}{4} \overline{\mathcal{D}}^2 \rightarrow R\right) e^{-V} \nabla_\alpha e^V$

$$= e^i (\partial_i \psi - i g A_i \psi)$$

Include gauge fields

gauge isomorphism $\mathfrak{g} \cong \mathfrak{K}$

gauge prepotential

$$V = V^T$$

$$V = V^T$$

Field strength

$$W_\alpha = T^a W_\alpha^a = -\left(\frac{1}{4} \bar{D}^2 - 2R\right) e^{-V} \nabla_\alpha e^V$$

$$V = \sum$$



$$= e^i (\partial_i \psi - g_j A_j \psi)$$

Include gauge fields

Gauge isomorphisms

Gauge prepotentials

Field strength

$$V = V^T K$$

$$W_\alpha = T^a \omega_\alpha^a = -\left(\frac{1}{4} \bar{D}^2 - 2R\right) e^{-V} \nabla_\alpha e^V$$

$$V = \left\{ A_\mu, \lambda_\alpha, D \right\}$$



$$= e^i (\partial_\mu \psi_j - A_\mu^i \psi_j)$$

Include gauge fields

Gauge isometries
gauge prepotentials

$$V = V^T K$$

$$V = V^0 T^a$$

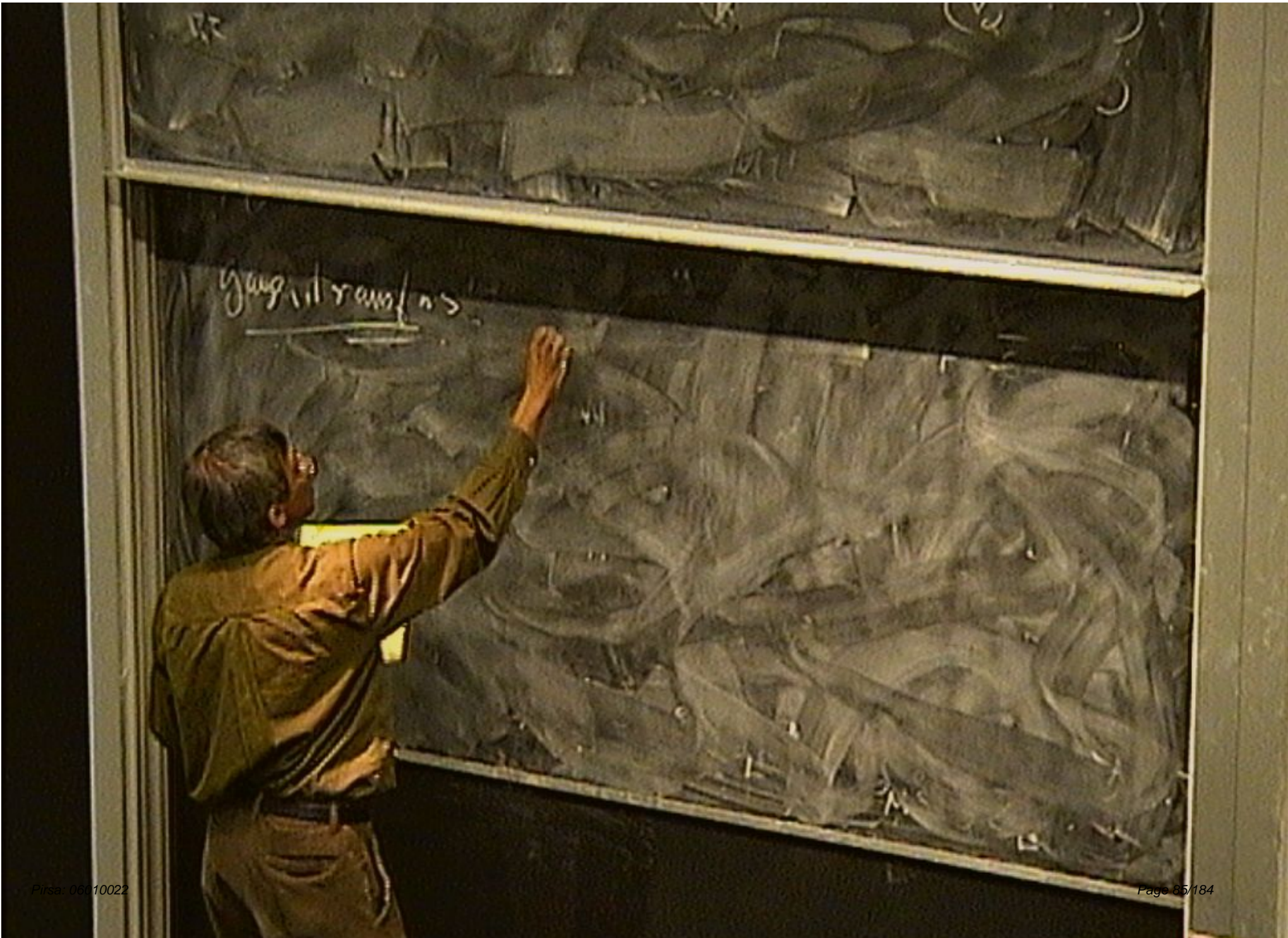
Field strength

$$W_\alpha = T^a \omega_\alpha^a = -\left(\frac{1}{4} \bar{v}^2 - 2R\right) e^{-v} \nabla_\alpha e^v$$

$$W \geq g \gamma$$

$$V = \left\{ A_\mu, \lambda_\alpha, D \right\}$$

$$W_\alpha = \left\{ \lambda_\alpha, F_{\mu\nu}, D \right\}$$



yang il ram / n s

gauge transformations

$$V \rightarrow V$$

$$e^{i\alpha} V$$

$=$

V

yang ditransf n

$$V \rightarrow V$$

\Rightarrow

$$e^V = e^{\Lambda} e^V e^{-\Lambda}$$

yang transitif

$$V \rightarrow V$$

$$\vec{\phi} \rightarrow e^{i\Lambda}$$

$$e^{i\Lambda} = e^{i\Lambda} e^{i\Lambda} e^{-i\Lambda}$$

gauge transformation

$$V \rightarrow V$$

$$\bar{\psi} \rightarrow e^{i\Lambda} \bar{\psi} \quad \psi \rightarrow e^{-i\Lambda} \psi$$

$$\bar{\psi} \psi$$

gauge transform

$$V \rightarrow V$$

$$\bar{\psi} \rightarrow e^{i\Lambda} \bar{\psi}$$

$$\psi \rightarrow e^{-i\Lambda} \psi$$

$$= e^{i\Lambda} e^{-i\Lambda} \psi$$

$$\bar{\psi} e^{i\Lambda} \psi \rightarrow \bar{\psi} e^{i\Lambda} e^{-i\Lambda} \psi$$

\mathbb{R}

gang, it ramf n

$$V \rightarrow V$$

$$\bar{\psi} \rightarrow e^{i\Lambda} \bar{\psi} \quad \psi \rightarrow e^{-i\Lambda} \psi$$

$$\bar{\psi} e^{\psi} \rightarrow \bar{\psi} e^{\psi} e^{-i\Lambda} e^{i\Lambda}$$



gauge transformations

$$V \rightarrow V$$
$$\psi \rightarrow e^{i\Lambda} \psi = e^{i\Lambda} e^V e^{-i\Lambda}$$

Kinetic term

$$\int d^4x \frac{E}{2R} \left(\frac{1}{4} F_{ab}^2 \right) W_{\alpha} W_{\alpha} + h.c$$

gauge transformations

$$V \rightarrow V$$
$$\psi \rightarrow e^{i\Lambda} \psi = e^{i\Lambda} e^{\Lambda} e^{-i\Lambda} \psi$$

Kinetic Terms

$$\int d^4x \frac{E}{2R} \left(\frac{1}{4} F_{ab}^2 W^a W^b + h.c. \right)$$

$V \rightarrow V$

Gauge transformation

$$V \rightarrow V \quad e^{i\Lambda} e^V = e^{i\Lambda} e^V e^{-i\Lambda}$$

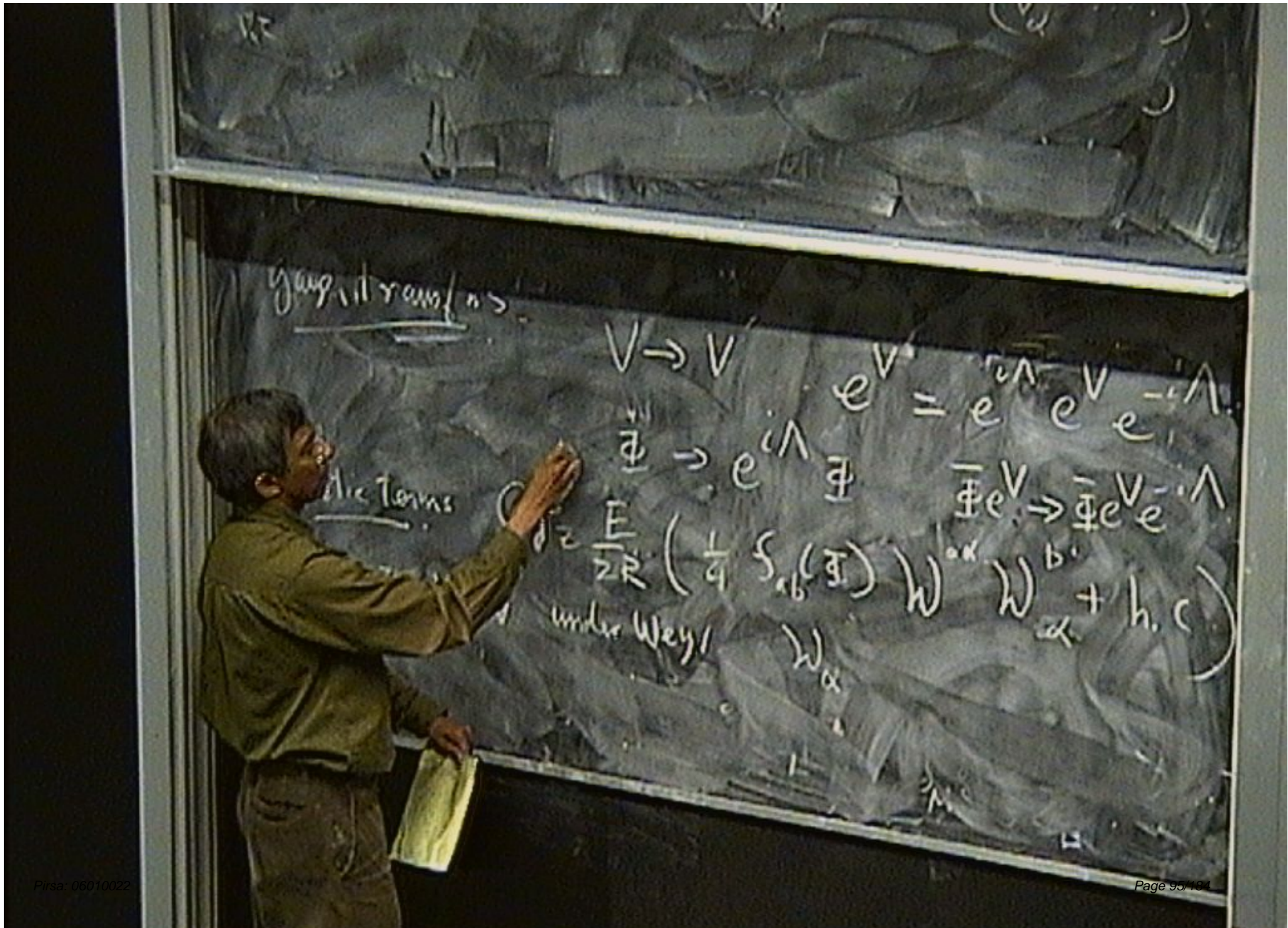
$$\bar{\psi} \rightarrow e^{i\Lambda} \bar{\psi} \quad \bar{\psi} e^V \rightarrow \bar{\psi} e^V e^{-i\Lambda}$$

Kinetic Terms

\rightarrow U(1) gauge

$$\int d^4x \frac{E}{2R} \left(\frac{1}{4} F_{ab}^2(\bar{\psi}) W_{\alpha}^a W_{\alpha}^b + h.c \right)$$

$$V \rightarrow V$$



gauge transformations

$$V \rightarrow V$$
$$\psi \rightarrow e^{i\Lambda} \psi \quad \bar{\psi} \rightarrow \bar{\psi} e^{-i\Lambda}$$

the terms

$$\mathcal{L} = \frac{E}{2R} \left(\frac{1}{4} F_{ab}^2(\mathcal{F}) + W_{\alpha}^{\alpha} W_{\beta}^{\beta} + h.c. \right)$$

under Weyl

[Faded handwritten notes on the top chalkboard panel]

Gauge Transformations

$$V \rightarrow V$$

$$\psi \rightarrow e^{i\Lambda} \psi = e^{i\Lambda} e^V e^{-i\Lambda}$$

Kinetic Terms

$$\int d^3x \frac{E}{2R} \left(\frac{1}{4} F_{ab}^2 W^a W^b + h.c. \right)$$

Weyl Invariance

$$V \rightarrow V$$

under Weyl

$$W_\alpha \rightarrow e^{-3\sigma} W_\alpha$$



[Faded handwritten notes on the top board]

gauge transform

$$V \rightarrow V$$

$$\bar{\psi} \rightarrow e^{i\Lambda} \bar{\psi} \quad \psi \rightarrow e^{-i\Lambda} \psi$$

Kinetic Terms

$$\int d^3z \frac{E}{2R} \left(\frac{1}{4} F_{ab}^2 \right) W^a W^b + h.c.$$

Weyl with
Boson
Feynman

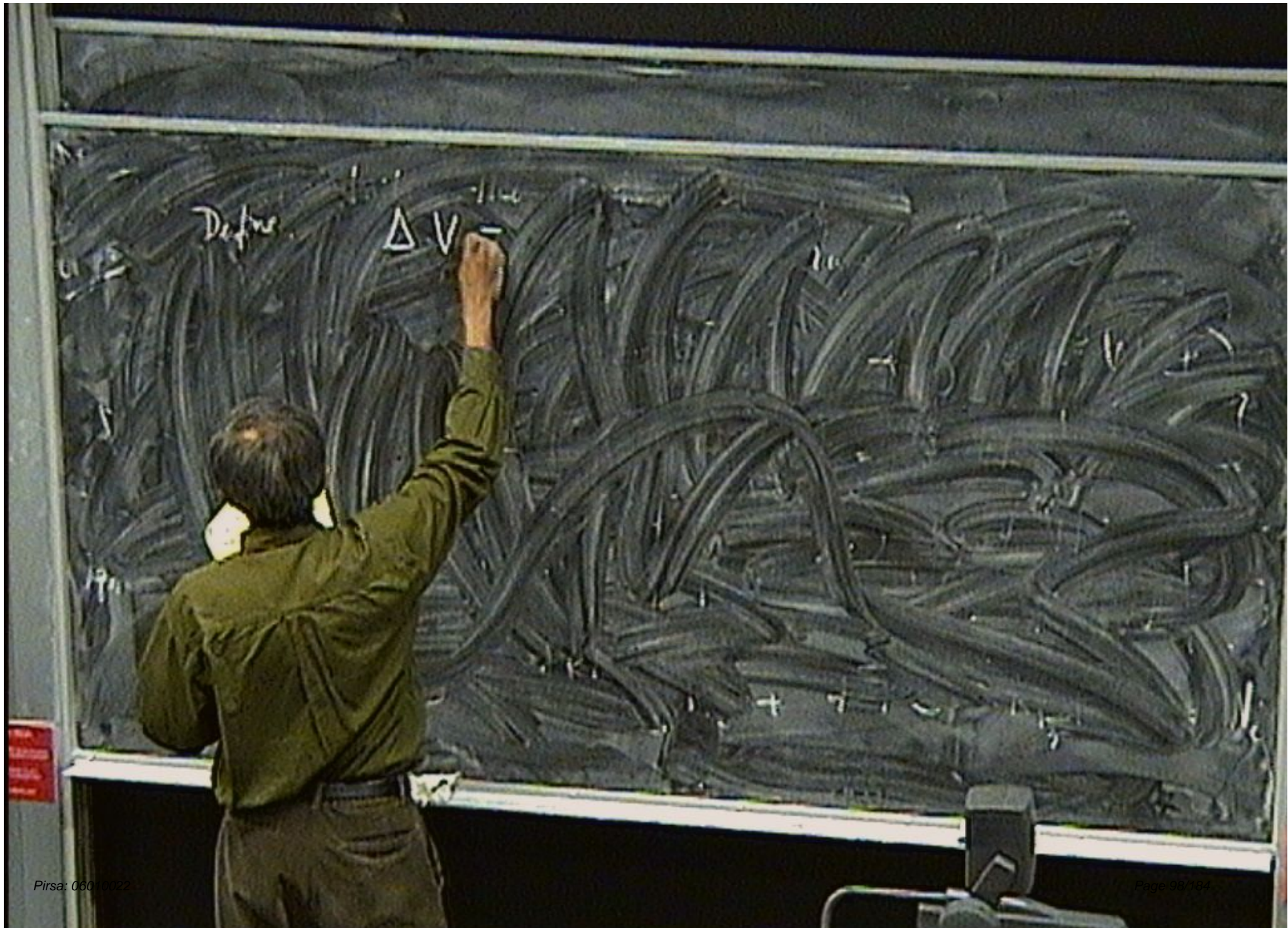
$$V \rightarrow V$$

under Weyl

$$\frac{1}{4} \int d^4x \text{tr} (F_{\mu\nu}^2)$$

$$W_\alpha \rightarrow e^{-3\alpha} W_\alpha$$





Define

$$\Delta V =$$

Define

$$\Delta V \equiv e^{-V} \delta e^V = \delta_{11} V + \dots = \Delta V^T$$

Define $\Delta V \equiv e^{-V} \delta e^V = \delta_{11} V + \dots = \Delta V^T$

$\delta_V \cdot \frac{1}{2} \int d^4x d^2\theta \int_{\text{fb}} \mathcal{W}^{ab}$



Define $\Delta V \equiv e^{-V} \delta e^V = \delta_{11}^V + \dots = \Delta V^T$

$$\delta_V \frac{1}{2} \int d^4x d^4\theta \sum_{ab} \omega^{aa} \omega_{bb} = - \int d^4x d^4\theta \Delta V$$



Define $\Delta V \equiv e^{-V} \delta e^V = \delta_{11}^V + \dots = \Delta V^T$

$$\delta_V \cdot \frac{1}{2} \int d^4x d^4\theta \sum_{ab} W^{aa} W_{ab}^b = - \int d^4x d^4\theta \Delta V \cdot \nabla^X (S_{ab} W_a^b)$$

$$\nabla^X \cdot e^{-V} \nabla_X e^V$$

Define $\Delta V \equiv e^{-V} \delta e^V = \delta_{ij} V + \dots = \Delta V^T$

$$\delta_V \cdot \frac{1}{2} \int d^4x d^4\theta \delta_{ab} W_{ab}^a W_{ab}^b = - \int d^4x d^4\theta \Delta V^a \nabla^b (S_{ab} W_d^b)$$

$$\nabla^a \cdot e^{-V} \nabla^b e^V = \nabla^a (S_{ab} W_d^b)$$

= 0



Define $\Delta V \equiv e^{-V} \delta e^V = \delta_{11}^V + \dots = \Delta V^T$

$$\delta_V \cdot \frac{1}{2} \int d^4x d^4\theta \sum_{ab} W^{aa} W_{ab}^b = - \int d^4x d^4\theta \Delta V^a \nabla^a (\sum_{ab} W_d^b)$$

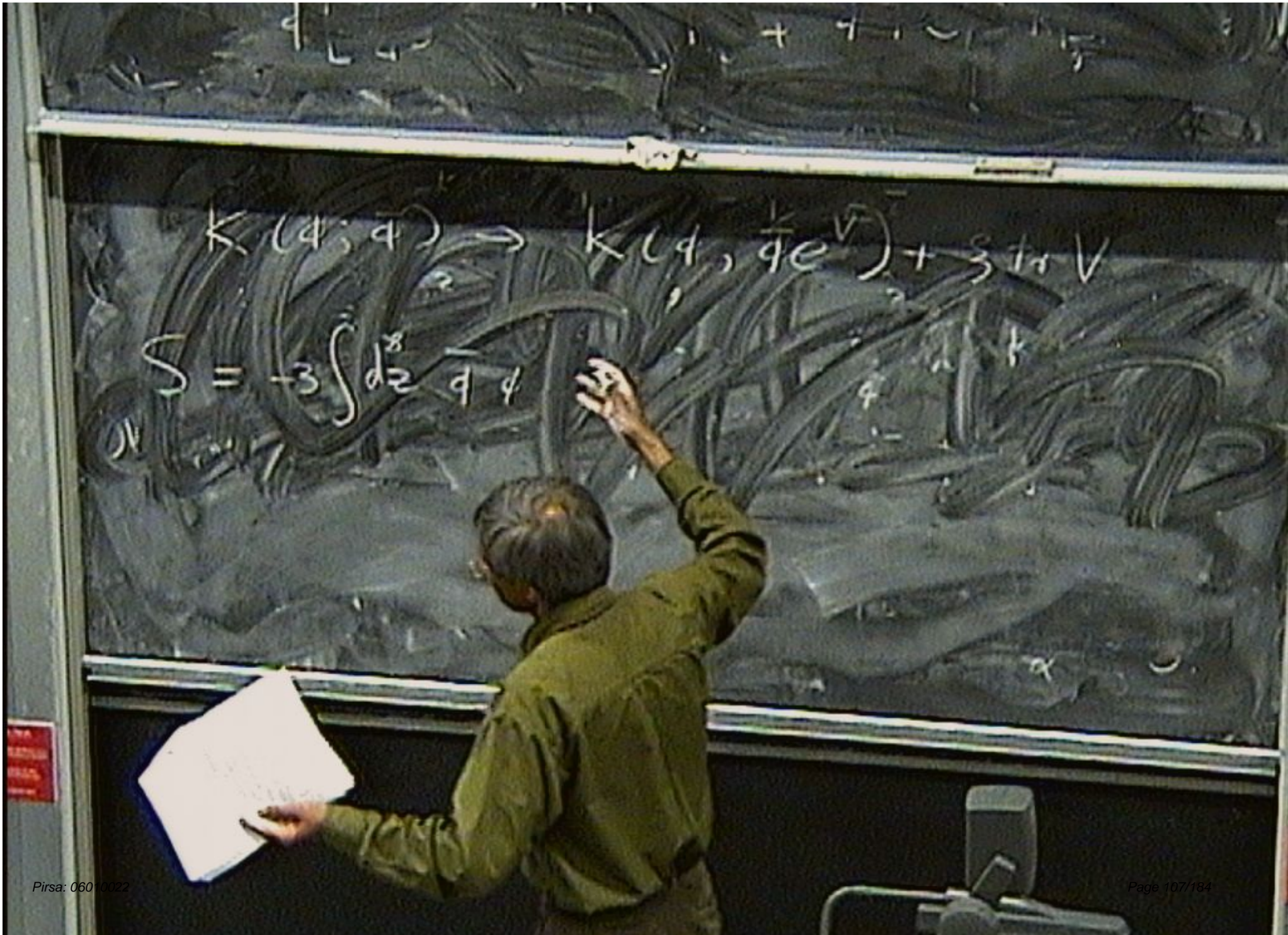
$$\nabla^a \cdot e^{-V} \nabla^a e^V \cdot \nabla^a (\sum_{ab} W_d^b)$$

$$\Delta_{\wedge} V = \wedge \cdot \wedge \cdot \wedge \cdot \wedge = e^{-V} \wedge e^V$$

$$+ + + + +$$

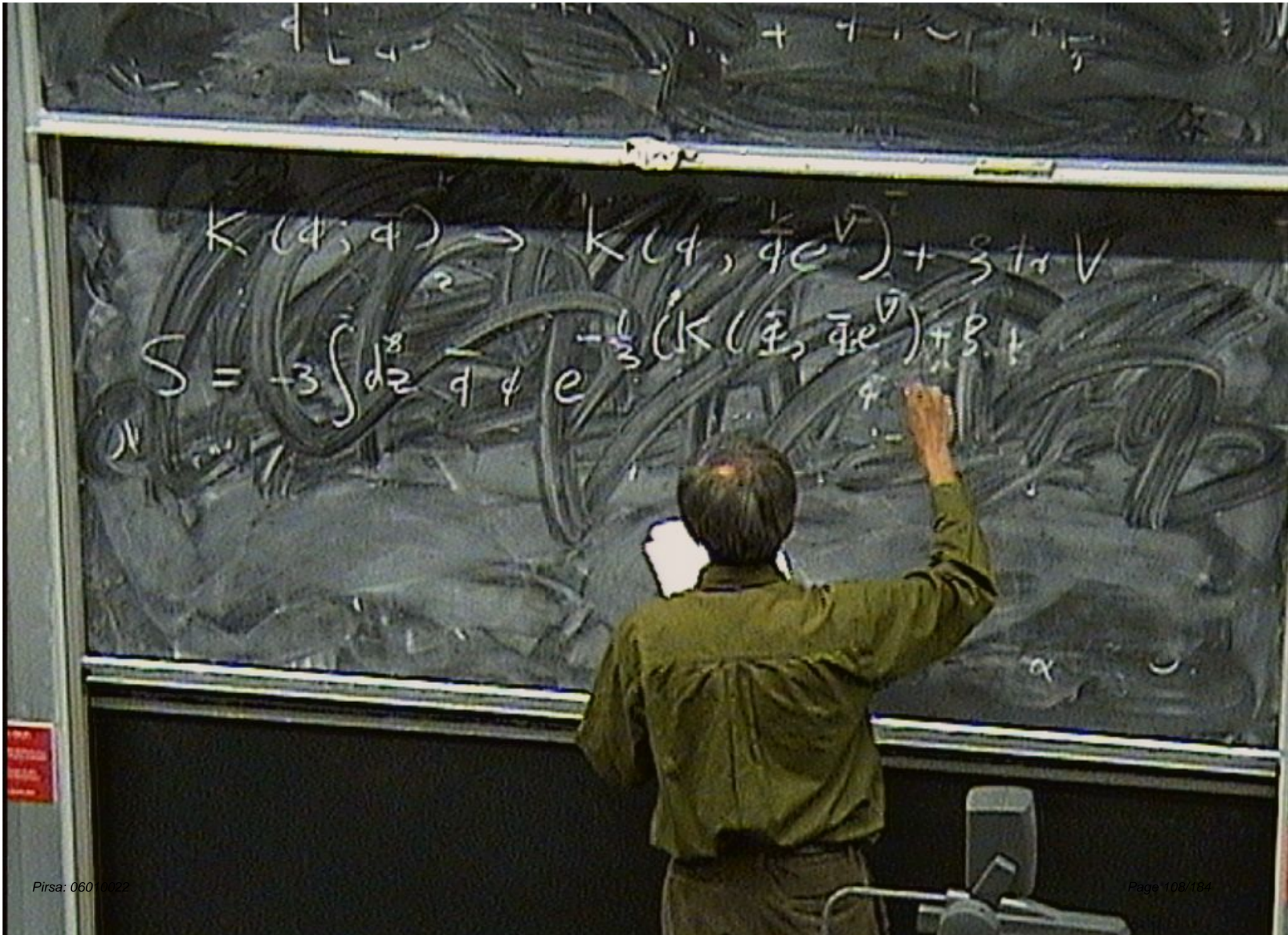


$$K(\psi, \psi) \rightarrow K(\psi, \psi e^V) + \text{str } V$$



$$K(\varphi; \varphi) \rightarrow K(\varphi, \frac{1}{q} e^V) + \text{str } V$$

$$S = -3 \int d^2 z \bar{q} \varphi$$



$$K(\psi; \psi) \rightarrow K(\psi, \frac{1}{\sqrt{2}} e^{\psi}) + 3 \text{tr} V$$

$$S = -3 \int d^2 z \bar{\psi} \psi e^{-\frac{1}{3} (K(\psi, \frac{1}{\sqrt{2}} e^{\psi}) + 3 \text{tr} V)}$$

$$K(\psi; \psi) \rightarrow K(\psi, \bar{\psi} e^V) + \int \text{tr } V$$

$$S = -3 \int d^8 z \bar{\psi} \psi e^{-\frac{1}{3} (K(\bar{\psi}, \bar{\psi} e^V) + \int \text{tr } V)}$$

$$+ \int d^6 z (\psi^3 W + \bar{\psi}^3 \bar{W})$$



$$K(\psi, \psi) \rightarrow K(\psi, \bar{\psi} e^V) + \int \text{tr } V$$

$$S = -3 \int d^8 z \bar{\psi} \psi e^{-\frac{1}{3} (K(\bar{\psi}, \bar{\psi} e^V) + \int \text{tr } V)}$$

$$+ \left\{ \int d^6 z (\psi^3 W + S_{ab} \psi^a \psi^b) + \text{h.c.} \right\}$$

$$K(\psi; \psi) \rightarrow K(\psi, \bar{\psi} e^V) + \text{str } V$$

$$S = -3 \int d^2 z \bar{\psi} \psi e^{-\frac{1}{3} (K(\bar{\psi}, \bar{\psi} e^V) + \text{str } V)}$$

$$+ \left\{ \int d^2 z (\psi^3 W + S_{ab} \psi^a \psi^b) + \text{h.c.} \right\}$$

Instances of K $\cdot \wedge$

$$K(\phi; \phi) \rightarrow K(\phi, \bar{\phi} e^V) + \beta \text{tr} V$$

$$S = -3 \int d^2 z \bar{\phi} \phi e^{-\frac{1}{3} (K(\bar{\phi}, \bar{\phi} e^V) + \beta \text{tr} V)}$$

$$+ \left\{ \int d^6 z (W + S_{ab} V^a W^b) + \text{h.c.} \right\}$$

Invariant of K $(\dots) + \dots$

$$K(\psi, \psi) \rightarrow K(\psi, \bar{\psi} e^V) + \text{str } V$$

$$S = -3 \int d^8 z \bar{\psi} \psi e^{-\frac{1}{3} (K(\bar{\psi}, \bar{\psi} e^V) + \text{str } V)}$$

$$+ \left\{ \int d^6 z (\psi^3 W + S_{ab} \psi^a \psi^b) + \text{h.c.} \right\}$$

Invariance of K $(\Lambda - i\tilde{\Lambda}) \frac{\delta K}{\delta V} + \Lambda^a k_a^c K_c + \tilde{\Lambda}^a k_a^c K_c = 0$

$$= e^{\mu} (\partial_{\mu} \psi_j \psi_j - \psi_j \partial_{\mu} \psi_j) \quad \psi = \psi_1 \psi_2 \dots$$

$$\frac{\partial K}{\partial v^i} = \sum_a v_a^i k_a^i$$



$$= e^{i\theta} (\partial_\mu \psi, \psi) - \mathcal{L}$$

$$g = T + iU$$

$$\frac{\delta \mathcal{K}}{\delta V^i} = i k_a^i k_i$$

Under gauge trans.

$$\xi + iV \rightarrow \xi + V + \xi T (i\Lambda - i\bar{\Lambda})$$



$$= e^{i\theta} (\partial_\mu \psi_j (y_j - z))$$

$$y = x + i\tau$$

$$\frac{\partial K}{\partial V^i} = i k_a^i k_i$$

Under gauge trans.

$$\xi^i \partial_i V \rightarrow \xi^i \partial_i V + \xi^i \partial_i (i\Lambda - i\bar{\Lambda})$$

$$= e^{i\theta} (\partial_\mu \psi) (\gamma^\mu - \gamma^5)$$

$$y = \dots$$

$$\frac{\partial K}{\partial V^\mu} = i k_a^\nu k_\nu$$

$$\xi \gamma_\mu V \rightarrow \xi \gamma_\mu V + \xi \gamma_\mu (i\Lambda - i\bar{\Lambda})$$

Under gauge trans.

$$\psi \rightarrow e^{i\theta} \psi$$

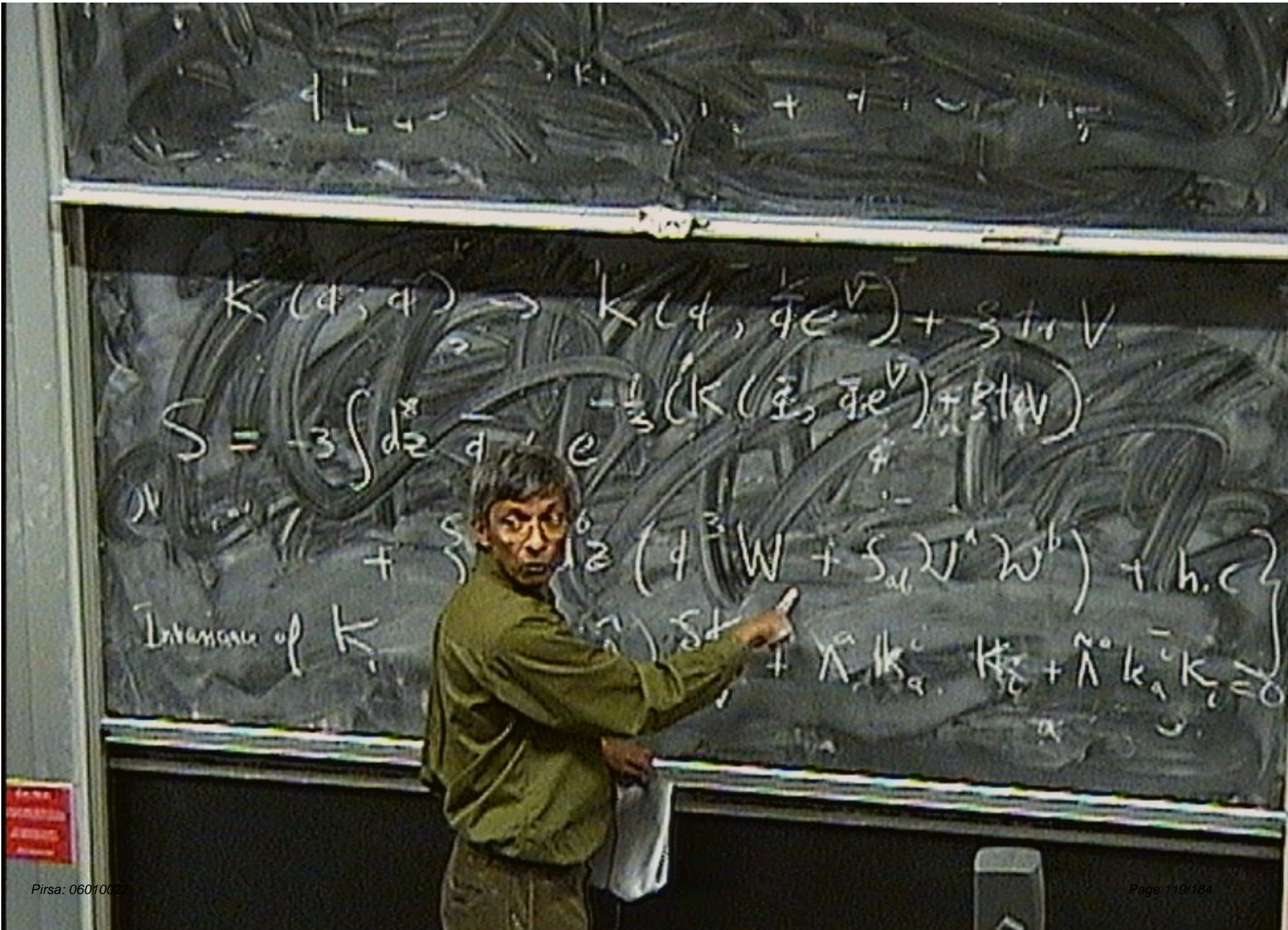
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$$K(\psi, \psi) \rightarrow K(\psi, \psi e^V) + \int \psi^\dagger \psi V$$

$$S = -3 \int d^4x \bar{\psi} \psi e^{-\frac{1}{3} (K(\psi, \psi e^V) + \int \psi^\dagger \psi V)}$$

$$+ \int d^4x (W + S_{ab} J^a W^b) + h.c.$$

Invariance of K $(\lambda - \lambda^*) S_{ab} \lambda^a k_a^\dagger k_b^\dagger + \lambda^0 k_a^\dagger k_b^\dagger = 0$



$$K(\psi, \psi) \rightarrow K(\psi, \psi e^V) + \text{str } V$$

$$S = -3 \int d^4x \bar{\psi} \psi e^{-\frac{1}{3} (K(\psi, \psi e^V) + \text{str } V)}$$

$$+ \int d^4x \left(\frac{1}{2} (\psi^\dagger W + S_{ab} V^a W^b) + \text{h.c.} \right)$$

Integrating out K

$$+ \int d^4x \left(\frac{1}{2} (\psi^\dagger W + S_{ab} V^a W^b) + \text{h.c.} \right) + \Lambda^4 \int d^4x \left(k_a^\mu k_a^\nu K_{\mu\nu} + \tilde{\Lambda}^4 \int d^4x \left(k_a^\mu k_a^\nu K_{\mu\nu} \right) \right) = 0$$

$$= e^{i\int (\partial_\mu \psi)^\dagger (\partial^\mu \psi - qA) - \dots}$$

$$\frac{\delta K}{\delta V^\mu} = i k_\mu^\dagger k^\mu$$

Under gauge trans

$$\psi \rightarrow e^{i\alpha} \psi \Rightarrow \partial_\mu \psi \rightarrow \partial_\mu \psi + i\alpha' \psi$$

$$\rightarrow e^{i\alpha} \psi$$



$$= e^{i\int (\partial_\mu \psi \partial^\mu \psi - \mathcal{L})}$$

$$\frac{\partial \mathcal{L}}{\partial v^\mu} = i k_\mu^\nu k_\nu$$

Under gauge trans.

$$\psi \rightarrow e^{i\alpha} \psi \Rightarrow \partial_\mu \psi \rightarrow \partial_\mu \psi + i\alpha' (\Lambda - \Lambda')$$

$$\delta(\int \mathcal{L}) = \int i\alpha' \Lambda' T$$



$$= e^{i\int (\partial_\mu \psi \partial_\mu \psi - \psi^2)}$$

$$\psi = \psi + \Lambda$$

$$\frac{\partial \mathcal{L}}{\partial V_\mu} = i k_\mu^\nu k_\nu^\mu$$

Under gauge trans.

$$\psi \rightarrow \psi + \Lambda \Rightarrow \psi \rightarrow \psi + \Lambda - \partial_\mu \Lambda$$

$$\psi \rightarrow e^{i\int \Lambda} \psi$$

$$\delta(\psi^3 W)$$

variation

$$\psi^3 W + \psi^3 \Lambda^\mu k_\mu^\nu \partial_\nu W = 0$$



$$= e^{i\phi} (\partial_\mu \psi) (\psi^\dagger - \bar{\psi})$$

$$y = \dots$$

$$\frac{\partial K}{\partial V^\mu} = i k_a^\mu k_c$$

Under gauge trans.

$$\psi \rightarrow e^{i\alpha} \psi \rightarrow e^{i\alpha} V + \dots (i\Lambda - i\bar{\Lambda})$$

$$\delta(\int \mathcal{L} W) = \int i\Lambda^\alpha T^a \psi^\dagger W + \int i\Lambda^\alpha k_a^\mu \partial_\mu W = 0$$

$$k_a^\mu \partial_\mu W = -i \int T^a W$$

$$= e^{i\theta} (\partial_\mu \psi_j - i g A_\mu^a T^a_{jk} \psi_k)$$

$$y = \dots$$

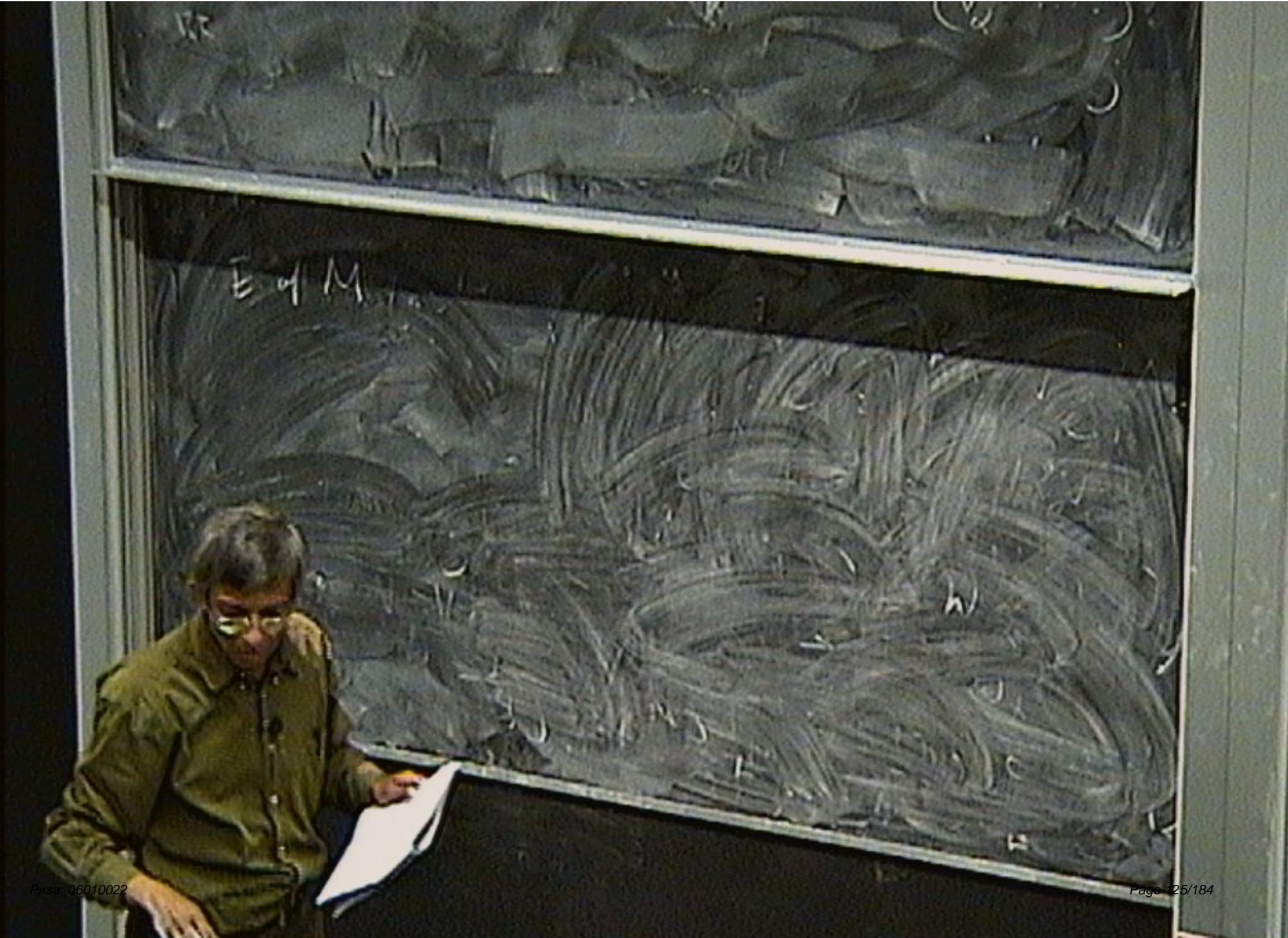
$$\frac{\partial K}{\partial V^a} = i k_a^c k_c$$

Under gauge tran.

$$\delta \text{tr} V \Rightarrow \delta \text{tr} V + \delta \text{tr} (i\Lambda - i\bar{\Lambda})$$

$$\delta(\phi^\dagger W) = 3i\Lambda^a \text{tr} T^a \phi^\dagger W + \phi^\dagger \Lambda^a k_a^i \partial_i W = 0$$

$$k_a^i \partial_i W = -i 3 \text{tr} T^a W$$



$$E \sim M$$
$$-\frac{1}{4} \bar{D}^2 (\not{+} e)$$



$$E \sim M, \dots, K \rightarrow G$$

$$-\frac{1}{4} \bar{D}^2 (\bar{+} e)$$

$$E \sim M \dots K \rightarrow G'' = K + |k| \omega F$$
$$-\frac{1}{4} \bar{D}^2 (\bar{4} e^{-\omega/3}) = 4^2$$

$$E \sim M \dots k \rightarrow G = k + |k| v_F$$

$$-\frac{1}{4} \bar{D}^2 (4e^{-\frac{2}{3}}) = 4^2$$

$$-47 e^{\frac{2}{3}} \frac{\bar{D}^2}{4} = -4^3 4^2$$



$$E \sim M \dots k \rightarrow G = k + k \dots$$

$$-\frac{1}{4} \bar{D}^2 (4 e^{-g/3}) = g^2$$

$$-4 \bar{D}^2 e^{g/3} = -4 \bar{D}^2 g_c = -4^3 g_c = -\frac{1}{4} \xi$$

$$E \sim M \dots K \rightarrow G = K + \ln|L|F$$

$$-\frac{1}{4} \bar{D}^2 (4e^{-\frac{2}{3}}) = q^2$$

$$-4\bar{7} e^{\frac{2}{3}} \frac{1}{4} \bar{D}^2 g_{ij} = -q^3 g_{ij} = \frac{1}{4} f_{ij}(q) \omega^{\mu\nu} \omega_{\mu\nu}^{\dagger}$$

$$E \sim M \quad K \rightarrow G = K + \ln |W|$$

$$-\frac{1}{4} \bar{D}^2 \left(\bar{t} e^{-g/3} \right) = q^2$$

$$-4 \bar{t} e^{g/3} \frac{1}{4} \bar{D}^2 g_c = -q^3 g_c - \frac{1}{4} \xi_{u,c}(q) W^+ W_c^+$$

$$st \quad -\bar{t} e^{-g/3} \frac{1}{4} \bar{D}^2 g_c$$

$$= e^{i\theta} (\partial_\mu \psi) (i \gamma^\mu - \gamma^5)$$

$$y = \dots$$

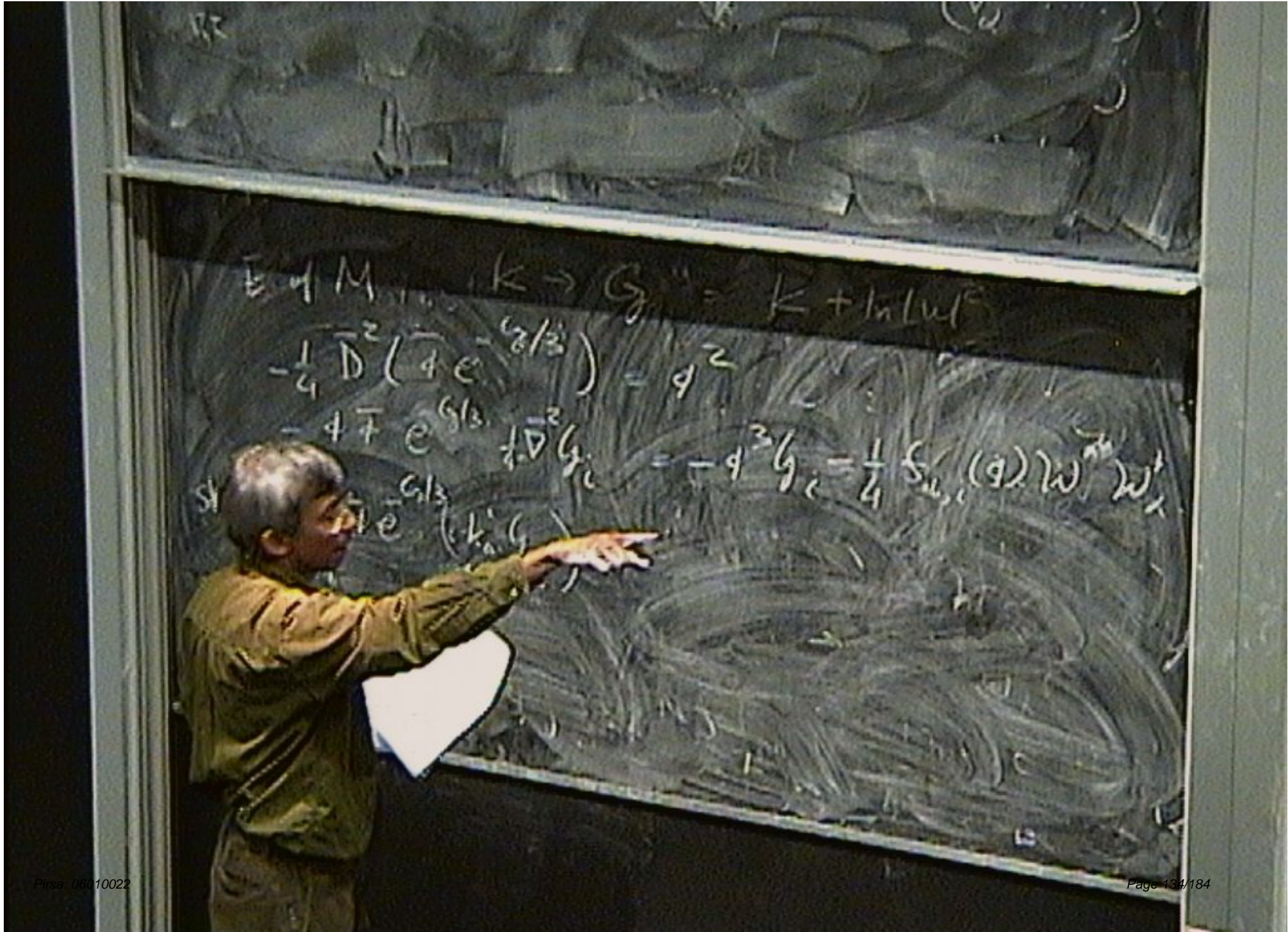
$$\frac{\partial \mathcal{L}}{\partial V^\mu} = i k_a^\nu k_\nu$$

Under gauge tran.

$$\xi T^a V \rightarrow \xi T^a V + \xi T^a (i\Lambda - i\bar{\Lambda})$$

$$\delta(\phi^3 W) = 3i\Lambda^a T^a \phi^3 W + \phi^3 \Lambda^a k_\nu \partial_\nu W = 0$$

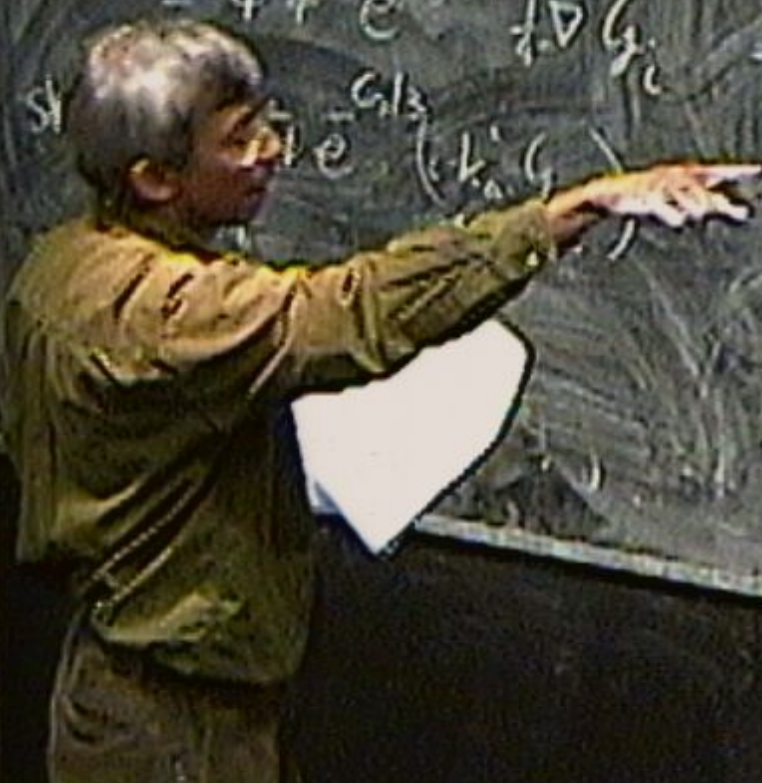
$$k_\nu \partial_\nu W = -i 3 T^a W$$



$$E \text{ of } M \dots k \rightarrow G = k + \ln(LW)$$

$$-\frac{1}{4} \bar{D}^2 (4e^{-2/3}) = d^2$$

$$-47 e^{G/3} \bar{D}^2 G_i = -d^3 G_i - \frac{1}{4} S_{d,i}(d) \omega^{\mu} \omega^{\nu}$$



$$E \ll M, \dots, K \rightarrow G_j = K + \ln LWF$$

$$-\frac{1}{4} \bar{D}^2 \left(\bar{4} e^{-\frac{g}{3}} \right) = d^2$$

$$-4 \bar{7} e^{\frac{g}{3}} \frac{1}{4} \bar{D}^2 g_{ic} = -d^3 g_{ic} - \frac{1}{4} f_{u,ic}(g) W^u W_i^+$$

$$-4 \bar{4} e^{-\frac{g}{3}} \left(\frac{1}{2} \bar{D}^2 g_{ic} \right) + \left(\frac{1}{2} \bar{D}^2 (f_{u,ic} W_i^h) + h.c. \right) = 0$$

$$E \ll M_{pl} \quad K \rightarrow G_{eff} = K + h^2 W^2$$

$$-\frac{1}{4} \bar{D}^2 (\bar{D}^2 e^{G/3}) = d^2$$

$$-4\bar{D}^2 e^{G/3} = -d^3 G_{,c} - \frac{1}{4} f_{ab,c} (a) W^a W^b$$

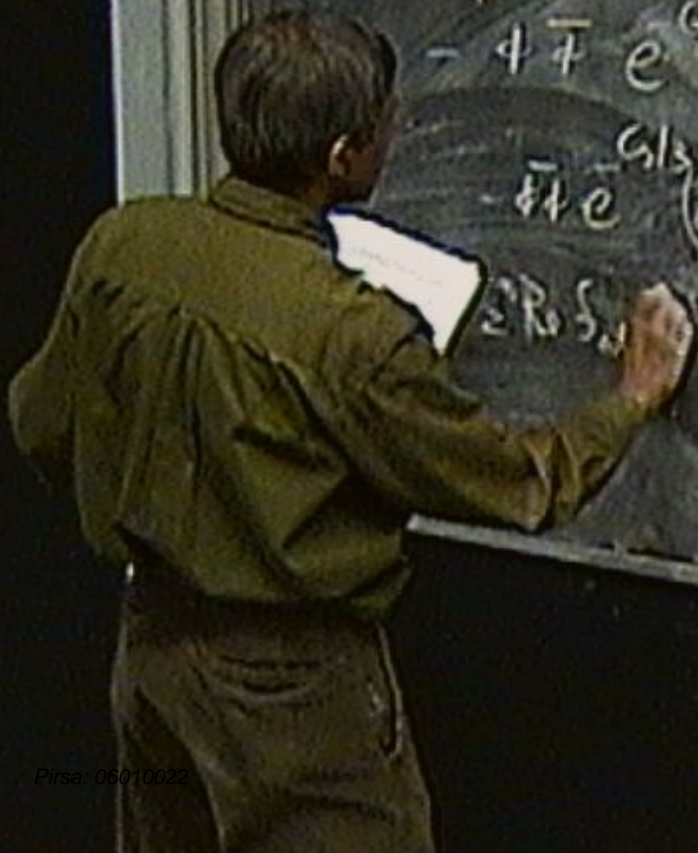
$$st \quad \bar{D}^2 e^{G/3} (k_a G_{,c}) + \left(\frac{1}{2} \bar{D}^2 (f_{ab} W^a W^b) + h c \right) = 0$$

$$E \text{ of } M_{1,1} \dots K \rightarrow G_f = K + \ln |W|$$

$$-\frac{1}{4} \bar{D}^2 \left(\bar{e}^{-\frac{g_{13}}{3}} \right) = d^2$$

$$-4 \bar{e}^{-\frac{g_{13}}{3}} \frac{1}{4} \bar{D}^2 g_{13} = -d^3 g_{13} - \frac{1}{4} f_{\mu\nu}(\varphi) W^{\mu\nu} W_{\mu\nu}^{\dagger}$$

$$-4 \bar{e}^{-\frac{g_{13}}{3}} \left(\frac{1}{2} \bar{D}^{\mu} (f_{\mu\nu} W_{\nu}^{\dagger}) + \text{h.c.} \right) = 0$$



$$E \sim M_{pl}^2, \quad K \rightarrow G_{\mu\nu} = K + \ln|W|$$

$$-\frac{1}{4} \bar{D}^2 (\bar{\psi} e^{-G/3}) = \psi^2$$

$$-4\bar{\psi} e^{G/3} \bar{D}^2 \psi = -4\bar{\psi}^3 \psi - \frac{1}{4} f_{\mu\nu}^a (g) W^{\mu\nu} W^{\dagger}$$

$$\text{st} \quad \bar{\psi} e^{-G/3} (ik_{\mu} \psi) + \left(\frac{1}{2} \bar{D}^{\dot{\alpha}} (f_{\mu\nu}^a W_{\dot{\alpha}}^{\mu\nu}) + \text{h.c.} \right) = 0$$

$$2R_{\mu\nu} D^{\mu} \psi = ik^{\mu} \frac{DW}{W} \Big|$$

$$= e^{i\theta} (\partial_\mu \psi - i g A_\mu \psi)$$

$$\frac{\partial \mathcal{L}}{\partial V^\mu} = i k_a^\mu k_c$$

Under gauge tran

$$g \text{tr} V \rightarrow g \text{tr} V + \delta \text{tr} (i\Lambda - i\bar{\Lambda})$$

$$\delta(\phi^\dagger W) = 3i\Lambda^a \text{tr} T^a \phi^\dagger W + \phi^\dagger \Lambda^a k_a^\mu \partial_\mu W = 0$$

$$k_a^\mu \partial_\mu W = -i 3 \text{tr} T^a W$$

$$E = \sqrt{M^2 + k^2} \rightarrow G_j = k + \ln L W F$$

$$-\frac{1}{4} \bar{D}^2 (4 e^{-g/3}) = d^2$$

$$-4 \bar{7} e^{g/3} \frac{1}{4} \bar{D}^2 g_{ic} = -d^3 g_{ic} - \frac{1}{4} f_{u,c}(g) W^u W_c^+$$

$$S_{ab} D^{ab} (e^{g/3} (i k_a g_c)) + \left(\frac{1}{2} \bar{D}^a (f_{u,c} W_c^u) + h.c. \right) = 0$$

$$i k^a g_{ic} = i k^a \frac{D W}{W} \Big|$$

$$E \sim M_{\dots} \quad k \rightarrow G_{\mu\nu} = k + h_{\mu\nu}$$

$$-\frac{1}{4} \bar{D}^2 (\bar{t} e^{-G/3}) = q^2$$

$$-4 \bar{t} e^{G/3} \bar{D}^2 G_{\mu\nu} = -q^3 G_{\mu\nu} - \frac{1}{4} f_{\mu\nu}(\varphi) W^{\mu\nu} W^{\dagger}$$

$$S \int \bar{t} e^{-G/3} (ik_{\mu} G_{\mu\nu}) + \left(\frac{1}{2} \bar{D}^2 (f_{\mu\nu} W^{\mu\nu}) + h.c. \right) = 0$$

$$2 \bar{t} e^{-G/3} D_{\mu} (ik^{\mu} G_{\nu\rho}) = ik^{\mu} \frac{D_{\mu} W}{W} = ik^{\mu} k_{\mu} + \epsilon \text{tr} T$$

$$E \text{ of } M_{11} \dots K \rightarrow G_{ij} = K + \ln |W|^2$$

$$-\frac{1}{4} \bar{D}^2 \left(\bar{4} e^{-\frac{g_{13}}{2}} \right) = d^2$$

$$-4 \bar{7} e^{g_{13}} \frac{1}{4} \bar{D}^2 g_{ij} = -d^3 g_{ij} - \frac{1}{4} f_{\mu\nu} (g) W^{\mu\nu} W_{\mu\nu}^{\dagger}$$

$$st \quad -\bar{4} e^{-\frac{g_{13}}{2}} \left(i k_{\alpha}^{\beta} g_{ij} \right) + \left(\frac{1}{2} \bar{D}^{\alpha} (f_{\mu\nu} W_{\alpha}^{\mu\nu}) \right)$$

$$2 R_{\alpha\beta} D_{\mu\nu} i k^{\alpha\beta} g_{ij} = i k^{\alpha\beta} \frac{D_{\mu\nu} W}{W}$$

$$M_{ij} D_{\mu\nu} = \frac{1}{2} \bar{D}^{\alpha} W_{\mu\nu}$$



$$E \sim M, \dots, K \rightarrow G = K + \ln W$$

$$-\frac{1}{4} \bar{D}^2 \left(\bar{\psi} e^{-\frac{g}{3}} \right) = d^2$$

$$-4 \bar{\psi} e^{\frac{g}{3}} \frac{1}{4} \bar{D}^2 \psi_c = -d^3 \psi_c - \frac{1}{4} f_{a,b,c}(g) W^a W^b$$

st

$$-4 \bar{\psi} e^{\frac{g}{3}} \left(i k_a \psi_c \right) + \left(\frac{1}{2} \bar{D}^2 (f_{a,b,c} W_c^b) + h.c. \right) = 0$$

$$D_a = \frac{1}{2} \bar{D}^2 W_a$$

$$i k^a \psi_c = i k^a \frac{D W}{W} = i k^a k_c + \epsilon \text{tr} T$$

$$K(\psi, \psi) \rightarrow K(\psi, \bar{\psi} e^V) + \text{str } V$$

$$S = -3 \int d^8 z \bar{\psi} \psi e^{-\frac{1}{3} (K(\bar{\psi}, \bar{\psi} e^V) + \text{str } V)}$$

$$+ \left\{ \int d^6 z (\psi^3 + S_{ab} V^a W^b) + \text{h.c.} \right\}$$

Invariant of K $(\Lambda - i\tilde{\Lambda}) \frac{1}{5V} K_{\tilde{c}} + \tilde{\Lambda}^a k_a K_c = 0$

$$E \neq M \dots k \rightarrow G = k + \ln(LW)^F$$

$$-\frac{1}{4} \bar{D}^2 (\bar{t} e^{-\alpha/3}) = d^2$$

$$-4\bar{t} e^{\alpha/3} \bar{D}^2 \gamma_{ij} = -d^3 \gamma_{ij} = \frac{1}{4} f_{\alpha\beta}(\alpha) W^{\alpha\beta} W_{ij}$$

$$\bar{t} e^{\alpha/3} (ik_{\alpha} \gamma_{ij}) + \left(\frac{1}{2} \bar{D}^{\alpha} (f_{\alpha\beta} W_{ij}^{\beta}) + h.c. \right) = 0$$

$$ik_{\alpha} \gamma_{ij} = ik_{\alpha} \frac{DW}{W} = ik_{\alpha} k_{ij} + \epsilon_{ij} T^{\alpha}$$

$$E \text{ of } M_{11} \dots K \rightarrow G_{ij} = K + \text{tr} W^T$$

$$-\frac{1}{4} \bar{D}^2 (1 + e^{-\frac{2}{3} \phi}) = \eta^2$$

$$-4 \bar{D}^2 e^{\frac{2}{3} \phi}$$

$$-4^3 \eta_i = \frac{1}{4} f_{\mu\nu} (q) W^{\mu\nu} W^{\mu\nu}$$

st

$$-4 \bar{D}^2 e^{\frac{2}{3} \phi} (k_a \eta)$$

$$(f_{\mu\nu} W^{\mu\nu}) + \text{h.c.} = 0$$

$\mathbb{R} S_{21} D$

$$D^a = \frac{1}{2} \bar{D}^a W_a$$

$$= i k^a \frac{D W}{W} = i k^a k_a + \epsilon \text{tr } T$$

$$D_a W = 0 \Rightarrow D^a = 0$$

$$E \sim M, \dots, k \rightarrow G_{\mu\nu} = k + \text{h.c.} W^{\mu\nu}$$

$$-\frac{1}{4} \bar{D}^2 (4e^{-G/3}) = d^2$$

$$-4\bar{7} e^{G/3} \frac{1}{4} \bar{D}^2 G_{\mu\nu} = -d^3 G_{\mu\nu} - \frac{1}{4} f_{\mu\nu} (g) W^{\mu\nu} W^{\mu\nu}$$

$$\text{st } -4\bar{7} e^{G/3} (ik^{\mu\nu} G_{\mu\nu}) + \left(\frac{1}{2} \bar{D}^{\mu} (f_{\mu\nu} W^{\nu\rho}) + \text{h.c.} \right) = 0$$

$$\frac{1}{2} \bar{D}^{\mu} (f_{\mu\nu} W^{\nu\rho}) = ik^{\mu\nu} \frac{DW}{W} = -ik^{\mu\nu} k_{\nu} + \epsilon \text{tr} T$$

$$\frac{1}{2} \int_{-b}^b dx d^2\sigma_{\alpha\beta} \nu^{\alpha a} \nu_{\alpha}^b =$$



$$V_{\text{bos}} = \frac{1}{2} \int d^4x d^2\theta \sum_{ab} W_{\alpha}^a W_{\alpha}^b \Big|_{\text{bosmic}}$$

$$V \sim -\frac{1}{2} \int d^4x d^3\theta \sum_{ab} \psi_a^\dagger \psi_b \psi_b^\dagger \psi_a \Big|_{\text{bosonic}}$$

$$\begin{aligned}
 \mathcal{L} &= \frac{1}{2} \int d^4x d^2\theta \, W^{ab} W_{ab} \\
 &= \frac{1}{2} (\text{Re } S_{\text{eff}}) \cdot D^a D^b
 \end{aligned}$$

bosonic

$$-V = -\frac{1}{4} \bar{D}^2 (\phi^3 W) \Big|_{\text{burin}}$$

$$= 3\phi^2 \bar{F}_4 W + \phi^3 W_i F^i$$

$$\Rightarrow -e^{-k/3} \phi^2 \bar{\phi}^2 \left(K^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - 3|W|^2 \right)$$

$$-3 \int d^2z \phi \bar{\phi} \mathcal{E}(H) e^{-k/3} \left(\phi | - \bar{\phi} | = e^{K/6} \right)$$

$$\psi = e^K \left(D_i W D_{\bar{j}} \bar{W} K^{i\bar{j}} - 3|W|^2 \right)$$

$$= e^{\frac{K}{6}} \left(\partial_i \phi \partial_{\bar{j}} \bar{\phi} K^{i\bar{j}} - 3 \right)$$

$$g = K + \ln|W|^2$$

$$\delta(\phi^3 W) = 3 \phi^2 \delta\phi W + \phi^3 \delta W$$

$$K_i^j \partial_i W = -c \delta^j_i$$

$$-V = -\frac{1}{4} \bar{D}^2 (\phi^3 W) \Big|_{\text{bottom}}$$

$$= 3\phi^2 \bar{F}_+ W + \phi^3 W_c F_c$$

$$\Rightarrow -e^{-k/3} \phi^2 \bar{\phi}^2 (K^{i\bar{j}} D_c W D_{\bar{c}} \bar{W} - 3|W|^2)$$

$$-3 \int d^2z \phi \bar{\phi} \mathcal{E}(H) e^{-k/3} \phi | - \bar{\phi} | = e^{k/6}$$

$$\mathcal{L} = e^K (D_c W D_{\bar{c}} \bar{W} K^{i\bar{j}} - 3|W|^2) + \frac{1}{2} (R_{S, W}) D_c D_{\bar{c}}$$

$$\delta(\phi^3 W) = 3 \phi^2 \delta \phi W + \phi^3 \delta W$$

$$K_a^i \partial_c W = -c \delta^i_c W$$

$$E \text{ of } M_{1,1} \dots K \rightarrow G_{\mu\nu} = K + \ln |W|^2$$

$$-\frac{1}{4} \bar{D}^2 (\bar{\psi} e^{-G/3}) = \psi^2$$

$$-4\bar{\psi} e^{G/3} \frac{1}{4} \bar{D}^2 G_{\mu\nu} = -\psi^3 G_{\mu\nu} - \frac{1}{4} S_{\mu\nu}(\psi) W^{\mu\nu} W^{\dagger}$$

$$* \left(\bar{\psi} e^{-G/3} (ik^{\mu} G_{\mu\nu}) + \left(\frac{1}{2} \bar{D}^{\mu} (S_{\mu\nu} W^{\nu}) + h.c \right) \right) = 0$$

$$D_{\mu} = \frac{1}{2} \bar{D}^{\mu} W | \quad ik^{\mu} G_{\mu\nu} = ik^{\mu} \frac{D_{\nu} W}{W} | = ik^{\mu} k_{\nu} + \epsilon_{\mu\nu} T$$



Quantum

Quantum effects and ψ potential

Quantum effects and V, γ potential

Weyl transformation

Quantum anomaly

Quantum effects and ψ , χ potential

Weyl transformation

Quantum anomalies

If we get $\tau(x, \theta) \rightarrow i \tau$

1.3.1

$$S = -3 \int d^3z E \ddot{\Phi} + \int d^3z \left(\frac{E}{R} \dot{\Phi}^2 W(\Phi) + h.c \right)$$

1.3.2

$$= -3 \int d^3z \dot{\Phi}^2 \left(-\frac{1}{4} \nabla^2 - \kappa^2 \right) + \left(\int d^3z \dot{\Phi}^2 W(\Phi) + h.c \right)$$

1.3.3

$$\tau : \nabla_{\mu} \tau = 0, \quad \Phi \rightarrow \Phi, \quad \psi \rightarrow e^{-\tau c} \psi, \quad \bar{\psi} \rightarrow e^{\tau c} \bar{\psi}$$

1.3.4

$$E_M^{\mu} \rightarrow e^{(c+\tau)z} (E_M^{\mu} \dots)$$

$$E \rightarrow e^{(c+\tau)z} \dots \nabla_{\mu} \rightarrow e^{(c-\tau)z} (\nabla_{\mu} \dots)$$

Quantum effects and V, χ potential

Weyl transformation

Quantum anomalies

If we get $\psi(x, \theta) \rightarrow \psi(x)$

Quantum effects and V, χ potential

Weyl transformation

Quantum anomalies

If we get $\tau(x, \theta) \rightarrow i\gamma$

$$\psi \rightarrow e^{i\gamma} \psi, \quad \lambda \rightarrow e^{-3i\gamma} \lambda$$

Quantum effects and V, χ potential

Weyl transformation

Quantum anomalies

If we let $\tau(x, \theta) \rightarrow i\gamma$

$$\gamma \rightarrow e^{i\gamma}, \quad \lambda \rightarrow e^{-3i\gamma}$$

Measurement
transform

$$d\phi$$

Quantum effects and V, χ potential

Weyl transformation

Quantum anomalies

If we let $\tau(x, \theta) \rightarrow i\gamma$

$$\psi_{\mu} \rightarrow e^{i\gamma} \psi_{\mu}, \quad \lambda_{\mu} \rightarrow e^{-3i\gamma} \lambda_{\mu}$$

Measure transform

$$[dg d\bar{g} dV] \rightarrow e^{i\gamma \frac{3c_H}{16\pi}} [dg d\bar{g} dV]$$

Quantum effects and V, χ potential

Weyl transformation

Quantum anomalies

If we get $\tau(x, \theta) \rightarrow i\gamma$

$$\gamma_\alpha \rightarrow e^{2i\gamma} \gamma_\alpha, \quad \lambda_\alpha \rightarrow e^{-3i\gamma} \lambda_\alpha$$

Measure transform!

$$[d\phi d\bar{\phi} dV] \rightarrow e^{i\gamma \frac{3c_g}{16\pi} \int d^2z}$$

Quantum effects and V, χ potential

Weyl transformation

Quantum anomalies

If we let $\tau(x, \theta) \rightarrow i\gamma$

$$\psi_\alpha \rightarrow e^{i\gamma} \psi_\alpha, \quad \lambda_\alpha \rightarrow e^{-3i\gamma} \lambda_\alpha$$

Measure transforms!

$$[d\phi d\bar{\phi} dV] \rightarrow e^{i\gamma} [d\phi d\bar{\phi} dV]$$

$$\rightarrow \frac{3c_A}{16\pi^2} \int d^4x$$

Quantum effects and V, χ potential

Weyl transformation

Quantum anomalies

If we put $c(x, \theta) \rightarrow i\gamma$

$$\psi_\alpha \rightarrow e^{i\gamma} \psi_\alpha, \quad \lambda_\alpha \rightarrow e^{-3i\gamma} \lambda_\alpha$$

labels
a. gauge
ggs

Measure transform

$$[d\bar{\psi} d\psi dV] \rightarrow e$$

$$\Rightarrow \frac{3c\alpha}{16\pi} \int d^4x \frac{E}{2R} \omega^{\mu\nu} \omega_{\mu\nu}$$

Quantum effects and V, χ potential

Weyl transformation

Quantum anomalies

If we put $c(x, \theta) \rightarrow i\gamma$

$$\psi_\alpha \rightarrow e^{z\gamma} \psi_\alpha, \quad \lambda_\alpha \rightarrow e^{-3i\gamma} \lambda_\alpha$$

a. labels
gauge
fields

Measure transform

$$[d\bar{\psi} d\psi dV] \rightarrow e$$

$$\Rightarrow \frac{3c_A}{16\pi^2} \int \frac{d^4x}{2\pi} E \omega^{\mu\nu} \omega^{\rho\sigma} \epsilon^{\mu\nu\rho\sigma}$$

$$T_a(r) = t_a^i (\vec{T}^i)^2$$

$$c_a = T(G_{\mu\nu}) - \sum_Y N_Y T_a(Y)$$

Quantum effects and V, χ potential

Weyl transformation

Quantum anomalies

If we put $\tau(x, \theta) \rightarrow i\psi$

$$\psi_\alpha \rightarrow e^{z\psi} \psi_\alpha, \quad \lambda_\alpha \rightarrow e^{-3i\psi} \lambda_\alpha$$

labels
a. game
ops

measure transforms

$$[d\phi d\bar{\phi} dV] \rightarrow e$$

$$\Rightarrow \frac{3c_a}{16\pi^2} \int d^8x \frac{E}{2R} \omega^{\alpha\beta} \omega^{\gamma\delta}$$

$$T_a(r) = t_r(\vec{T}_a)$$

$$c_a = \mathcal{T}(G_a) - \sum_r N T_a(r)$$

Messung und transformiert $\int [d\Phi d\bar{q} dV] \rightarrow e$

$$T_a(r) = \text{tr}_r(\hat{T}_a)$$

$$c_a = \mathcal{F}(G_a) = \sum_Y N_Y T_a(r)$$

Replacer $\int_a(\Phi) \rightarrow \int_a(\Phi)$

Int

Messung und
transformations
 $\nabla_a(r) = \dots$

$$[d\Phi \, d\vec{q} \, dV] \rightarrow e^{\dots} \left(\frac{1}{16\pi} \right)^{n_c/2}$$

$$c_{\mu} = \mathcal{V}(G_{\mu}) - \sum_{\nu} \lambda_{\nu} T_{\mu}(\nu)$$

Replace

$$S_c(\Phi) \rightarrow S_a(\Phi) - \frac{3c_a}{8\pi^2} \ln f_c$$



Messung und transformiert $\left[d\bar{\Phi} d\bar{q} dV \right] \rightarrow e^{\frac{3C_u}{16\pi^2} \ln \frac{r}{r_0}}$

$$\Psi_a(r) = \ln \left(\frac{r}{r_0} \right) \quad \rho_a = \Psi(G_{1a}) - \sum_Y N_Y T_a(r)$$

Replace $\int_a(\Phi) \rightarrow \int_a(\Phi) - \frac{3C_u}{8\pi^2} \ln \frac{r}{r_0}$ $\int w$

$$\phi \rightarrow e^{-\frac{3C_u}{8\pi^2} \ln \frac{r}{r_0}} \phi$$

In ∇

Messung und transformiert $[d\Phi \ d\bar{g} \ dV] \rightarrow e^{\frac{1}{16\pi^2} \dots}$

$$\Psi_a(r) = \dots$$

$$c_a = \Psi(\dots) - \sum_Y \dots$$

Replace $\int_a(\Phi) \rightarrow \int_a(\Phi) - \frac{3c_a}{8\pi^2} \ln \dots$

Supp \dots

In \dots

Mass and transform $\int [d\Phi d\bar{\psi} dV] \rightarrow e^{-\frac{1}{16\pi^2} \int \dots}$

$$\Psi_a(r) = \int_{\mathbb{R}^3} \frac{d^3k}{(2\pi)^3} \tilde{\Psi}_a(\vec{k}) e^{i\vec{k}\cdot\vec{r}}$$

$$c_a = \mathcal{F}(G_a) - \sum_Y N_Y T_a(r)$$

Replace $\int_a(\Phi) \rightarrow \int_a(\Phi) - \frac{3c_a}{8\pi^2} \ln \mu$

$\phi \rightarrow e^{-\gamma} \phi$

Suppose that a gauge group develops a mass gap.

In

measure transforms $\int [d\Phi d\bar{\psi} dV] \rightarrow e^{\frac{1}{16\pi^2} \int \mathcal{L}}$

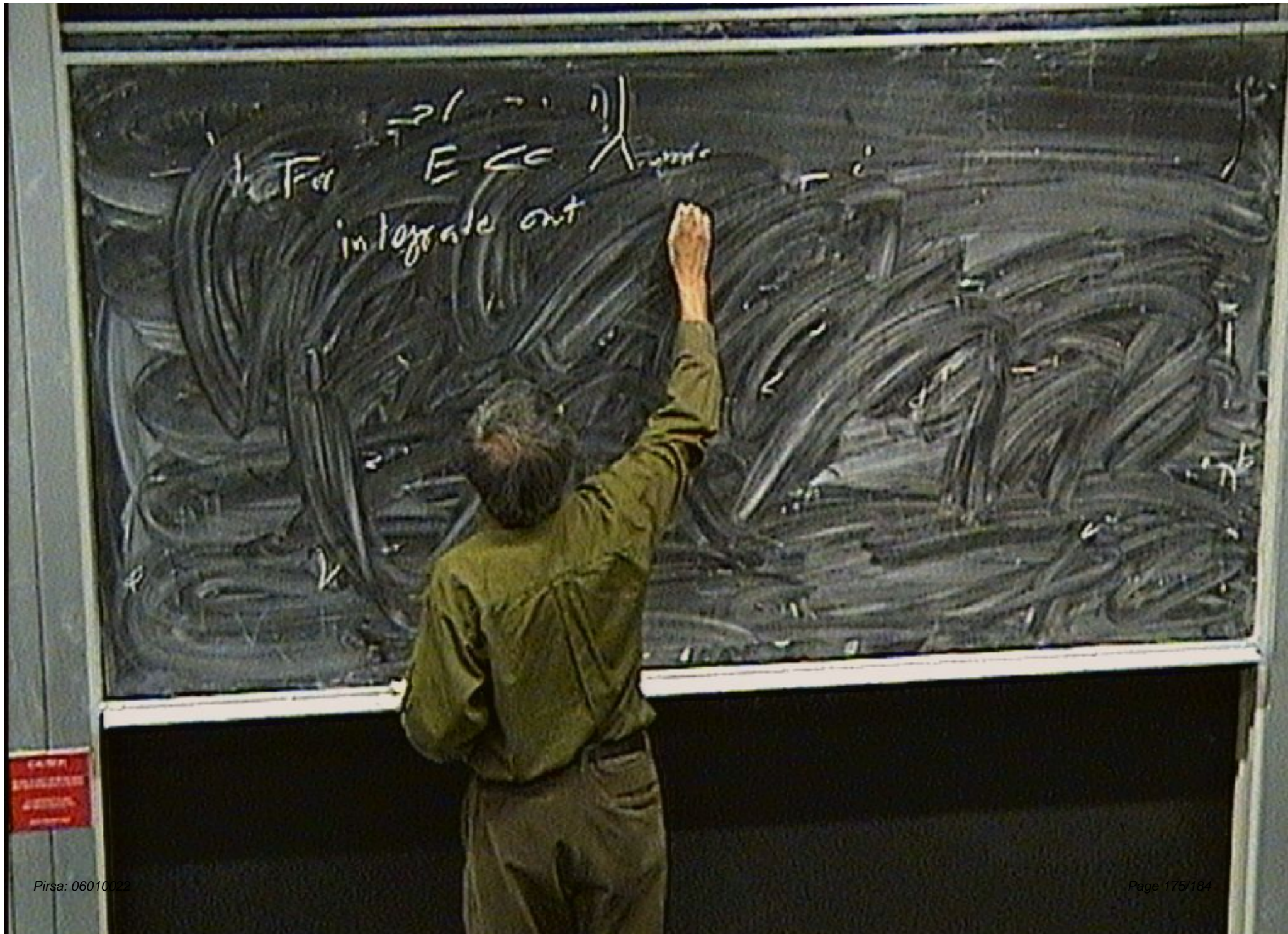
$$T_a(r) = t_a(\vec{r}, \vec{n}) \quad c_a = \mathcal{V}(G_a) - \sum_Y N_Y T_a(r)$$

Replace $\int_a(\Phi) \rightarrow \int_a(\Phi) - \frac{3c_a}{8\pi^2} \ln \mu$

$$\psi \rightarrow e^{-\gamma} \psi$$

Suppose that a gauge groups develops a mass gap at some scale Λ





$\int_{-\infty}^{\infty} E \lll X_{\text{qu}} \text{ integrate out}$

$\int_{\mathcal{C}} \mathbf{F} \cdot d\mathbf{r}$ $\int_{\mathcal{C}} \mathbf{E} \cdot d\mathbf{r}$ $\int_{\mathcal{C}} \mathbf{g} \cdot d\mathbf{r}$
integrate out this gauge g_b

$$\int_{\mathcal{C}} \mathbf{F}(\mathbf{r}, t) \cdot d\mathbf{r}$$

$\int_{\mathcal{E}} \mathcal{F} \rightarrow \int_{\mathcal{E}} \mathcal{E} \ll \int_{\mathcal{E}} \mathcal{F}$

integrate out this gauge g_b

$$e^{-\Gamma(\mathbb{E}, \mathcal{F})} = \int [dV] e^{-\frac{1}{4} \int \mathcal{F}_\mu \mathcal{F}^\mu - \frac{3C_0}{2}}$$



$\int_{\mathcal{F}} E \ll \int_{\mathcal{F}} \dots$
 integrate out this gauge g_b

$$e^{-\Gamma(\mathbb{F}, \mathcal{F})} = \int [dV] e^{-\frac{1}{4} \int \mathcal{F}_\mu \mathcal{F}^\mu - \frac{3c_0}{8\pi^2} \text{Int} \mathcal{W} + \dots}$$



Γ For $E \subset \subset \Omega$ integrate out this gauge $g \phi$

$$\int \mathcal{P}(\Phi, \phi) = \int [dA] e^{-\frac{1}{4} \int F_{\mu\nu}^2 - \frac{3C_0}{8\pi} \text{Int} \mathcal{W} + h.c.}$$

$\int \mathcal{P}$ - terms ϕ^3



$\int_{\mathcal{F}} \mathcal{L}(\Phi, \psi)$
 $E \ll \dots$
 integrate out this gauge $g \psi$

$$\underline{\Gamma(\Phi, \psi)} = \int [dV] e^{-\frac{1}{4} \int \{S_{\text{eff}}(\Phi) - \frac{3c_0}{8\pi^2} \ln t\} \mathcal{W} + \dots}$$

terms $\phi^3 W_{\text{NP}} = W_a \phi^3 e^{-\frac{8\pi^2}{c_0} S_{\text{eff}}(\Phi)}$

$\int_{\mathcal{F}} \int_{\mathcal{E}} \int_{\mathcal{G}}$
 integrate out this gauge g

$$\underline{\Gamma(\Phi, \psi)} = \int [dV] e^{-\frac{1}{4} \int \{S_4(\Phi) - \frac{3c_4}{8\pi^2} \ln t\} \mathcal{W} + h.c.}$$

$$\int_{\mathcal{F}} \int_{\mathcal{E}} \text{terms} \rightarrow \int \phi^3 W_{\text{NP}} = \int W_a \phi^3 e^{-\frac{8\pi^2}{c_4} S_4(\Phi)}$$

$\int \mathcal{L}(\Phi) \mathcal{D}\Phi$ \rightarrow $\int \mathcal{L}(\Phi) \mathcal{D}\Phi$ \rightarrow $\int \mathcal{L}(\Phi) \mathcal{D}\Phi$
 integrate out this gauge g_b

$$\int \mathcal{L}(\Phi) \mathcal{D}\Phi = \int \mathcal{L}(\Phi) \mathcal{D}\Phi = \frac{1}{4} \int \left\{ \mathcal{L}(\Phi) - \frac{3c_0}{8\pi^2} \ln \mathcal{L}(\Phi) \right\} \mathcal{D}\Phi + \dots$$

$$\int \mathcal{L}(\Phi) \mathcal{D}\Phi = \int \mathcal{L}(\Phi) \mathcal{D}\Phi = \frac{8\pi^2}{c_0} \int \mathcal{L}(\Phi) \mathcal{D}\Phi$$

$\int \mathcal{L}(\Phi) \mathcal{D}\Phi$ - terms

$$\int \mathcal{L}(\Phi) \mathcal{D}\Phi = \int \mathcal{L}(\Phi) \mathcal{D}\Phi = \int \mathcal{L}(\Phi) \mathcal{D}\Phi$$

transformations $U = [d\Phi, dg, dV] \rightarrow e$

$$a(r) = \frac{1}{r} \left(\frac{r}{\Lambda} \right)^{2\beta} \quad c_a = \mathcal{N}(\Lambda) - \sum_Y \mathcal{N}_Y T_a(Y)$$

Replace $\int_a(\Phi) \rightarrow \int_a(\Phi) - \frac{3c_a}{8\pi^2} \ln \mu$ $\int W$

$\phi \rightarrow e^{-\frac{2\sigma}{f}} \phi$

Suppose that a gauge groups develops a mass gap at some scale Λ



$\int_{\mathcal{C}} \frac{1}{z} dz = 2\pi i$
 integrate out this gauge g

$$\langle \Gamma(\Phi, \psi) \rangle = \int [dV] e^{-\frac{1}{f} \int S_V(\Phi) - \frac{3c_0}{8\pi} \ln f} \mathcal{W} + \dots$$

$$\int \mathcal{F} \sim \text{terms} \quad \phi^2 \mathcal{W}_{\text{HP}} = \mathcal{W}_a \phi^3 e^{-\frac{8\pi^2}{c_4} S_a(\Phi)}$$

$$(\text{IR S}) \int \mathcal{F} \wedge \mathcal{F}$$