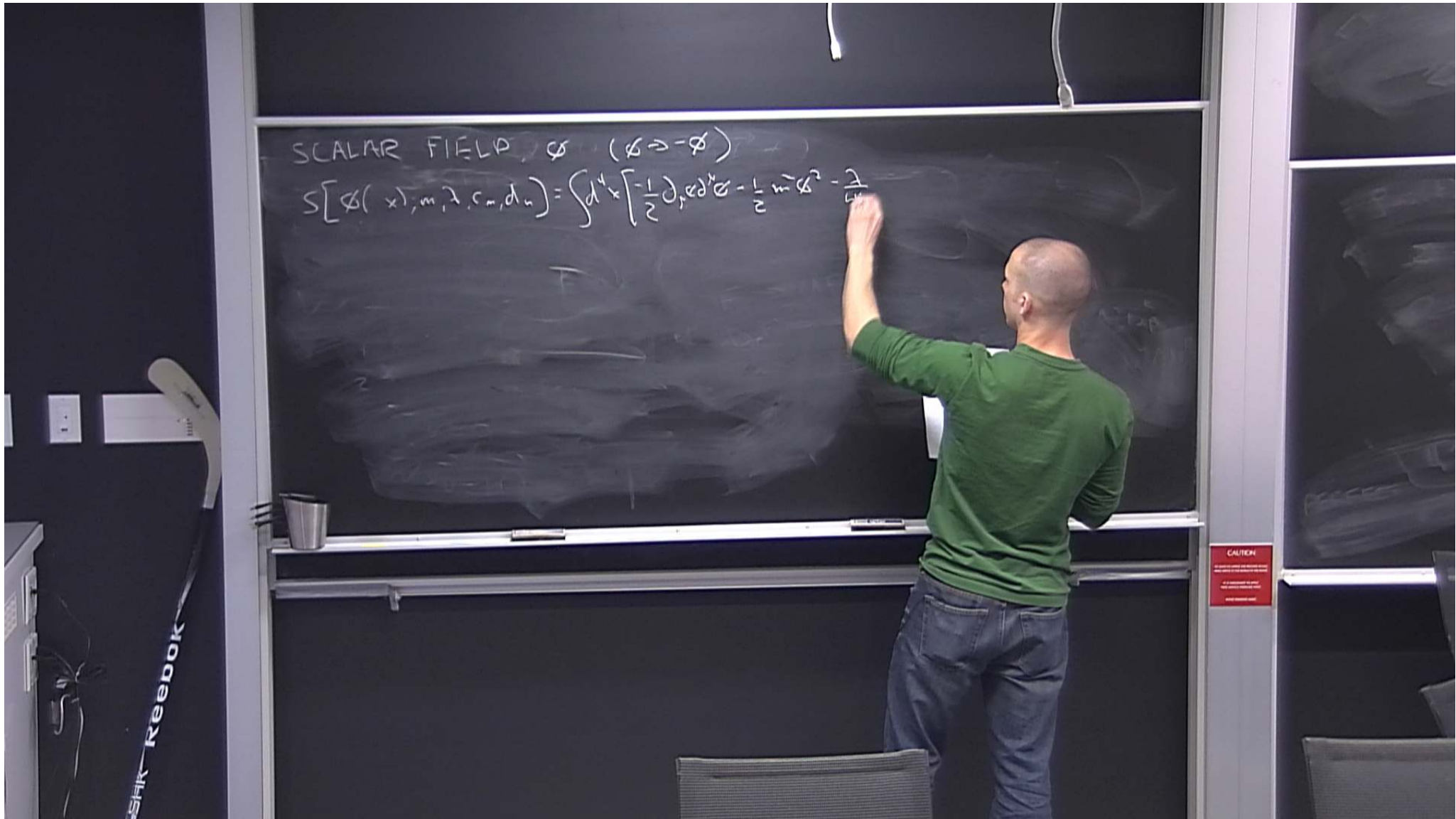


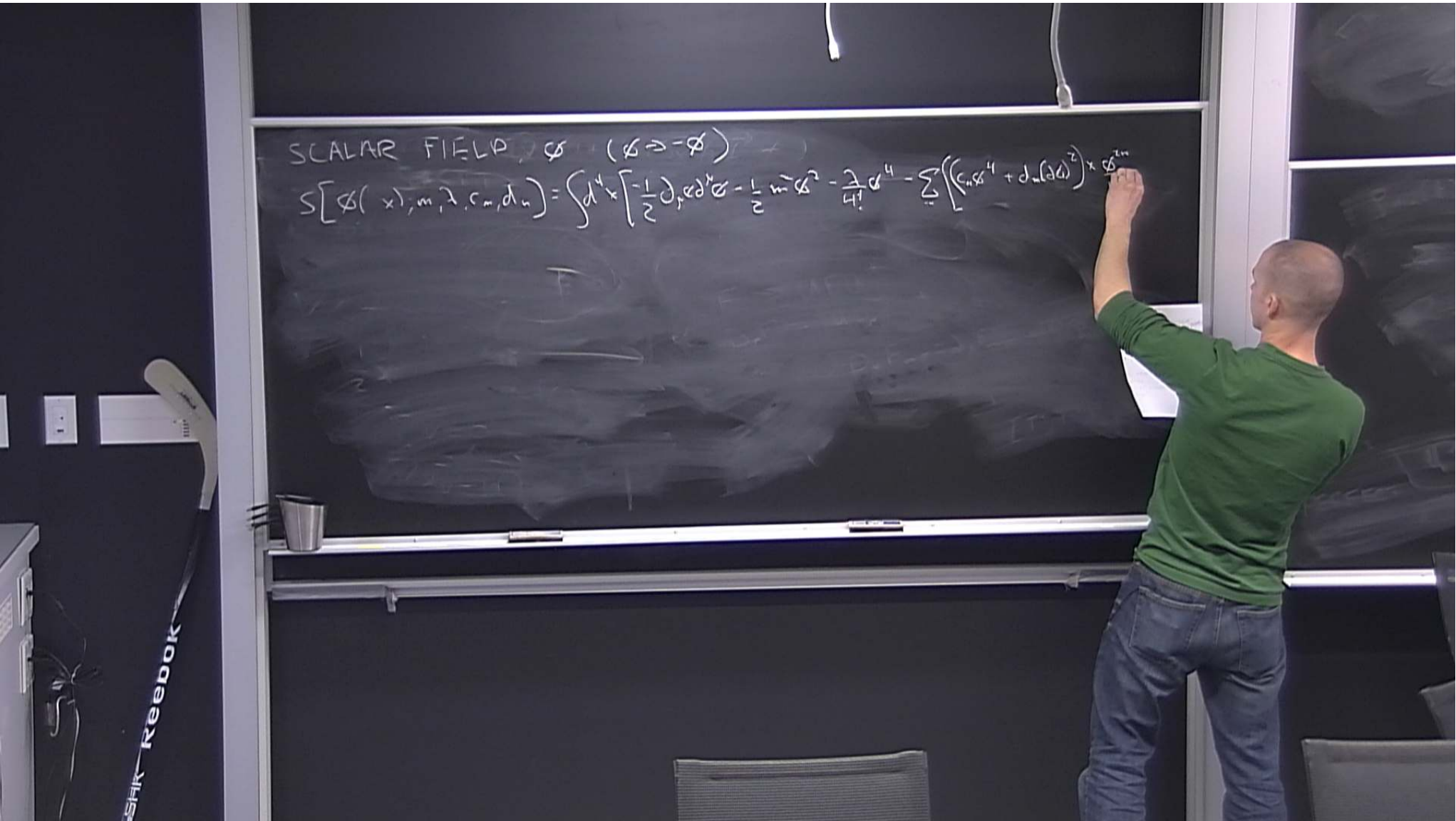
Title: Introduction to Effective Field Theories - Lecture 20

Date: Mar 28, 2014 02:30 PM

URL: <http://pirsa.org/14030080>

Abstract:





SCALAR FIELD ϕ ($\phi \rightarrow -\phi$)

$$S[\phi(x); m, \lambda, c_n, d_n] = \int d^4x \left[-\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - \frac{1}{2} m^2 \phi^2 - \frac{\lambda}{4!} \phi^4 - \sum_{n=1}^{\infty} \left(c_n \phi^n + d_n (\partial \phi)^2 \right) \frac{\phi^{2n}}{n!} + \dots \right]$$

$\phi(x) \rightarrow \phi(\tilde{x})$
 $x = \tilde{x}$

$$= \int d^4x' \left[-\frac{1}{2} \partial'_\mu \phi \partial'^\mu \phi - \frac{1}{2} m^2 \phi^2 - \frac{\lambda}{4!} \phi^4 \right]$$

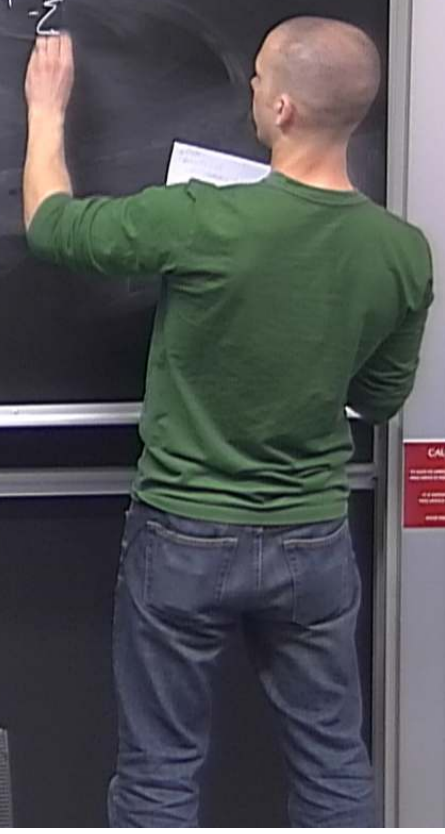


SCALAR FIELD ϕ ($\phi \rightarrow -\phi$)

$$S[\phi(x); m, \lambda, c_n, d_n] = \int d^4x \left[-\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - \frac{1}{2} m^2 \phi^2 - \frac{\lambda}{4!} \phi^4 - \sum_{n=1}^{\infty} \left(c_n \phi^n + d_n (\partial \phi)^2 \right) \frac{\phi^{2n}}{n!} + \dots \right]$$

$\phi(x) \rightarrow \phi(\tilde{x})$
 $x = \tilde{x}$

$$= \int d^4x' \left[-\frac{1}{2} \partial'_\mu \phi \partial'^\mu \phi - \frac{1}{2} m^2 \phi^2 - \frac{\lambda}{4!} \phi^4 - \sum \dots \right]$$



SCALAR FIELD ϕ ($\phi \rightarrow -\phi$)

$$S[\phi(x); m, \lambda, c_n, d_n] = \int d^4x \left[\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - \frac{1}{2} m^2 \phi^2 - \frac{\lambda}{4!} \phi^4 - \sum_{n=1}^{\infty} \left(c_n \phi^n + d_n (\partial^2)^n \right) \frac{\phi^{2n}}{n!} + \dots \right]$$

$$\phi(x) \rightarrow \phi(\tilde{x})$$

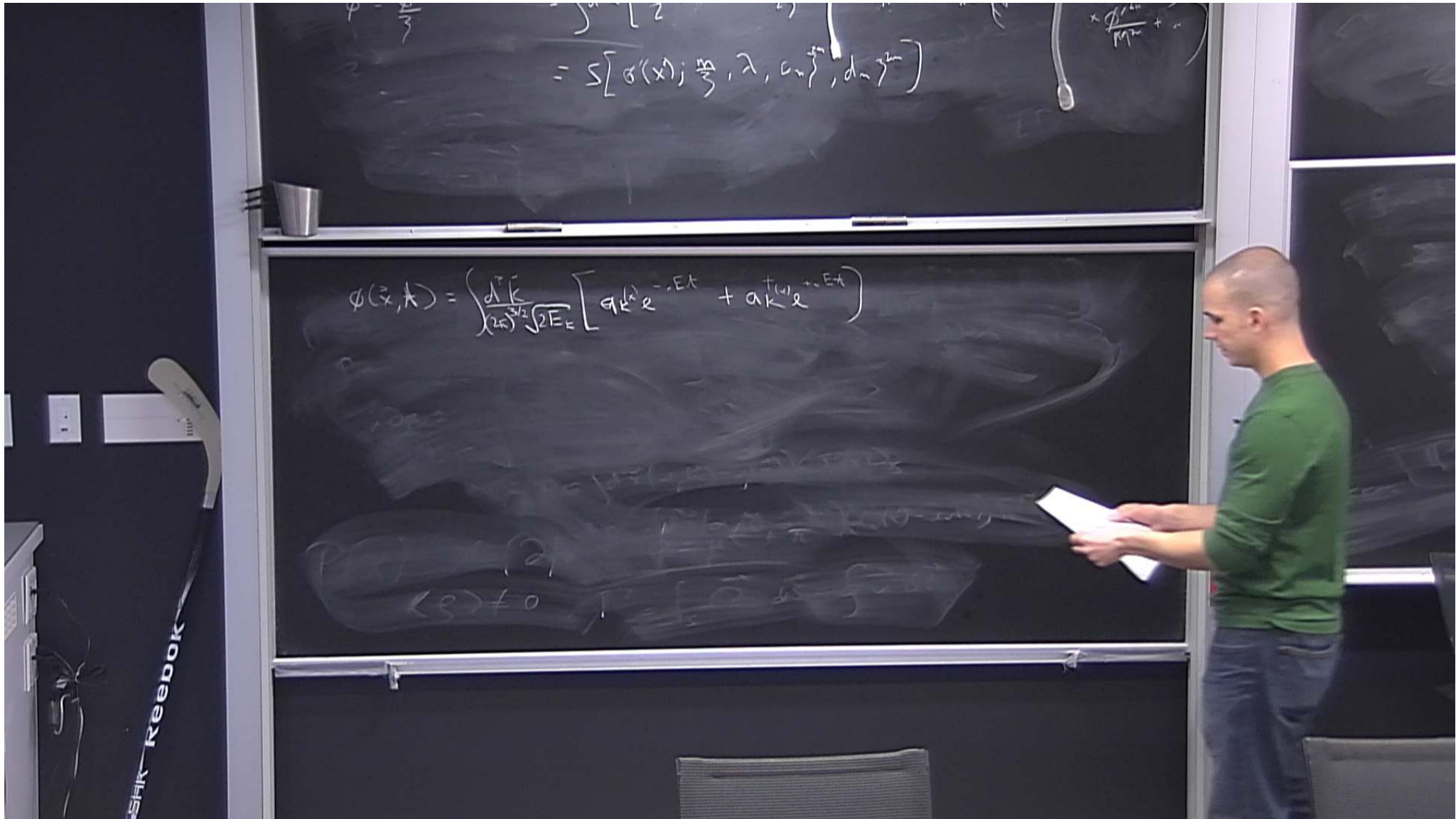
$$x = \tilde{x}$$

$$\phi' = \frac{\phi}{\tilde{x}}$$

$$= \int d^4x' \left[\frac{1}{2} \partial'_\mu \phi \partial'^\mu \phi - \frac{1}{2} m^2 \phi^2 - \frac{\lambda}{4!} \phi^4 - \sum_{n=1}^{\infty} \left(\frac{c_n \phi^n}{\tilde{x}^n} + \frac{d_n (\partial^2)^n}{\tilde{x}^{2n}} \right) \frac{\phi^{2n}}{n!} + \dots \right]$$

$$= \int d^4x' \left[\frac{1}{2} (\partial \phi')^2 - \frac{m^2}{2} \phi'^2 - \frac{\lambda}{4!} \phi'^4 - \sum_{n=1}^{\infty} \left(\frac{c_n \phi'^n}{\tilde{x}^n} + \frac{d_n (\partial^2)^n \phi'^{2n}}{\tilde{x}^{2n}} \right) \frac{1}{n!} + \dots \right]$$

CAUTION
 ATTENTION
 ATTENTION



$$\phi' = \frac{\phi}{\lambda}$$

$$= \int d^3x \left[\frac{1}{2} (\partial_t \phi)^2 - \frac{1}{2} \nabla^2 \phi^2 \right]$$

$$= S[\phi(x); \frac{m}{\hbar}, \lambda, c, \dots, d_0, \dots]$$

$$|\vec{k}| \ll m$$

$$\phi(\vec{x}, t) = \int \frac{d^3k}{(2\pi)^{3/2} \sqrt{E_k}} \left[a_{\vec{k}} e^{-iE_k t} + a_{\vec{k}}^\dagger e^{+iE_k t} \right], \quad E = m + \frac{k^2}{2m} + \dots$$

$$\phi = c \left[e^{-imt} \psi(\vec{x}, t) + e^{+imt} \psi^\dagger(\vec{x}, t) \right], \quad (c = \frac{1}{\sqrt{2m}})$$

$$\mathcal{L} = -i c^2 m \psi \partial_t \psi^\dagger + i c^2 m \psi^\dagger \partial_t \psi + \frac{1}{2} \nabla^2 \psi^\dagger \psi - c^2 \nabla \psi^\dagger \cdot \nabla \psi - \frac{\lambda c^4}{4!} \psi^\dagger \psi^2$$

$$+ e^{2imt} \left(\dots \right)$$

$$+ e^{-2imt} \left(\dots \right)$$

$$\mathcal{L} = i\hbar c^2 (\nabla^2 \psi^\dagger) \psi + c^2 \psi^\dagger \nabla^2 \psi - \frac{\lambda c^4}{4} (\psi^\dagger \psi)^4$$

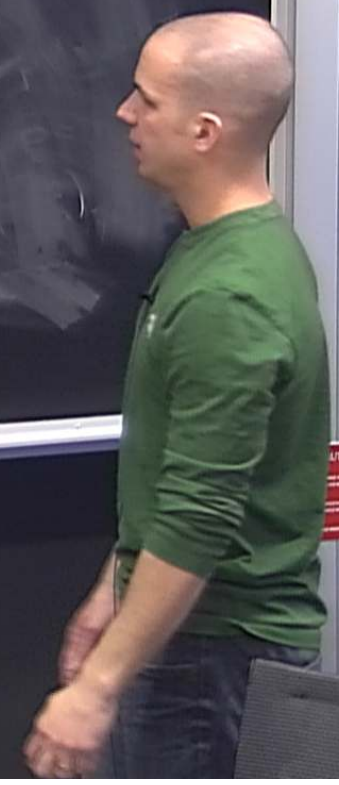
$$= \psi^\dagger \left(i\hbar \partial_t + \frac{\nabla^2}{2m} \right) \psi \quad \psi(\vec{x}, t) \rightarrow \psi(\vec{x}, t)$$

$$\mathcal{L} = i\hbar c^2 (2m) \psi^\dagger \partial_t \psi + \hbar^2 c^2 \psi^\dagger \nabla^2 \psi - \frac{\lambda c^4}{4} (\psi^\dagger \psi)^4$$

$$= \psi^\dagger \left(i\hbar \partial_t + \frac{\nabla^2}{2m} \right) \psi$$

$$\psi(\vec{x}, t) \rightarrow \psi(\vec{x}, \vec{p}, t)$$

$$\psi' = \frac{\psi}{\sqrt{2\pi^3}}$$



CAUTION
 Do not lean against the chalkboard.
 Do not touch the chalk or the eraser.
 Do not use the chalkboard as a desk.
 Do not use the chalkboard as a storage area.

$$\mathcal{L} = i\hbar c^2 (2m) \psi^\dagger \partial_t \psi + \hbar^2 c^2 \psi^\dagger \nabla^2 \psi - \frac{\lambda c^4}{4} (\psi^\dagger \psi)^4$$

$$= \psi^\dagger \left(i\hbar \partial_t + \frac{\nabla^2}{2m} \right) \psi$$

$$\psi(\vec{x}, t) \rightarrow \psi(\vec{x}, \vec{\sigma}, t)$$

$$\psi' = \frac{\psi}{\sqrt{2}}$$

$$S = \int d^4x \mathcal{L}$$

$$d^4x = \sum d^4x$$

CAUTION
 Do not touch the screen and writing board
 when using the remote control or the board
 It is recommended to wear
 safety glasses when using
 the remote control

CAUTION
 Do not touch the screen and writing board
 when using the remote control or the board
 It is recommended to wear
 safety glasses when using
 the remote control

$$\mathcal{L} = i\hbar c^2 (2m) \psi^\dagger \partial_t \psi + \hbar^2 c^2 \psi^\dagger \nabla^2 \psi - \frac{\lambda c^4}{4} (\psi^\dagger \psi)^4$$

$$= \psi^\dagger \left(i\hbar \partial_t + \frac{\nabla^2}{2m} \right) \psi$$

$$\psi(\vec{x}, t) \rightarrow \psi(\vec{x}', t')$$

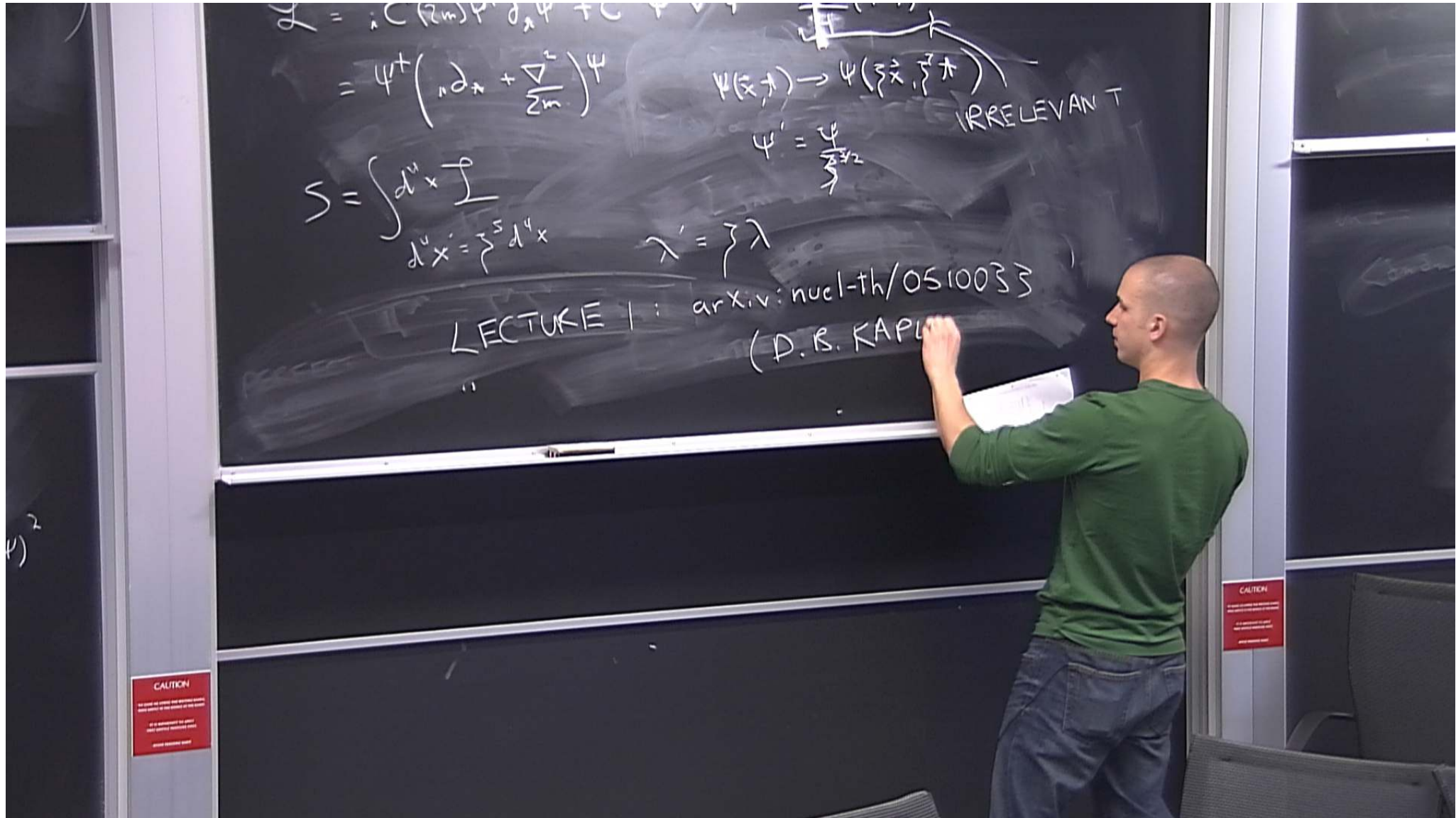
$$\psi' = \psi$$

$$S = \int d^4x \mathcal{L}$$

$$d^4x = \int d^4x'$$

CAUTION
Do not lean against the chalkboard.
Do not touch the chalkboard eraser.
Do not touch the chalkboard markers.
Do not touch the chalkboard.

CAUTION
Do not lean against the chalkboard.
Do not touch the chalkboard eraser.
Do not touch the chalkboard markers.
Do not touch the chalkboard.



$$\mathcal{L} = i c^2 (\partial_m) \psi^\dagger \partial_m \psi + c^2 \psi^\dagger \nabla^2 \psi - \frac{\lambda c^4}{4} (\psi^\dagger \psi)^4$$

$$= \psi^\dagger \left(i \partial_m + \frac{\nabla^2}{2m} \right) \psi$$

$$\psi(\vec{x}, t) \rightarrow \psi(\vec{x}', t')$$

$$\psi' = \frac{\psi}{\sqrt{Z}}$$

IRRELEVANT

$$S = \int d^4x \mathcal{L}$$

$$d^4x = \int d^4x'$$

$$\lambda' = \lambda$$

LECTURE 1: arXiv:nucl-th/0510033
(D.B. KAPLAN)

CAUTION
Do not touch the screen or writing board
when using the remote or the laser
It is dangerous to your
eyes wearing glasses
avoid wearing them

CAUTION
Do not touch the screen or writing board
when using the remote or the laser
It is dangerous to your
eyes wearing glasses
avoid wearing them

$$\mathcal{L} = i c^2 (\hbar m) \psi^\dagger \partial_t \psi + c^2 \psi^\dagger \nabla^2 \psi - \frac{\lambda c^4}{4} (\psi^\dagger \psi)^4 + \frac{c^2}{M^2} (\partial_x \psi)^2 + (\nabla^2 \psi)^\dagger (\nabla^2 \psi)$$

$$= \psi^\dagger \left(i \partial_t + \frac{\nabla^2}{2m} \right) \psi$$

$$\psi(\vec{x}, t) \rightarrow \psi(\vec{x}', \vec{t}')$$

$$\psi' = \frac{\psi}{\sqrt{Z}}$$

IRRELEVANT

$$S = \int d^4x \mathcal{L}$$

$$d^4x = \int d^4x$$

$$\lambda' = \lambda$$

LECTURE 1 : arXiv:nucl-th/0510033
(D.B. KAPLAN)



CAUTION
DO NOT TOUCH THE BOARD
OR THE SURFACE OF THE BOARD
OR THE SURFACE OF THE BOARD
OR THE SURFACE OF THE BOARD

$$\mathcal{L} = iC^2(\partial_m)\psi^\dagger \partial_m \psi + C^2 \psi^\dagger \nabla^2 \psi - \frac{\lambda C^4}{4} (\psi^\dagger \psi)^4 + \frac{g_1}{M} (\partial_\mu \psi)^2 + \frac{g_1}{M} (\nabla^2 \psi)$$

$$= \psi^\dagger \left(i \partial_\mu + \frac{\nabla^2}{2m} \right) \psi$$

$$\psi(\vec{x}, t) \rightarrow \psi(\vec{x}', t')$$

$$\psi' = \frac{\psi}{\sqrt{Z}}$$

IRRELEVANT

$$S = \int d^4x \mathcal{L}$$

$$d^4x' = \int d^4x$$

$$\lambda' = \lambda$$

$$\begin{cases} \vec{x}' = \vec{x} \\ t' = t \end{cases}$$

LECTURE 1: arXiv:nucl-th/0510033
(D.B. KAPLAN)