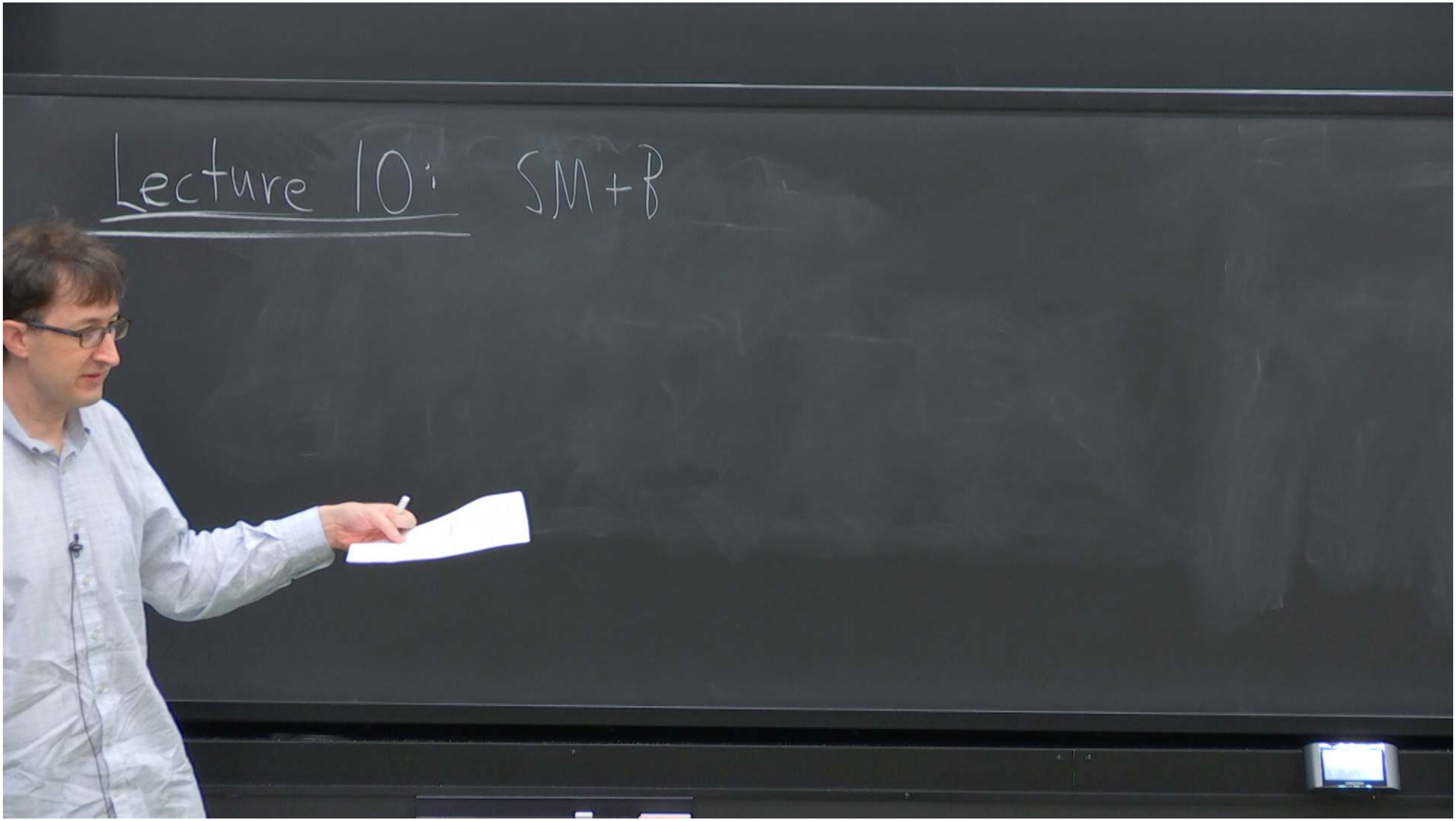
Title: PSI 2019/2020 - Standard Model and Beyond - Part 1 - Lecture 10

Speakers: Latham Boyle

Collection: PSI 2019/2020 - Standard Model and Beyond - Part 1

Date: February 10, 2020 - 11:15 AM

URL: http://pirsa.org/20010069


Lecture 10: SM+B

Lecture 10: SM + β

	$SU(3)$	$SU(2)$	$U(1)$
q_L	3	2	$1/6$
u_R	3	1	$2/3$
d_R	3	1	$-1/3$
ℓ_L	1	2	$-1/2$
$(\nu_R$	1	1	$0)$
e_R	1	1	-1
h	1	2	$1/2$

(2)	U(1)
	1/6
	2/3
	-1/3
	-1/2
	0
	-1
	1/2

1) **SM**: don't include ν_R or dim > 4

2) **SMEFT**: don't include ν_R, do include dim > 4

3) **νSM**: don't include dim > 4, do include ν_R

1) SM can't explain: i) ν's have mass, and oscillate.

ii) DM

iii) matter/anti-matter asym.

2) SMEFT: can explain (i), but not (ii) or (iii)

• most conservative picture, but not complete

3) νSM: • does explain (i, ii, iii)

Lecture 10: SM+R | SU(3) | SU(2) | U(1)

1) SM can't explain: i) ν's have mass, and oscillate.

ii) DM

iii) matter/anti-matter asym.

2) SMEFT: can explain (i), but not (ii) or (iii)

• most conservative picture, but not complete

3) νSM: • does explain (i, ii, iii)

• sets stage for elegent extensions/unifications of SM.

$$\psi \to U(\Lambda)\psi \qquad \psi^* \to \underbrace{U^*(\Lambda)}_{\neq U(\Lambda)}\psi^* \qquad \psi^c$$

$$x \to \Lambda x$$

$$\psi^c = -i\gamma^2\psi^*$$

$$\gamma^\mu = \begin{pmatrix} 0 & \sigma^\mu \\ \bar{\sigma}^\mu & 0 \end{pmatrix}$$

(Weyl basis)

$$\sigma^\mu = (1, \sigma^1, \sigma^2, \sigma^3)$$

$$\bar{\sigma}^\mu = (1, -\sigma^1, -\sigma^2, -\sigma^3)$$

$$\psi^c = -i\gamma^2\psi^*$$

$$\gamma^\mu = \begin{pmatrix} 0 & \sigma^\mu \\ \bar{\sigma}^\mu & 0 \end{pmatrix}$$

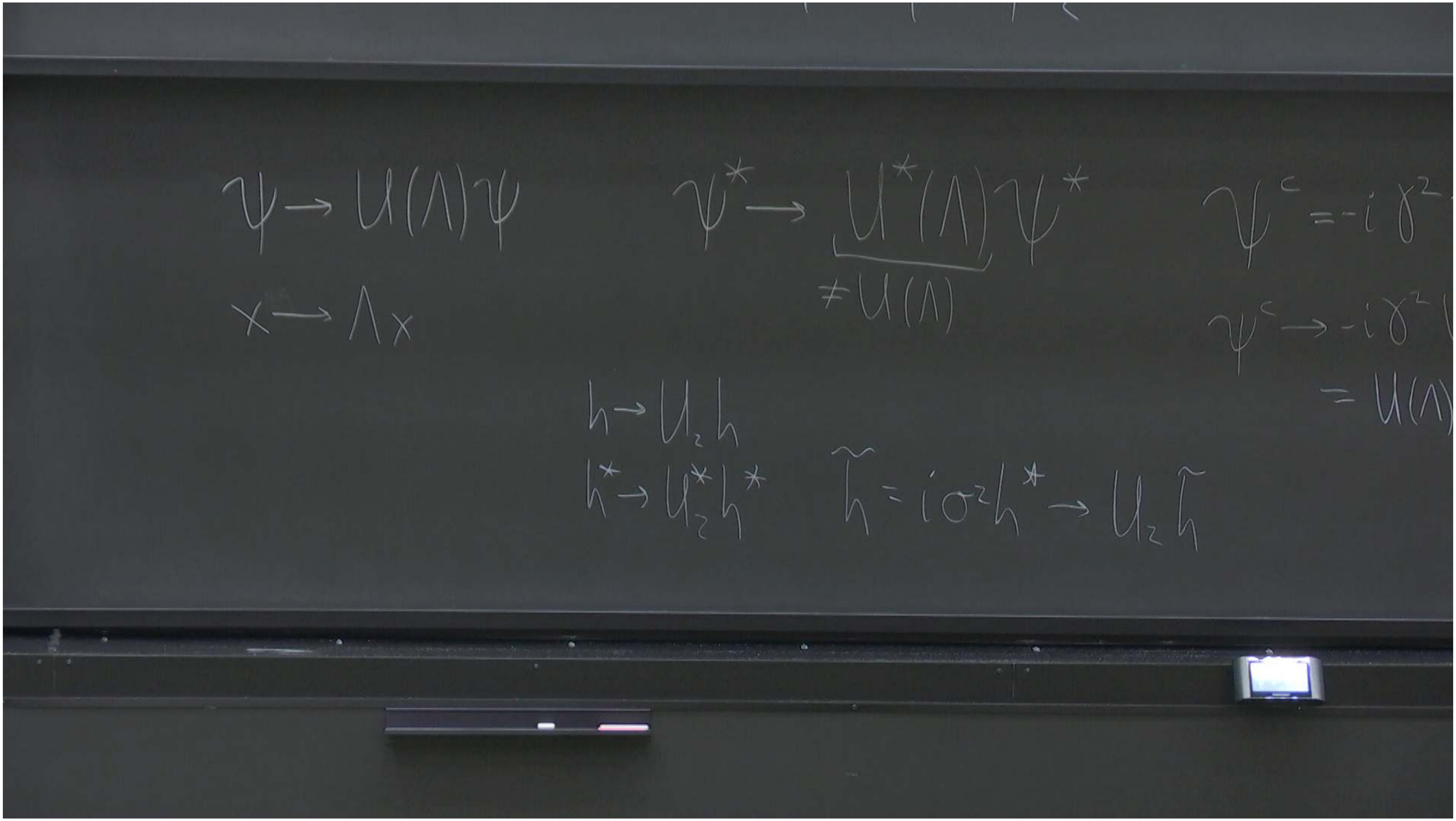
(Weyl basis)

$$\sigma^\mu = (1, \sigma^1, \sigma^2, \sigma^3)$$

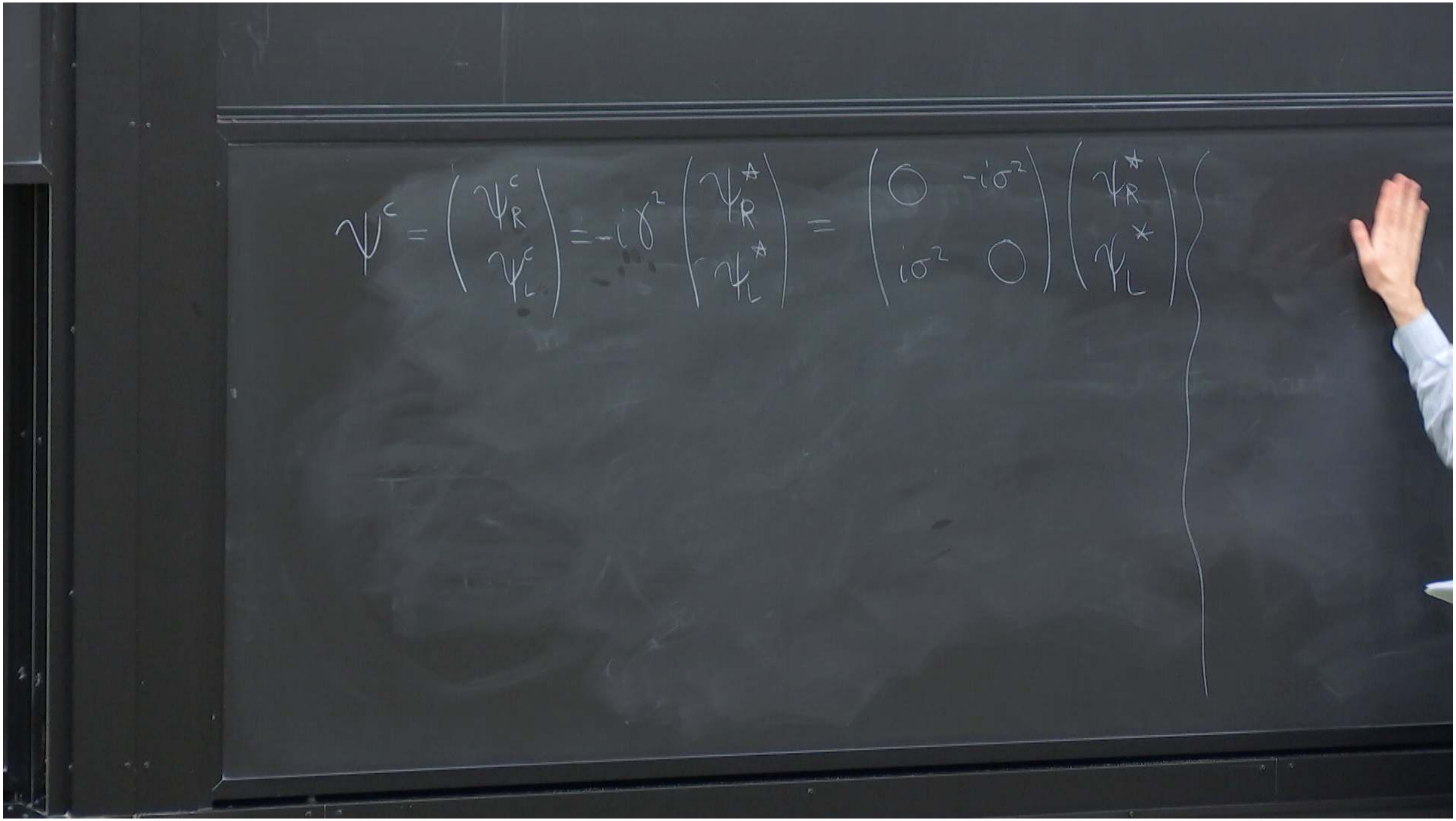
$$\bar{\sigma}^\mu = (1, -\sigma^1, -\sigma^2, -\sigma^3)$$

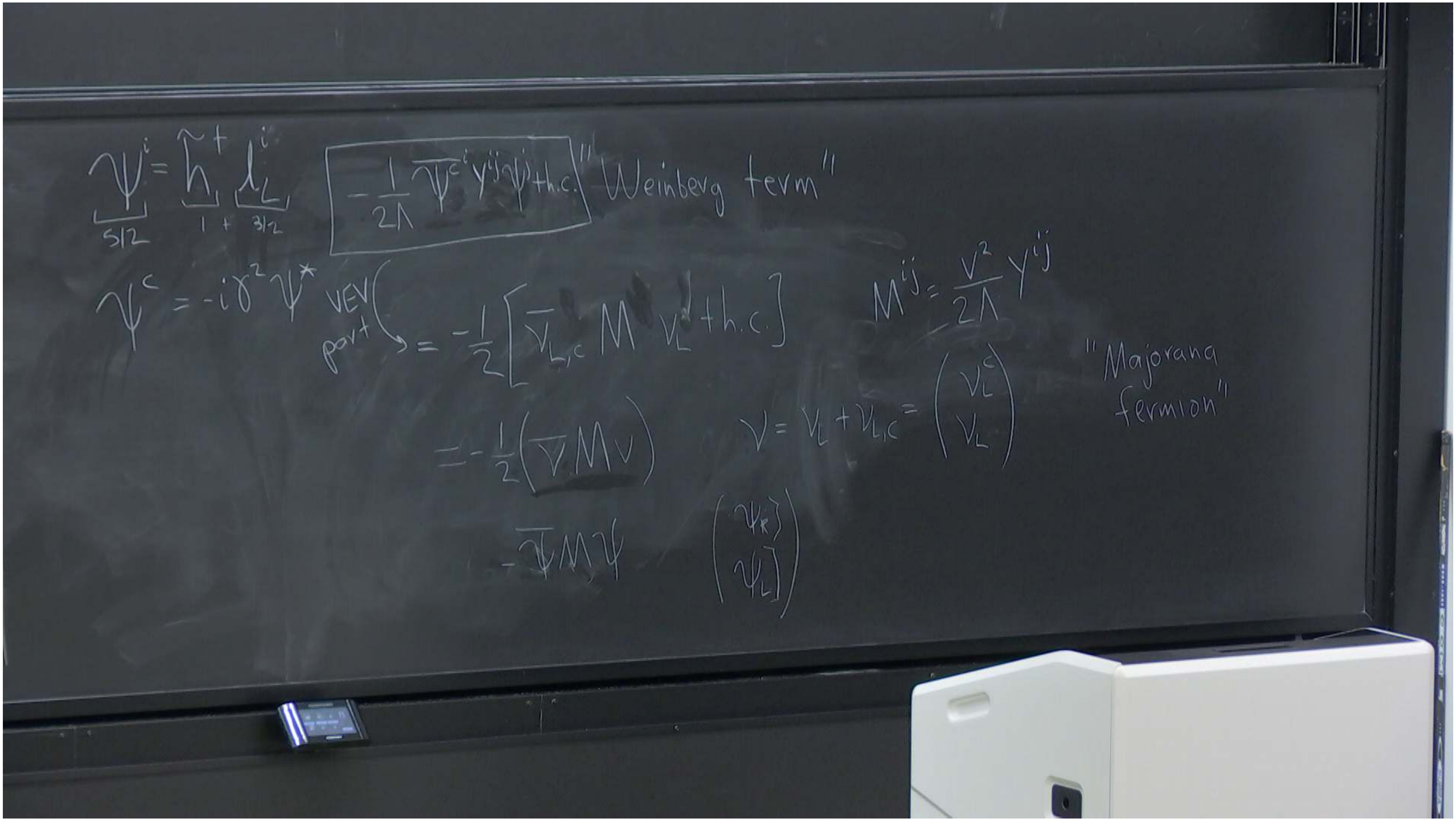
$$\psi^c \to -i\gamma^2 U^*(\Lambda)\psi^*$$

$$= U(\Lambda)(-i\gamma^2)\psi^* = U(\Lambda)\psi^c$$



$\psi \to U(\Lambda)\psi$
$x \to \Lambda x$
$\psi^* \to \underbrace{U^*(\Lambda)}_{\neq U(\Lambda)}\psi^*$
$\psi^c = -i\gamma^2$
$\psi^c \to -i\gamma^2$
$= U(\Lambda)$
$h \to U_2 h$
$h^* \to U_2^* h^*$
$\tilde{h} = i\sigma^2 h^* \to U_2 \tilde{h}$


$\psi^c = \begin{pmatrix} \psi_R^c \\ \psi_L^c \end{pmatrix} = -i\gamma^2 \begin{pmatrix} \psi_R^* \\ \psi_L^* \end{pmatrix} = \begin{pmatrix} 0 & -i\sigma^2 \\ i\sigma^2 & 0 \end{pmatrix} \begin{pmatrix} \psi_R^* \\ \psi_L^* \end{pmatrix}$



$\underbrace{\Psi^i}_{5/2} = \underbrace{\tilde{h}^\dagger}_{1} \underbrace{l_L^i}_{+\,3/2}$
$\boxed{-\frac{1}{2\Lambda}\overline{\Psi^c}^i y^{ij} \Psi^j + h.c.}$ "Weinberg term"
$\Psi^c = -i\gamma^2\Psi^*$
VEV part
$= -\frac{1}{2}\left[\overline{\nu}_{L,c} M \nu_L + h.c.\right]$
$M^{ij} = \frac{v^2}{2\Lambda} y^{ij}$
"Majorana fermion"
$= -\frac{1}{2}(\overline{\nu} M \nu)$
$\nu = \nu_L + \nu_{L,c} = \begin{pmatrix} \nu_L^c \\ \nu_L \end{pmatrix}$
$-\overline{\Psi} M \Psi$
$\begin{pmatrix} \Psi_R \\ \Psi_L \end{pmatrix}$

$$\psi^c = \begin{pmatrix}\psi_R^c \\ \psi_L^c\end{pmatrix} = -i\gamma^2 \begin{pmatrix}\psi_R^* \\ \psi_L^*\end{pmatrix} = \begin{pmatrix}0 & -i\sigma^2 \\ i\sigma^2 & 0\end{pmatrix}\begin{pmatrix}\psi_R^* \\ \psi_L^*\end{pmatrix}$$

Majorana:

$$\boxed{\phi^\dagger = \phi}$$

$$\phi = \int \frac{d^3p}{(2\pi)^3}\left[a_{\vec p}\, e^{i(\vec p\cdot\vec x-\omega t)} + b^\dagger_{\vec p}\, e^{-i(\vec p\cdot\vec x-\omega t)}\right]$$

$$\psi = \sum_\sigma \int \frac{d^3p}{(2\pi)^3}\left[a_{\vec p,\sigma}\, u(\vec p)\, e^{i(\dots)} + a^\dagger_{\vec p,\sigma}\, v(\vec p)\, e^{-i(\dots)}\right]$$

$$\psi^c = \psi$$

$$\underbrace{\psi^i}_{5/2} = \underbrace{\tilde h^\dagger}_{1} + \underbrace{l_L^i}_{3/2}$$

$$\psi^c = -i\gamma^2\psi^*$$

VEV

part

$$= \begin{pmatrix} 0 & -i\sigma^2 \\ i\sigma^2 & 0 \end{pmatrix} \begin{pmatrix} \psi_R^* \\ \psi_L^* \end{pmatrix}$$

$$a_{\vec p}\, e^{i(\vec p\cdot\vec x-\omega t)} + b^\dagger_{\vec p}\, e^{-i(\vec p\cdot\vec x-\omega t)}]$$

$$3\left[a_{\vec p,\sigma} u(\vec p) e^{i(\ldots)} + a^\dagger_{\vec p,\sigma} v(\vec p) e^{-i(\ldots)} \right]$$

$$\underbrace{\psi^i}_{5/2} = \underbrace{\tilde h^\dagger}_{1\ +} \underbrace{l_L^i}_{3/2}$$

$$\psi^c = -i\gamma^2\psi^*$$

$$\boxed{-\frac{1}{2\Lambda}\overline{\psi^c}^i y^{ij}\psi^j + h.c.}$$ "Weinberg term"

VEV port

$$= -\frac{1}{2}\left[\bar\nu_{L,c} M \nu_L + h.c.\right] \qquad M^{ij} = \frac{v^2}{2\Lambda} y^{ij}$$

"Majorana fermion"

$$= -\frac{1}{2}\left(\bar\nu M \nu\right) \qquad \nu = \nu_L + \nu_{L,c} = \begin{pmatrix} \nu_L^c \\ \nu_L \end{pmatrix}$$

$$-\bar\Psi M \Psi \qquad \begin{pmatrix} \psi_R \\ \psi_L \end{pmatrix}$$