Lecture 10: SM+B
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<table>
<thead>
<tr>
<th></th>
<th>SU(3)</th>
<th>SU(2)</th>
<th>U(1)</th>
</tr>
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<tbody>
<tr>
<td>qL</td>
<td>3</td>
<td>2</td>
<td>1/6</td>
</tr>
<tr>
<td>uR</td>
<td>3</td>
<td>1</td>
<td>2/3</td>
</tr>
<tr>
<td>dR</td>
<td>3</td>
<td>1</td>
<td>-1/3</td>
</tr>
<tr>
<td>eL</td>
<td>1</td>
<td>2</td>
<td>-1/2</td>
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<tr>
<td>(νR</td>
<td>1</td>
<td>1</td>
<td>0</td>
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<td>eR</td>
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<td>-1</td>
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<td>h</td>
<td>1</td>
<td>2</td>
<td>1/2</td>
</tr>
</tbody>
</table>
1) **SM**: don't include $\nu_R$, or $\text{dim} > 4$

2) **SMEFT**: don't include $\nu_R$, do include $\text{dim} > 4$

3) **$\nu$SM**: don't include $\text{dim} > 4$, do include $\nu_R$
1) SM can't explain: i) V'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) VSU:  
       does explain (i, ii, (ii)

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           SU(3)|SU(2)|U(1)
1) SM can't explain: i) \( V \)'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) \( \nu_{SM} \):
   - does explain (i, ii, iii)
   - sets stage for elegant extensions/unifications of SM.
\[ \begin{align*} \psi & \rightarrow U(1)\psi \\ x & \rightarrow \Lambda x \\ \psi^* & \rightarrow U^*(1)\psi^* \end{align*} \]
\[ \psi^c = -i \delta^2 \psi^* \]
\[ \psi^m = \begin{pmatrix} 0 & \sigma^m \\ \overline{\sigma}^m & 0 \end{pmatrix} \]
\[ \text{(Weyl basis)} \]
\[ \sigma^m = \begin{pmatrix} 1, \sigma^1, \sigma^2, \sigma^3 \end{pmatrix} \]
\[ \overline{\sigma}^m = \begin{pmatrix} 1, -\sigma^1, -\sigma^2, -\sigma^3 \end{pmatrix} \]
\[ \psi^c = -i \nabla^2 \psi^* \]
\[ \psi^c - i \nabla^2 U(i\Lambda) \psi^* \]
\[ = U(i\Lambda)(-i \nabla^2) \psi^* = U(i\Lambda) \psi^c \]

\[ \chi^m = \begin{pmatrix} 0 & \sigma^m \\ \overline{\sigma}^m & 0 \end{pmatrix} \]

(Weyl basis)

\[ \sigma^m = (1, \sigma^1, \sigma^2, \sigma^3) \]

\[ \overline{\sigma}^m = (1, -\sigma^1, -\sigma^2, -\sigma^3) \]
\[ \psi \rightarrow U(\Lambda)\psi \]
\[ \psi^* \rightarrow U^*(\Lambda)\psi^* \]
\[ \psi^* = -i \psi \]
\[ \psi^* = -i \psi \]
\[ h \rightarrow U_2 h \]
\[ h^* \rightarrow U_2^* h^* \]
\[ \tilde{h} = i \sigma^2 h^* \rightarrow U_2 \tilde{h} \]
\[ \Psi^c = \begin{pmatrix} \Psi_R^c \\ \Psi_L^c \end{pmatrix} = \begin{pmatrix} i \gamma^2 & 0 \\ 0 & -i \gamma^2 \end{pmatrix} \begin{pmatrix} \Psi_R^+ \\ \Psi_L^+ \end{pmatrix} = \begin{pmatrix} 0 & -i \gamma^2 \\ i \gamma^2 & 0 \end{pmatrix} \begin{pmatrix} \Psi_R^- \\ \Psi_L^- \end{pmatrix} \]
\[ \psi^i = \frac{\bar{\psi}^i}{\sqrt{2}} \]

\[ \psi^c = -i \sqrt{2} \psi^* \]

\[ \text{\textit{Majorana fermion}} \]

\[ \text{\textit{Weinberg term}} \]

\[ \text{\textit{Part}} = -\frac{1}{2} \left[ \overline{\nu_L} M \nu_L + \text{h.c.} \right] \]

\[ M^i_j = \frac{v^2}{2 \Lambda} \gamma^i_j \]

\[ \nu = \nu_L + \nu_L^c = \begin{pmatrix} \nu_L \\ \nu_L^c \end{pmatrix} \]