# Little Higgs and T Parity

Claudia Frugiuele

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*Carleton University*

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*in collaboration with Thomas Gregoire*

# Outline

- Little Higgs models
- Strong dynamics and T parity
- SU(6)/Sp(6) model with a new T-parity

# Little Higgs models

# Little Higgs Models(LH):

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The Higgs is light because it is a pseudo-Goldstone boson in a G/H non linear sigma model

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$$m_h^2 = \frac{g^2}{4\pi^2}\Lambda^2 \sim (1\text{Tev})^2$$

$\Lambda \sim 10\text{TeV} \longleftarrow$ not dangerous for EWPO

> Naive breaking of the the global symmetry G

- Gauge couplings
- Yukawa coupling
- Quartic coupling

> global symmetry broken explicitly via *collective symmetry breaking*

# Example: *Littlest Higgs*

## >SU(5)/SO(5) non linear sigma model

$$\Sigma \to V\Sigma V^T \qquad V \in SU(5)$$

$$\langle\Sigma\rangle = \Sigma_0 = \begin{pmatrix} 0 & 0 & \mathbf{1} \\ 0 & 1 & 0 \\ \mathbf{1} & 0 & 0 \end{pmatrix}$$

$5 \times 5$

$2 \times 2$

$$\Sigma = e^{i\pi/f}\Sigma_0 e^{i\pi^T/f}$$

$$\pi\Sigma_0 = \Sigma_0\pi^T$$

$$\pi = \begin{pmatrix} \chi + \frac{\eta}{2\sqrt{5}} & \frac{h^*}{\sqrt{2}} & \phi^\dagger \\ \frac{h^T}{\sqrt{2}} & -\frac{2\eta}{\sqrt{5}} & \frac{h^\dagger}{\sqrt{2}} \\ \phi_l & \frac{h}{\sqrt{2}} & \chi^T + \frac{\eta}{2\sqrt{5}} \end{pmatrix}$$

14 Goldstones
1 complex doublet
1 complex triplet
1 real triplet (eaten)
1 complex singlet

# Collective symmetry breaking

Enlarge the gauge group to implement collective symmetry breaking, new gauge bosons

- Gauge structure: $SU(2)_1 \times SU(2)_2 \times U(1)_Y$

$$Q_{1a} = \begin{pmatrix} \frac{\sigma_a}{2} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \qquad Q_{2a} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -\frac{\sigma_a^*}{2} \end{pmatrix}$$

$$SU(2)_1 \times SU(2)_2 \times U(1)_Y \to SU(2)_{ew} \times U(1)_Y$$

The Higgs is kept light as the symmetry which protect it is not broken by each singular gauge group, but just by the two of them together. Just one loop logarithmic contribution!

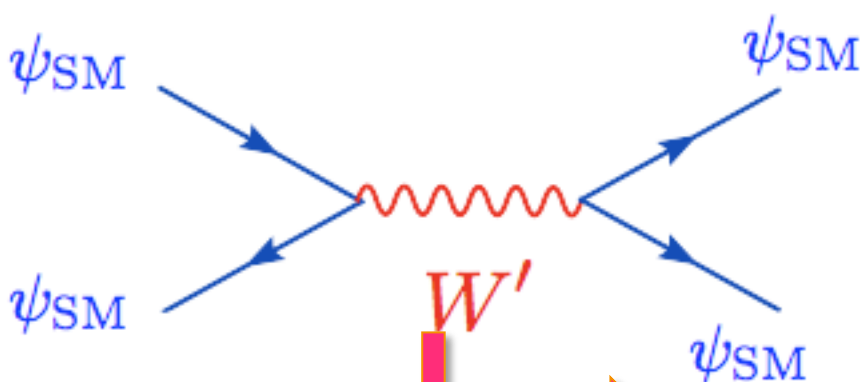
$$g_1 \neq 0 \;\; g_2 = 0$$
$$g_1 = 0 \;\; g_2 \neq 0$$

The higgs is an exact Goldstone

# Electroweak precision measurement (EWPM)

New Tev particle can induce higher dimensional operators dangerous for EWPM

$$\frac{\Psi_{SM}\Psi_{SM}\Psi_{SM}^{\dagger}\Psi_{SM}^{\dagger}}{f^2}$$




New gauge boson

# One more ingredient: T-Parity

Discrete symmetry ( called *T-parity** )imposed to solve problems with EWPM

$$\phi_{\rm SM} \to \phi_{\rm SM}$$

$$\phi_{\rm partner} \to -\phi_{\rm partner}$$

Coefficient of higher dimensional operator loop suppressed.
Lightest T-odd particle stable, dark matter candidate

*Low, Cheng JHEP09(2003)051

# UV Completion

- Little Higgs models are non linear sigma model with a cutoff $\Lambda \cong 10$ Tev

Energy

UV completion

SUSY? Another Little Higgs model? Strongly coupled interaction?

$\Lambda \cong 10$ Tev

Little Higgs model

# Strongly coupled UV completion

- Littlest Higgs model

$$SO(N) \text{ strong interaction}$$

$SU(5)$ flavor group

$\Sigma$ Fermionic condensation

$$\Psi_5 = \begin{pmatrix} \psi_2 \\ \psi_0 \\ \psi_2' \end{pmatrix} \longrightarrow \quad < \Psi_5 \Psi_5 >= \Sigma_0$$

$$\psi_2 \in 2 \text{ of } SU(2)_1$$

$$\psi_2' \in 2^* \text{ of } SU(2)_2$$

E .Katz et al
hep-ph 0312287

# Strongly coupled UV completion and T parity

- Hill and Hill* showed that in strong interacting UV completion T-parity is broken by Wess-Zumino-Witten(WZW) terms.
- Lightest T-odd particle decays promptly
- Do not contribute to EWPM

Situation analogous with the pion decay in QCD!

***Hill & Hill Phys. Rev. D 75, 115009 (2007)**

Our Goal: to build a LH model with a new definition of T-parity compatible with a strongly coupled UV completion.

# Strong dynamics and T parity

# How T-parity is defined in a strongly coupled UV completion?

$$\Sigma \to \Omega \Sigma^\dagger \Omega^\dagger \quad \Rightarrow \quad \begin{aligned} \psi_2 &\to \psi_2^{\prime\dagger} \\ \psi_0 &\to -\psi_0^\dagger \end{aligned}$$

$$\Omega = \begin{pmatrix} 0 & 0 & \mathbf{1} \\ 0 & -1 & 0 \\ \mathbf{1} & 0 & 0 \end{pmatrix} \in SO(5) \qquad \Psi_5 = \begin{pmatrix} \psi_2 \\ \psi_0 \\ \psi_2' \end{pmatrix}$$

Not a symmetry of the fermionic kinetic term!

# Solution: $\psi_i \longrightarrow \psi_j$

We can't implement this symmetry in SU(5)

$$\psi_2 \longrightarrow \psi_2'$$

$\boxed{Y = \frac{1}{2}}$

$\boxed{Y = -\frac{1}{2}}$

$$\Psi_5 = \begin{pmatrix} \psi_2 \\ \psi_0 \\ \psi_2' \end{pmatrix}$$

T- parity

$$Q_{1a} \rightarrow Q_{2a}$$

$$Y \rightarrow Y$$

$$\psi_2 \rightarrow \psi_2' \qquad Y = 0$$

$$\psi_0 \rightarrow \psi_0 \qquad Y = \frac{1}{2}$$

- This assignment of the hypercharge leads to a charged vacuum

# SU(5) $\longrightarrow$ SU(6)

| | | $SU(2)_1$ | $SU(2)_2$ | $U(1)_Y$ |
|---|---|---|---|---|
| | $\Psi_2$ | 2 | 1 | 0 |
| $SU(6)$ | $\Psi_0$ | 1 | 1 | 1/2 |
| $SU(6)$ | $\Psi'_0$ | 1 | 1 | $-1/2$ |
| $SU(6)$ | $\Psi'_2$ | 1 | $2^*$ | 0 |

SU(6)/Sp(6) vacuum not charged

# A new definition of T-parity

$$\Psi_2 \to \epsilon \Psi_2'$$

$$\Psi_0 \to \Psi_0$$

$$\Psi_0' \to \Psi_0'$$

$$\Psi_2' \to -\epsilon \Psi_2$$

Exchange Symmetry

Global symmetry

$$SU(6)/Sp(6)$$

# SU(6)/Sp(6) with T-parity

# SU(6)/Sp(6) model

$$\Sigma_0 = f \begin{pmatrix} 0 & 0 & -\mathbf{I} \\ 0 & -i\sigma_2 & 0 \\ \mathbf{I} & 0 & 0 \end{pmatrix}$$

$SU(6)$ broken $(X_a)$ and unbroken $(T_a)$ generators

$$X_a \Sigma_0 - \Sigma_0 X_a^T = 0,$$
$$T_a \Sigma_0 + \Sigma_0 T_a^T = 0.$$

$$\Sigma = e^{i\Pi_a X_a/f}\ \Sigma_0\ e^{i\Pi_a X_a^T/f} = e^{2i\Pi_a X_a/f}\ \Sigma_0,$$

14 Goldstone bosons

$$\Pi = \begin{pmatrix} \phi - \frac{\eta}{2} & h_1 & h_2 & \chi \\ h_1^\dagger & \frac{\eta}{2} & 0 & -h_2^T \\ h_2^\dagger & 0 & \frac{\eta}{2} & h_1^T \\ \chi^\dagger & -h_2^* & h_1^* & \phi^T - \frac{\eta}{2} \end{pmatrix}$$

Two doublet, 2Higgs model (2HM)
One real triplet
One complex and one real singlet

Low, Skiba, Smith
[ hep-ph/ 0 2 0 7 2 4 3 ]

# New exchange T-parity

T-parity: $\Sigma \to T\Sigma T^T$ ,

$T \in Sp(6)$

$$T = \begin{pmatrix} 0 & 0 & i\sigma_2 \\ 0 & \mathbf{I} & 0 \\ -i\sigma_2 & 0 & 0 \end{pmatrix}$$

Sp(6) is not anomalous

Dark matter candidate!

# Inert doublet model

Our dark matter candidate is contained in the Higgs sector which is an Inert Doublet Model (IDM)

$$\langle h_+ \rangle = \begin{pmatrix} 0 \\ v \end{pmatrix} \qquad \langle h_- \rangle = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

Physical scalars:

$$h, \underbrace{H_0, H^\pm}_{\text{T-odd}}, A_0$$

h looks SM higgs

$$m_{H_0} < m_{H^\pm} < m_h < m_{A_0}$$
$$m_{H_0} \sim m_{H^\pm}$$

Approximate custodial symmetry
Small contribution to the T parameter

Lightest particle is H0 and it is a good dark matter
Candidate for mass around 60Gev *

*E.Dolle, S. Su hep-ph 0906.1609

# Conclusion & Summary

- New definition of T parity in a SU(6)/Sp(6) LH model compatible with strong interacting UV completion

- Dark matter candidate

- Natural and well motivated inert doublet model

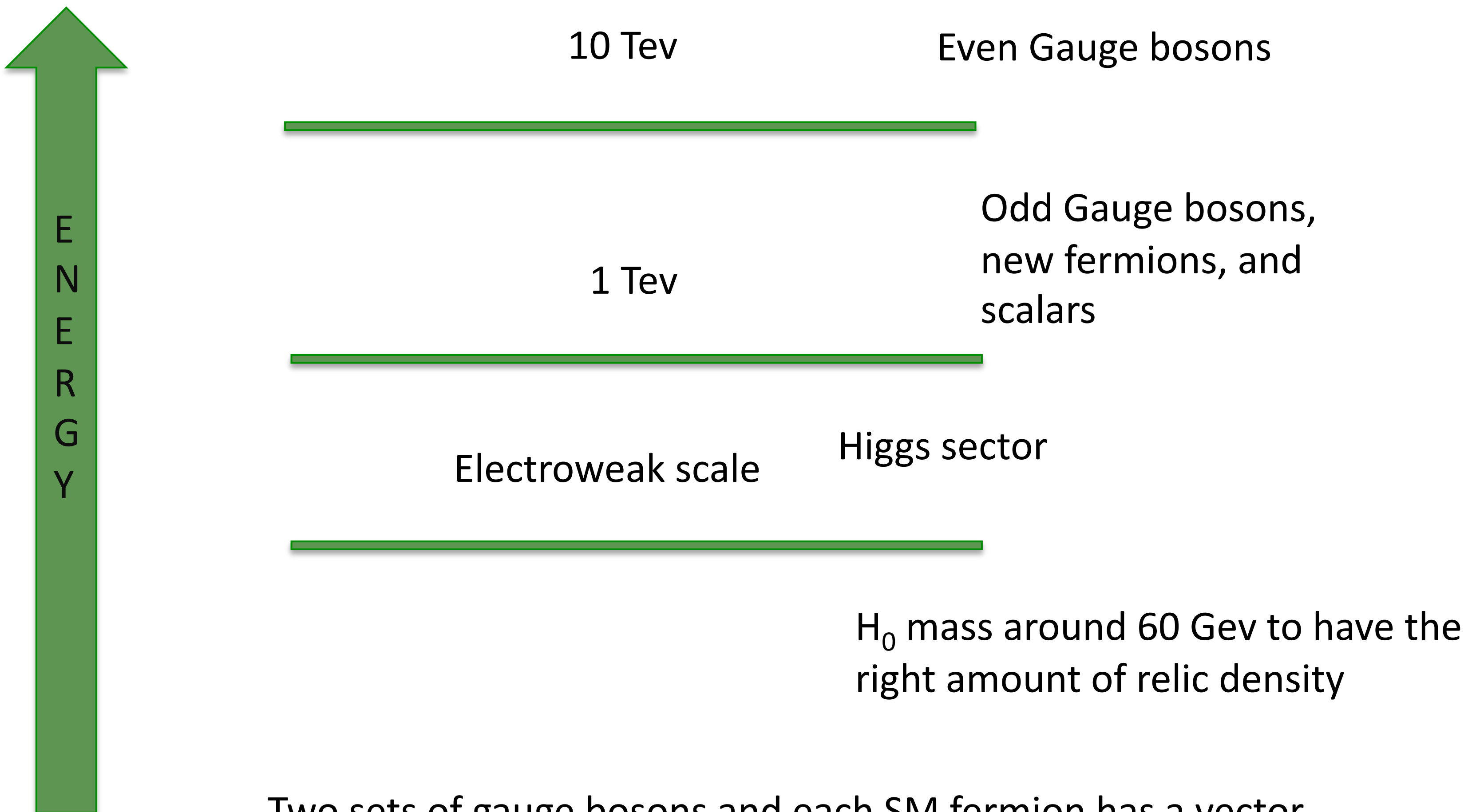
- UV completion change the structure and the phenomenology of the low energy theory

# Work in progress

- We are studying the phenomelogy of the model
- Parameters space for dark matter
- Smoking gun?

# Backup

# Particle content




Two sets of gauge bosons and each SM fermion has a vector-like T odd partner. Extra states compared to SU(6)/Sp(6) without T parity

# Wess-Zumino-Witten terms

- WZW fixed by anomaly structure of the flavor group
- In the low energy theory these are complicated terms function of the sigma fields
- To simplify we can think about

$$\pi F_{\mu\nu}\tilde{F}_{\mu\nu}$$

# Inert doublet model

$$
\begin{aligned}
V(H_{even}, H_{odd}) = \mu_1^2 \mid H_{even} \mid^2 + \mu_2^2 \mid H_{odd} \mid^2 + \tilde{\lambda}_1 \mid H_{even} \mid^4 + \tilde{\lambda}_2 \mid H_{odd} \mid^4 \\
+ \tilde{\lambda}_3 \mid H_{even} \mid^2 \mid H_{odd} \mid^2 + \tilde{\lambda}_4 \mid H_{even}^\dagger H_{odd} \mid^2 + \frac{\tilde{\lambda}_5}{2}((H_{even}^\dagger H_{odd})^2 + h.c.),
\end{aligned}
$$

# Fermionic sector

# Extra Gauge group

Need to enlarge the gauge group to implement T-parity in a chiral theory

$$SU(2)_1 \otimes SU(2)_2 \otimes SU(2)_3 \otimes U(1)_Y,$$

Extra SU(2) not in SU(6)

$$K_1 \to V_1 K_1 V_3^\dagger$$
$$K_2 \to V_2 K_2 V_3^\dagger$$

$$SU(2)_1 \otimes SU(2)_3 \to SU(2)_{1+3},$$
$$SU(2)_2 \otimes SU(2)_3 \to SU(2)_{2+3}$$

# Top Sector

$$\mathcal{L}_{top} = k_1 f Q^T \Sigma^\dagger Q^c + k_2 f_k [q_3^T K_1^T (-i\sigma_2 q_1^c) + q_3^T K_2^T q_2^c] + k_3 u \tilde{u}^c + h.c.$$

$$Q = \begin{pmatrix} q_1 \\ u \\ d \\ q_2 \end{pmatrix} \qquad Q^c = \begin{pmatrix} q_2^c \\ d^c \\ u^c \\ q_1^c \end{pmatrix}$$

Vector like partner of the top:

One even doublet

One odd doublet

Two even singlets