Flavor **and Little Higgs**

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Physics Beyond the Standard Model

WHY ?

WHAT ?

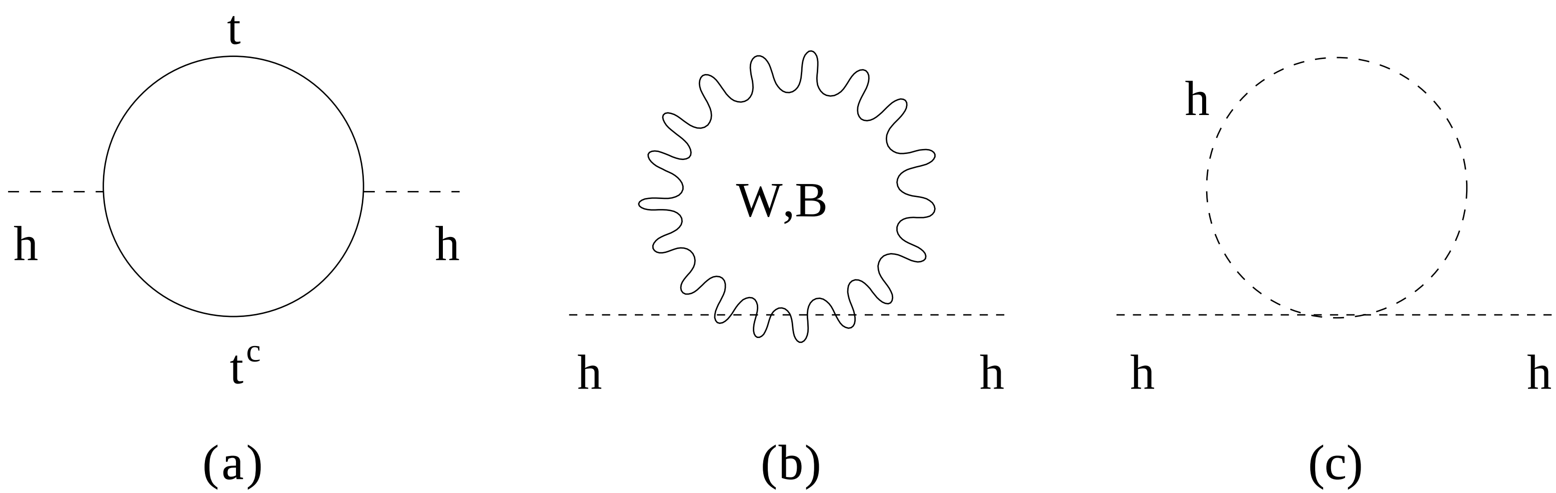
WHERE ?

- **Theoretical** —**supersymmetry Vs little Higgs**
- **Experimental** — m_ν, $B \to K\phi$, Δa_μ (?)

$\star$ **Flavor Problems**

The Hierarchy Problem :-

— one-loop corrections to the boson mass contain quadratically divergent contributions



e.g. for $\Lambda = 10$ (TeV)

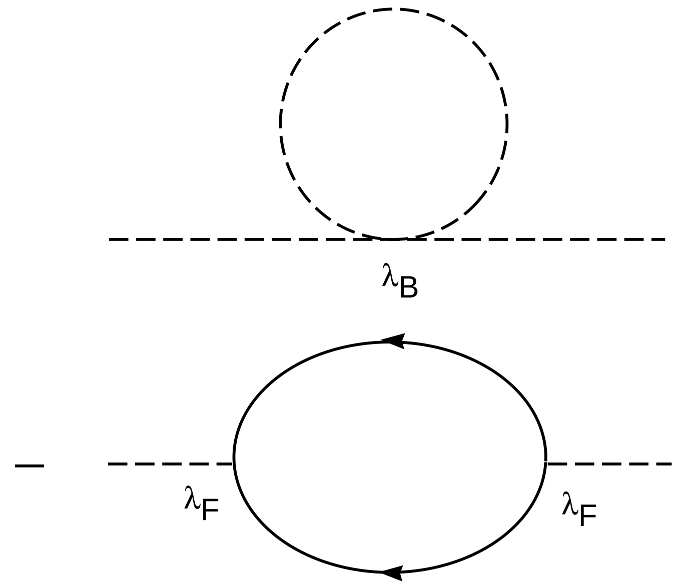
Schmaltz hep-ph/0210415

$$-\frac{3}{8\pi^2}\lambda_t^2\Lambda^2 \sim -(2)^2 \qquad \frac{1}{16\pi^2}g^2\Lambda^2 \sim (0.7)^2 \qquad \frac{1}{16\pi^2}\lambda^2\Lambda^2 \sim (0.5)^2$$

$$m_h^2 = m_{tree}^2 - [100 - 10 - 5]\ (200GeV)^2$$

Solution — cancellation by pairing (protected by symmetry)

e.g. supersymmetry :

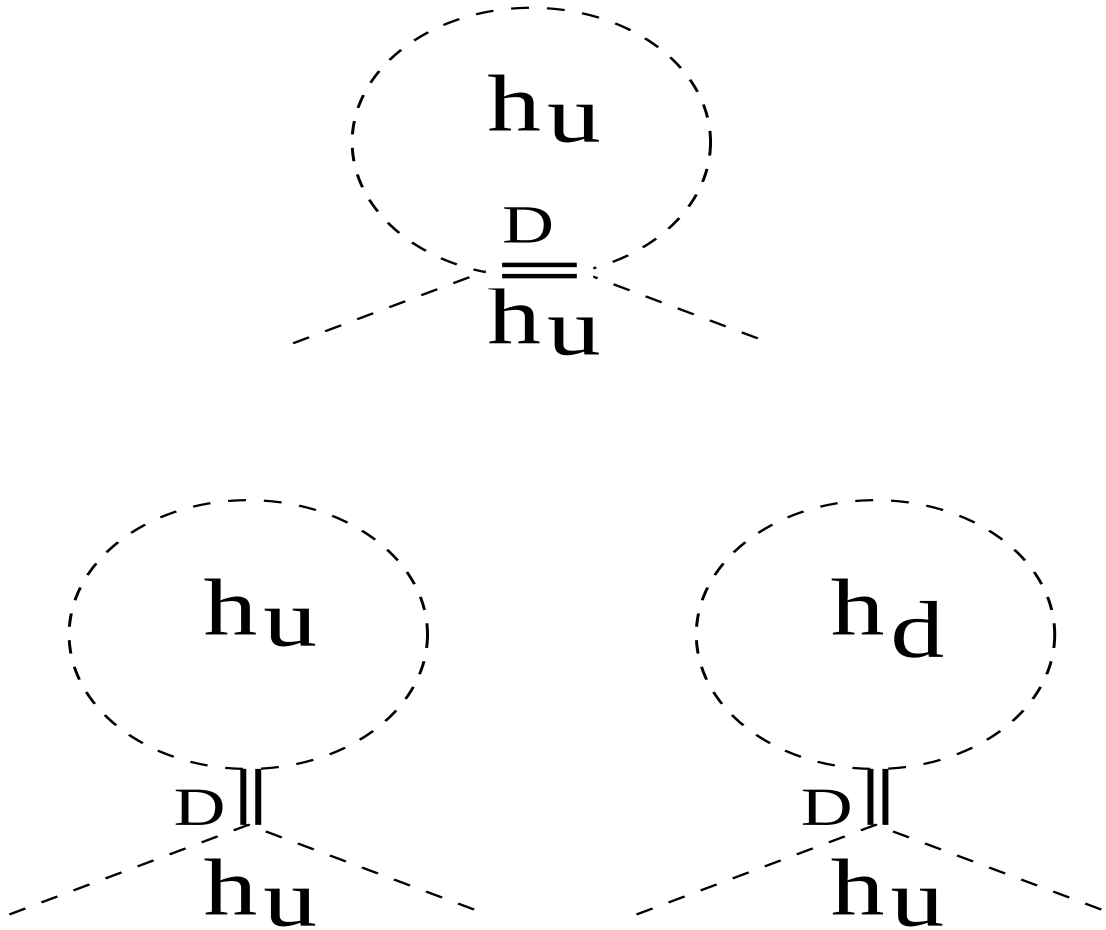


$$\delta M_B^2 = \frac{\lambda_B}{16\pi^2}\,\Lambda^2 - \frac{\lambda_F^2}{16\pi^2}\,\Lambda^2$$

$$\lambda_B = \lambda_F^2 \longrightarrow \delta M_B^2 = 0$$

- *note* (Schmaltz) there is also bosonic pairing

— even in SUSY (SSM) : squark, gaugino, & *higgsino*



The Little Higgs Idea :-

- cancel *only* one-loop quadratic divergence
- mainly for the t contribution
- use only bosonic symmetry

— Higgs as *pseudo-Nambu-Goldstone boson*
described by nonlinear sigma model

$\Longrightarrow$ produce *safe* little hierarchy

— to be completed by background strong dynamics at 10-50 TeV
cf. (TeV scale) technicolor

UV completion ?

10 TeV — sigma model cut-off

colored fermion related to top quark

1 TeV — new gauge bosons related to SU(2)

new scalars related to Higgs

200 GeV — 1 or 2 Higgs doublets, possibly more scalars

Little Higgs ······

- bosonic pairings required

SM loop	maximum mass of new particles
top	2 TeV
weak bosons	5 TeV
Higgs	10 TeV

⋆ phenomenological constraints (PDG)

100 GeV	new leptons
200 GeV	new quarks
300 GeV	leptoquarks
700 GeV	W' or Z'

A Toy Model (Kaplan & Schmaltz)

hep-ph/0302049

- extended EW gauge symmetry

— $SU(3)_L \times U(1)_X$ with $Q^a = (T^a, t^a, b^a)^T$

- Higgs sector global symmetry protecting hierarchy

— $[SU(3)/SU(2)]^2$

— *violated* by gauge and Yukawa couplings

— but one-loop diagrams are protected

e.g. Φ_1 & Φ_2 with *aligned* VEVs

$$\begin{aligned}\mathcal{L}_{top} &= y_1\,\bar{t}'_a\,\Phi_1\,Q^a + y_2\,\bar{T}'_a\,\Phi_2\,Q^a \\ &= f\,(y_1\,\bar{t}' + y_2\,\bar{T}')\,T + \frac{i}{\sqrt{2}}\,(y_1\,\bar{t}' - y_2\,\bar{T}')\,h\begin{pmatrix} t \\ b \end{pmatrix} + \cdots\end{aligned}$$

• either $\Phi \longrightarrow$ 5 NGB states from gauged $SU(3) \rightarrow SU(2)$

• either $\Phi \longrightarrow$ 5 NGB states from (axial) global $SU(3) \rightarrow SU(2)$
— protected from having mass term

• nonlinear sigma model —

$$\Phi_1 = e^{i\theta/f} \begin{pmatrix} 0 & 0 & f \end{pmatrix}^T \qquad \Phi_2 = e^{-i\theta/f} \begin{pmatrix} 0 & 0 & f \end{pmatrix}^T$$

$$\theta = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 & \\ 0 & 0 & h \\ & h^\dagger & 0 \end{pmatrix} + \frac{\eta}{4} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$$

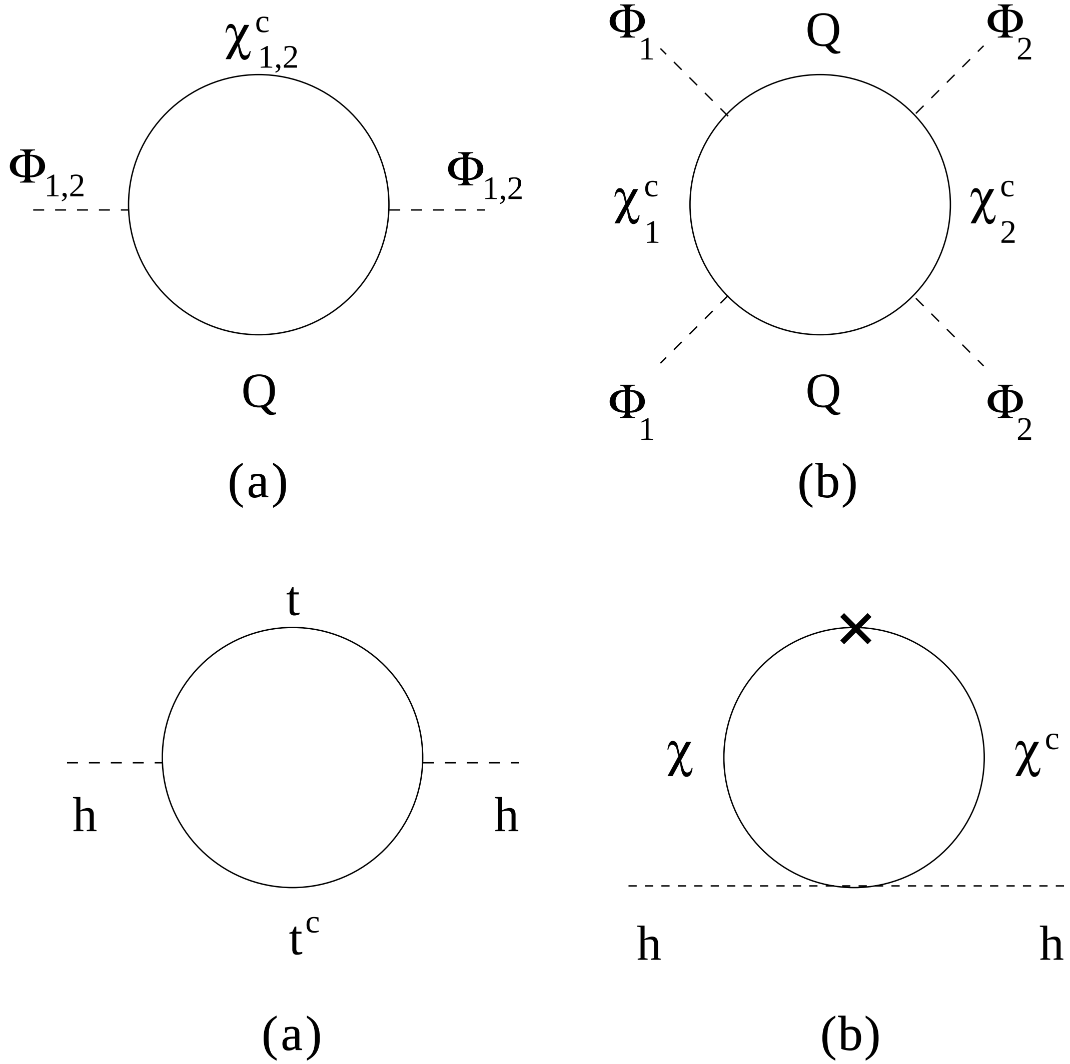
⋆ *HOWEVER* —

• Q^a no consistent quantum numbers under $SU(3)$'s
— h (SM Higgs doublet) and η $\longrightarrow$ PNGB's

• subtle symmetry breaking
— 1-loop diagram without both Φ's
$\longrightarrow$ each Φ behaves like the one with NGB

• gauge boson loop
$\longrightarrow$ small log-divergent mass contribution

QUARTIC COUPLING PROBLEM $\longrightarrow$ $SU(4)$ MODEL *e.g.*



Towards Realistic Little Higgs Models :-

— Is it a really viable alternative to SUSY (SSM) ?

- nice toy models *that work*

- need to have realistic models

— has to be complete

— does incorporate everything in SM

— need consistent fermion spectrum

- the Major Step :

— anomaly free fermionic spectra for the extended EW symmetries
(3 families SM fermion + vectorlike states)

SM spectrum :-

— one-family spectrum *very unique*

• taking $SU(3)_C \times SU(2)_L \times U(1)_Y$

• assuming a $(3, 2, 1)$ multiplet

• *obtained* as the minimal chiral set free from all gauge anomalies

O.K. Mod. Phys. Lett. A11, 2547
O.K. Phys. Rev. D55, 383

— $SU(3)$ requires $(\bar{3}, 1, a)$ and $(\bar{3}, 1, b)$

— $SU(2)$ requires an extra $(1, 2, c)$

— $U(1)$ anomalies have no solution

$\longrightarrow$ adding a $(1, 1, k)$ give *the* unique solution

⋆ idea extended to derive the 3-family spectrum

e.g. $SU(4)_A \times SU(3)_C \times SU(2)_L \times U(1)_X$

multiplets	X	Gauge anomalies					$U(1)_Y$ states	
		t-1	441	331	221	1^3		
$(\mathbf{4},\mathbf{3},\mathbf{2})$	**1**	24	6	8	12	24	3 $\mathbf{1}(Q)$	$\mathbf{-5}(Q^{'})$
$(\bar{\mathbf{4}},\bar{\mathbf{3}},\mathbf{1})$	**5**	60	15	20		1500	3 $\mathbf{-4}(\bar{u})$	$\mathbf{2}(\bar{d})$
$(\bar{\mathbf{4}},\mathbf{1},\mathbf{2})$	**3**	24	6		12	216	3 $\mathbf{-3}(L)$	$\mathbf{3}(\bar{L})$
$(\bar{\mathbf{4}},\mathbf{1},\mathbf{1})$	**9**	36	9			2916	3 $\mathbf{-6}(\bar{E})$	$\mathbf{0}(N)$
$(\mathbf{6},\mathbf{1},\mathbf{1})$	**-18**	-108	-36			-34992	3 $\mathbf{6}(E)$	3 $\mathbf{12}(S)$
$(\mathbf{1},\bar{\mathbf{3}},\mathbf{2})$	**-10**	-60		-20	-30	-6000	$\mathbf{5}(\bar{Q}^{'})$	
$(\mathbf{1},\bar{\mathbf{3}},\mathbf{1})$	**-4**	-12		-4		-192	$\mathbf{2}(\bar{d})$	
$(\mathbf{1},\bar{\mathbf{3}},\mathbf{1})$	**-4**	-12		-4		-192	$\mathbf{2}(\bar{d})$	
$(\mathbf{1},\mathbf{1},\mathbf{2})$	**6**	12			6	432	$\mathbf{-3}(L)$	
3 $(\mathbf{1},\mathbf{1},\mathbf{1})$	**24**	72				41472	3 $\mathbf{-12}(\bar{S})$	
3 $(\mathbf{1},\mathbf{1},\mathbf{1})$	**-12**	-36				-5184	3 $\mathbf{6}(E)$	
	Total	0	0	0	0	0		

Flavor Physics :-

⋆ *Why 3 families ? !*

- mass heirarchy (quarks & charged leptons), CKM mixing
- MNS mixing (BSM neutrino masses)
- ? FCNC, CP violations

Vs **little Higgs** (Kaplan & Schmaltz) :-

- $SU(3)_L \times U(1)_X$ gauge symmetry forbides $\bar{b}_a\, \Phi_i\, Q^a$ or $\bar{b}_a\, \Phi_i^\dagger\, Q^a$
- family universal embeddings of SM fermions *inconsistent*

— *e.g.* $SU(3)_L$ gauge anomaly

⋆ realistic little Higgs models $\Longrightarrow$ *new perspective* on flavor physics

Anomaly Free Gauged $SU(N)_L \times U(1)_X$ Models :-

— with family non-universal SM embeddings

• some in the literature

— Frampton, PRL 69, 2889; Singer *et.al.*, PRD 22, 738; Pisano & Pleitez, PRD 46, 410; Foot *et.al.*, PRD 50, R34

• infinite number exist under simple construction rules !

Compatible with little Higgs ?

• *one* for $N = 3$

— *cf.* Kaplan & Schmaltz; Skiba & Terning, hep-ph/0305302

• *more* for $N = 4$ — Kaplan & Schmaltz + $\cdots\cdots$

The Construction Rules :-

- (t, b) containing Q^a as $(3, N, X_Q)$
- other quark doublets in $(3, \bar{N}, X_{Q'})$
- because $N_f = N_c \longrightarrow SU(N)_L$ anomaly cancels

by 3 N's - 6 $\bar{N}$'s + *3* family universal leptonic $(1, N, X_L)$'s

- $[SU(N)_L]^2 U(1)_X$ anomaly with correct doublet embeddings

$N_c X_Q + 2\, N_c X_{Q'} + N_f X_L = 0$

e.g. (with $N = 4$*)*

$$\mathcal{Q} = \frac{1}{2}\,\lambda^3 + \frac{A}{3}\,\lambda^8 + \frac{B}{6}\,\lambda^{15} + X$$

$\longrightarrow$ condition : $A + B + X_Q = \frac{1}{6}$ etc.

- add singlets to keep QCD & QED spectra vectorlike

See Anomaly Spreadsheets

Flavor Structure of the 331-little Higgs Model(s) :-

- top Yukawa — $y_1\,\bar{t}'_a\,\Phi_1\,Q^a + y_2\,\bar{T}'_a\,\Phi_2\,Q^a \longrightarrow y_t\,\bar{t}\,h\binom{t}{b}$
- bottom Yukawa — no $\bar{b}\,\Phi_i^\dagger\,Q^a$ but $\bar{b}\,\Phi_i^\dagger\,\Phi_j^\dagger\,Q^a$
- extra S and D may be relevant to B (b) physics

$\star$ others — may be killed by the global $SU(3)$'s

otherwise :-

— u and c Yukawa $\rightarrow 1_L\,\Phi_i\,\Phi_j\,\bar{3}_L$

— d and s Yukawa $\rightarrow 1_L\,\Phi_i^\dagger\,\bar{3}_L$

— *family universal* leptonic Yukawa $\rightarrow \ell^+\,\Phi_i^\dagger\Phi_j^\dagger\,L$

- also extra singlet neutrinos $\cdots\cdots$

Flavor Structure of new 341-little Higgs Model :-

• top Yukawa — standard

• bottom Yukawa — same as t

• Higgs sector — 2 doublets (+ singlets) with NFC (?), large tanβ
— 2 set of 2 aligned Φ's with opposite X-charges

• b-loop quadratic divergence canceled by B (as t-T)

⋆ duplicated fermion spectrum (*e.g.* U, D, C, S, also T, B)

• need the global $SU(4)$'s to suppress other Yukawa

• also extra singlet neutrinos $\cdots\cdots$

Final Remarks :-

- fermion spectra is the key

  for taking any (scalar sector) little Higgs model realistic

- $SU(N) \times U(1)$ extended EW symmetry models exist

  with little Higgs compatibility options

- fermion spectra likely to be (SM) family non-universal

— strong implications on flavor structure issues

- anomaly cancellation conditions link the 3 families

— may be a way to answer why 3 $(= N_c)$

- spectra *not* as beautiful as one-family SM (SUSY ?)

  but viable alternatives

THANK YOU !

Supplementary (Vs *T.Han's talk*) :-

- different models —

  simple models Vs littlest Higgs ($SU(5)/SO(5)$ — Georgi *et.al.*)

"The littler the Higgs the bigger the group" (S.Glashow)

K & S

- model building Vs phenomenology

  may be *"The earlier the model the less complete the physics"*

— care mainly about establishing the little Higgs mechanism

- my focus — complete (*not UV*) model(s) of TeV physics

— ? full $SU(5)$ or $SO(5)$, and gauge group, multiplets

- *survival hypothesis* Vs vectorlike fermions