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\(^1\)arXiv:1001.1361 – JAE, J. Galloway, M.A.Luty and R.A.Tacchi
\(^2\)In Progress – JAE, J. Galloway, M.A.Luty and R.A.Tacchi
Outline

Motivation

Technicolor
  The Idea
  The Problems

Minimal Conformal Technicolor
  The Idea
  The Solutions

Into the UV

Flavor
  Model I
  Model II

Phenomenology

Conclusion
The standard model of particle physics is very successful at explaining low energy physics.
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Without a Higgs, *the model predicts its own demise around a TeV*. But with a Higgs, *the electroweak scale should be dragged up to $M_{pl}$*. 

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**THE STANDARD MODEL**

<table>
<thead>
<tr>
<th>Fermions</th>
<th>Bosons</th>
</tr>
</thead>
<tbody>
<tr>
<td>$u$ up</td>
<td>$y$ photon</td>
</tr>
<tr>
<td>$c$ charm</td>
<td>$Z$ Z boson</td>
</tr>
<tr>
<td>$t$ top</td>
<td>$W$ W boson</td>
</tr>
<tr>
<td>$d$ down</td>
<td>$g$ gluon</td>
</tr>
<tr>
<td>$s$ strange</td>
<td></td>
</tr>
<tr>
<td>$b$ bottom</td>
<td></td>
</tr>
</tbody>
</table>

**Leptons**

| $e$ electron | $V_e$ electron neutrino |
| $\mu$ muon | $V_\mu$ muon neutrino |
| $\tau$ tau | $V_\tau$ tau neutrino |

**Quarks**

*Yet to be confirmed*

*Source: AAAS*
Sans Higgs contribution there are three WW scattering diagrams:

\[ \sim E^2 \]

The cross section rises as \( \frac{E^4}{M_W^4} \Rightarrow \) unitarity violation at a TeV!
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The cross section rises as $\frac{E^4}{M_W^4} \Rightarrow$ unitarity violation at a TeV!

Some *new physics* must enter to cancel this growth before a TeV

Standard model Higgs s and t channel diagrams will do exactly that
The Standard Model
The Hierarchy Problem

Higgs boson receives a mass correction from high scale physics loops

\[ \text{New Physics} \]

These corrections give \( \Delta m^2 \sim \Lambda^2_{\text{NEW PHYSICS}} \)

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For $\Lambda_{NP} \sim O(M_{pl})$ we have $O(10^{38}) - O(10^{38}) = O(10^4)$, meaning disagreement only after the 34th decimal place
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A very strong suggestion that the SM Higgs is wrong
Technicolor: The Good

One idea is Technicolor!

- $SU(N)$ gauge theories can introduce a completely natural hierarchy from the coupling constant running strong –

  \[
  \text{scale} = \Lambda_{\text{strong}} \sim \Lambda_{\text{cutoff}} e^{-\frac{8\pi^2}{bg^2(\Lambda_{\text{cutoff}})}}
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- No Dangerous Mass Scales: chiral symmetry protects masses
- Example Already Exists (sort of): the Standard Model without a Higgs should give a mass to the W and Z bosons (QCD)
Technicolor: The Bad

Technicolor sounds great, but . . .

Although it has its merits, technicolor is definitely not without problems. The worst of which:

Fig. 1. Expected range of $S$ and $T$ parameters in a general theory of electroweak symmetry breaking that is strongly coupled at the TeV scale. The reference Higgs mass is taken to be 1 TeV. The region denoted by NDA ("naive dimensional analysis") is what is expected in a general theory of strong electroweak symmetry breaking [4]. The region denoted by QCD is what is expected in a theory of scaled-up QCD [8]. The present model is similar in spirit to the early composite Higgs models, but it is based on a conformal rather than an asymptotically free gauge theory. The large coupling to the top quark is another important new ingredient in the present model.

Asymptotically free $SU(2)$ gauge theories that give rise to the symmetry breaking pattern $SU(4) \rightarrow Sp(4)$ were considered as composite Higgs theories in the second paper in Ref. [7]. Ref. [9] analyzes a version of this theory where the top quark is included and top partners are introduced to raise the scale of compositeness above the TeV scale. Ref. [10] analyzes a 5D model with the same coset, but considers a different stabilizing potential with different phenomenology. In the 5D models, the top loop contribution to the Higgs mass are also off by top partners. In the present model, the top quark contribution to the composite Higgs mass is cut off entirely by compositeness of the Higgs sector, and there is strong dynamics near the TeV scale.

The experimental signature of the top quark coupling to the symmetry breaking sector

The $S$ parameter is too large! ($S \sim \frac{M_{TC}}{3\pi}$)

Even the most generous estimates, put the theory outside of the $S$-$T$ plane ellipse.
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Fits to **Precision Electroweak Data** are awful in technicolor models

![Diagram showing the range of S and T parameters](image)

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**Evans (UCD)**  
**MCTC: Flavor**  
**October 11, 2010**  
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Technicolor: The Ugly

Fermion Masses:
- Generically, no simple mass mechanism for fermions
- Extended Technicolor (ETC) can be introduced

Low Mass Particles:
- Generic ETC models have myriad low mass PNGBs
- About as problematic as explaining absence of SUSY partners

Flavor Changing Neutral Currents (FCNCs):
- Generically ETC adds FCNCs that require extreme fine tuning
- Adding Walking TC ameliorates these

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- An $SU(2)_{CTC}$ coupling approaches a strong conformal fixed point

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**Minimal Conformal Technicolor**: A New Hope

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- Sterile technifermions get mass terms, force the coupling strong

Conformal dynamics:

- $d \equiv d(H) \lesssim 1.5$ to separate EW scale from flavor scale
- $\Delta \equiv d(H^\dagger H) \geq 4$ to evade the hierarchy problem
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Conformal dynamics:

- Need $d \equiv d(H) \lesssim 1.5$ to separate EW scale from flavor scale
- While $\Delta \equiv d(H^\dagger H) \geq 4$ to evade the hierarchy problem
In the good ol’ days, all dimensions were integer – half integer if things got really crazy!

The arguments of CTC rely on large anomalous dimensions, there exists support from both:

Theory:

Lattice:
The arguments of CTC rely on large anomalous dimensions, there exists support from both:

**Theory:** (Rattazzi, Rychkov, Tonni, Vichi 2008; Rychkov, Vichi 2009; Rattazzi, Rychkov, Vichi 2010; Poland, Simmons-Duffin 2010)

- $\Delta_M \equiv \text{Min}\{d(\mathcal{H}^\dagger \tau^a \mathcal{H}), d(\mathcal{H}^\dagger \mathcal{H})\}$ bound is very strong ($\Delta_M > 4 \Rightarrow d \geq 1.6$)
- Bounds on singlet $\mathcal{H}^\dagger \mathcal{H}$ are weak

**Lattice:**

![Graph showing continuum running](image-url)
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- Bounds on singlet \( \mathcal{H}^\dagger \mathcal{H} \) are weak

**Lattice:**

- Evidence for conformal window \( N_c = 3, 12 \lesssim N_f \lesssim 16 \)
- Measure of \( d \) \( (\text{Bursa et al. 2010}) \)
  - \( N_c = 2, N_f = 6, 1.97 \lesssim d \lesssim 2.87 \)
- S-parameter suppression! \( (\text{LSD 2010}) \)
Field Content: \((\text{SU}(2)_{CTC}, \text{SU}(2)_W)_{U(1)_Y}\)

\[
\psi \sim (2, 2)_0; \quad \chi \sim (2, 1)_{-\frac{1}{2}}; \quad \chi' \sim (2, 1)_{\frac{1}{2}}; \quad \xi \sim (2, 1)_0 \times N \sim 8
\]

\[
\mathcal{L} \ni -\kappa \psi \psi - \tilde{\kappa} \chi \chi' - K \xi \xi
\]

\[
+ \frac{g_t^2}{\Lambda_t^{d-4}} \left( Q_t^c \right)^{\dagger} (\psi \chi) + \text{h.c.}
\]

\[
+ \frac{g_{4TC}^2}{\Lambda_t^{\Delta-4}} |\psi \chi|^2 + \ldots
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Minimal Conformal Technicolor

The Model

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\[+ \frac{g_t^2}{\Lambda_t^{d-1}} (Q t^c)^\dagger (\psi \chi) + \text{h.c.}\]

\[+ \frac{g_{4TC}^2}{\Lambda_t^{\Delta-4}} |\psi \chi|^2 + \ldots\]

This mass term knocks \(SU(2)_{CTC}\) running out of its conformal fixed point
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\[+ \frac{g_{4TC}^2}{\Lambda_t^{A-4}} |\psi \chi|^2 + \ldots\]

Vacuum alignment

Fermion mass \(\propto -\cos \theta\)

Top loop, gauge, Higgs \(\propto \sin^2 \theta\)

EW vacuum is \(\theta = 0\)

TC vacuum is \(\theta = \frac{\pi}{2}\)
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The mixing angle, \(\theta\), can be small \((\sim 0.1)\)
Minimal Conformal Technicolor
Return of the TC Model

Fermion Masses?
Low Mass Particles?
FCNCs?
S-Parameter?

Natural! (through MSSM-like Higgs messenger)
A Higgs-like PNGB, \( h \), and a “hidden” PNGB, \( a \)
Suppressed by high scale!
Small \( \theta \) ⇒ small \( S \)-parameter!
Small enough to fit EW data?

▶ Top loop contribution gives:
\[ m_h \sim \sqrt{3} c_t M_{\text{top}} \]
▶ For \( c_t & \sin \theta \ll 1/4 \), model in inside the S-T EW ellipse

\[ \frac{S}{T} \]
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Fig. 4. Precision electroweak fit in the model described in the text for $m_h = 120$ GeV.
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Small enough to fit EW data?

Fig. 4. Precision electroweak fit in the model described in the text for $m_h = 120$ GeV.

We use the recent electroweak fit of Ref. [27]. Like the standard model, the present model has a single parameter (in this case $\sin \theta$) that controls the precision electroweak fit, and has a good fit for a small range of this parameter. However, the limit $\theta \ll 1$ is fine tuned, and we must be close to this limit to get a good electroweak fit. To quantify this tuning, we evaluate the sensitivity of the electroweak VEV to the technifermion mass $\kappa$, a parameter in the fundamental theory that controls the vacuum angle $\theta$. We have

$$\text{sensitivity} = \frac{d \ln v^2}{d \ln \kappa} = -\frac{2}{\tan^2 \theta}. \quad (4.16)$$

As expected, this goes as $f^2/v^2 \sim \theta^{-2}$ for small $\theta$. For $\theta \sim 0.25$ the sensitivity is $\sim -30$. The fine tuning is further reduced for smaller $m_h$. Fine tuning may be completely absent if there are additional positive contributions to the T parameter. In this case, we can allow $\sin \theta \sim 0.5$, which gives a sensitivity parameter $\sim 5$. 

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Evans (UCD)  
MCTC: Flavor  
October 11, 2010
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\[ SU(3)_{SCTC} \times SU(2)_L \times SU(2)_R \supset U(1)_Y \]
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\[
\begin{align*}
\Psi & \sim (3, 2, 1) \\
\Psi^c & \sim (\bar{3}, 1, 2) \\
\Sigma_a & \sim (3, 1, 1) \\
\Sigma^c_a & \sim (\bar{3}, 1, 1) \\
P & \sim (1, 2, 1) \\
P^c & \sim (1, 1, 2) \\
H & \sim (1, 2, 2) \\
a & = 1, \ldots, 4
\end{align*}
\]
Consider a supersymmetric theory with the following field content:

$$SU(3)_{SCTC} \times SU(2)_L \times SU(2)_R \supset U(1)_Y$$

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SU(3)_{SCTC} \times SU(2)_L \times SU(2)_R \supseteq U(1)_Y
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- \( \Psi \sim (3, 2, 1) \) → technifermions (ultimately cause EWSB)
- \( \Psi^c \sim (\bar{3}, 1, 2) \)
- \( \Sigma_a \sim (3, 1, 1) \) → sterile technifermions (break \( SU(3)_{SCTC} \), get \( N_f = 6 \) for conformal running)
- \( \Sigma^c_a \sim (\bar{3}, 1, 1) \)
- \( P \sim (1, 2, 1) \)
- \( P^c \sim (1, 1, 2) \)
- \( H \sim (1, 2, 2) \)
- \( a = 1, \ldots, 4 \)
Consider a supersymmetric theory with the following field content:

\[ SU(3)_{SCTC} \times SU(2)_L \times SU(2)_R \supset U(1)_Y \]

- \( \Psi \sim (3, 2, 1) \rightarrow \) technifermions (ultimately cause EWSB)
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- H \sim (1, 2, 2)
- a = 1, \ldots, 4

At SUSY breaking scale $\Sigma_4$ gets a VEV

$$\langle \Sigma \rangle = \langle \Sigma^c \rangle = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \nu_\Sigma \end{pmatrix}$$

$$SU(3)_{SCTC} \rightarrow SU(2)_{CTC}$$
Superconformal Technicolor

Superpotential

Superpotential terms $W \ni \Sigma \Sigma^c + (\Sigma \Sigma^c)^2$ break SCTC at the SUSY scale (and gives mass to 3rd SCTC color of $\Sigma$ terms)
Superconformal Technicolor

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$$W \ni \psi \Sigma \psi^c + \psi \Sigma^c P + \psi^c \Sigma P^c + \Sigma \Sigma \Sigma + \Sigma^c \Sigma^c \Sigma^c + \Sigma \psi \psi + \Sigma^c \psi^c \psi^c$$
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Communicates mass to SM fermions
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Masses for 3rd SCTC color (and $P$ fields)
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Communicates mass to SM fermions

Masses for 3rd SCTC color (and $P$ fields)

Masses for fermions of CTC

After SUSY breaking, we find:

$$L_{\text{eff}} \sim \xi_a\xi_b + \psi\psi + \psi^c\psi^c + |\psi\psi^c|^2 + (\psi\psi^c)^\dagger (Qt^c)$$

where $\Sigma_{1,2,3}, \Sigma_{1,2,3}^c \rightarrow \xi_a (a = 1, \ldots, 6)$
Superconformal Technicolor

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\[
W \supset \psi H \psi^c - \psi \Sigma^c P + \psi^c \Sigma P^c + \Sigma \Sigma \Sigma + \Sigma^c \Sigma^c \Sigma^c + \Sigma \psi \psi + \Sigma^c \psi^c \psi^c
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Which is almost the lagrangian for Minimal Conformal Technicolor!
Superconformal Technicolor

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\( + \lambda_a^\dagger \lambda_a \)

Which is almost the lagrangian for Minimal Conformal Technicolor!
Seiberg argued SUSY QCD with $\frac{3}{2} N_c < N_f < 3 N_c$ will flow to a SCFT. Strong fixed points expected for $N_f \approx 2 N_c$ ($N_f \approx 4 N_c$ for non-SUSY)
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- Fix large Yukawas marginal
- Neglect other superpotential terms
- Apply a-maximization

This will try to construct the theory with Yukawa fixed points.
We have: $m_{\text{top}} \sim 4\pi v_{\text{ew}} \left( \frac{y_{TC}}{4\pi} \right) \left( \frac{y_t}{4\pi} \right) \left( \frac{\Lambda_{TC}}{M_{\text{flavor}}} \right)^{d-1}$

$\Rightarrow \left( \frac{y_{TC}}{4\pi} \right) \left( \frac{y_t}{4\pi} \right) \left( \frac{\Lambda_{TC}}{M_{\text{flavor}}} \right)^{d-1} \sim \frac{1}{10}$
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We need both $y_{TC}$ and $y_t$ strong at the flavor scale!
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But \( d (H_u) > 1 \Rightarrow \) We need strong color group!

i.e. \( SU(N)_{\text{strong}} \times SU(3)_{\text{weak}} \rightarrow SU(3)_C \)
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In SM, \( N_c = 3 \) and \( N_f = 6 \Rightarrow \) No room for fields to do breaking
Flavor in the UV
That Dastardly Top!

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Two options: \( N_c > 3 \) or split the quark flavors!
Field Content of the Flavor Sector

\[(SU(6)_{SC} \times SU(3)_A \times SU(3)_B \times SU(2)_L)_{U(1)_Y}\]

\[W \ni y_{ij}^u Q_i H_u U_j^c + y_{ij}^d Q_i H_d D_j^c \]
\[+ x_{ij}^u \bar{q}_i H_d \bar{u}_j^c + x_{ij}^d \bar{q}_i H_u \bar{d}_j^c \]
\[+ z_{ij}^Q Q_i \Delta^c \bar{q}_j + z_{ij}^u U_i \Delta \bar{u}_j + z_{ij}^Q D_i \Delta \bar{d}_j \]

\[\Phi \sim (6, \bar{3}, 1, 1) \]
\[\Phi^c \sim (\bar{6}, 3, 1, 1) \]
\[\Delta \sim (6, 1, \bar{3}, 1) \]
\[\Delta^c \sim (\bar{6}, 1, 3, 1) \]
\[Q_i \sim (6, 1, 1, 2)_{1/6} \]
\[U_i^c \sim (\bar{6}, 1, 1, 1)_{-2/3} \]
\[D_i^c \sim (\bar{6}, 1, 1, 1)_{1/3} \]
\[\bar{q}_i \sim (1, 1, \bar{3}, 2)_{-1/6} \]
\[\bar{u}_i^c \sim (1, 1, 3, 1)_{2/3} \]
\[\bar{d}_i^c \sim (1, 1, 3, 1)_{-1/3} \]
Flavor with $N_c > 3$

Field Content of the Flavor Sector

$$(SU(6)_{SC} \times SU(3)_A \times SU(3)_B \times SU(2)_L)_{U(1)_Y}$$

These fields get VEVs:

$$\langle \Phi \rangle = \langle \Phi^c \rangle \propto \begin{pmatrix} 1_3 \\ 0_3 \end{pmatrix}$$

$$\langle \Delta \rangle = \langle \Delta^c \rangle \propto \begin{pmatrix} 0_3 \\ 1_3 \end{pmatrix}$$

$$\begin{align*}
\Phi & \sim (6, \bar{3}, 1, 1)_0 \\
\Phi^c & \sim (\bar{6}, 3, 1, 1)_0 \\
\Delta & \sim (6, 1, \bar{3}, 1)_0 \\
\Delta^c & \sim (\bar{6}, 1, 3, 1)_0 \\
Q_i & \sim (6, 1, 1, 2)_{1/6} \\
U^c_i & \sim (\bar{6}, 1, 1, 1)_{-2/3} \\
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\bar{q}_i & \sim (1, 1, \bar{3}, 2)_{-1/6} \\
\bar{u}^c_i & \sim (1, 1, 3, 1)_{2/3} \\
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\end{align*}$$
Flavor with $N_c > 3$

Field Content of the Flavor Sector

\[
(SU(6)_{SC} \times SU(3)_A \times SU(3)_B \times SU(2)_L)_{U(1)_Y}
\]

These fields get VEVs:

\[
\langle \phi \rangle = \langle \phi^c \rangle \propto \begin{pmatrix} 1_3 \\ 0_3 \end{pmatrix}
\]

\[
\langle \Delta \rangle = \langle \Delta^c \rangle \propto \begin{pmatrix} 0_3 \\ 1_3 \end{pmatrix}
\]

These break:

\[
SU(6)_{SC} \times SU(3)_A \times SU(3)_B \\
\rightarrow SU(3)_C \times SU(3)_{C'}
\]
Flavor with $N_c > 3$
Field Content of the Flavor Sector

$$(SU(6)_{SC} \times SU(3)_A \times SU(3)_B \times SU(2)_L)_{U(1)_Y}$$

These fields contain the SM quarks

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- $\Phi^c \sim (\bar{6}, 3, 1, 1)_0$
- $\Delta \sim (6, 1, \bar{3}, 1)_0$
- $\Delta^c \sim (\bar{6}, 1, 3, 1)_0$
- $Q_i \sim (6, 1, 1, 2)_{1/6}$
- $U^c_i \sim (\bar{6}, 1, 1, 1)_{-2/3}$
- $D^c_i \sim (\bar{6}, 1, 1, 1)_{1/3}$
- $\tilde{q}_i \sim (1, 1, \bar{3}, 2)_{-1/6}$
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Flavor with $N_c > 3$

Field Content of the Flavor Sector

$$(SU(6)_{SC} \times SU(3)_A \times SU(3)_B \times SU(2)_L)_{U(1)_Y}$$

These fields contain the SM quarks

They will be separated into:

$Q_i^{(1,...,6)} \rightarrow Q_i^{(1,2,3)} + Q_i^{(4,5,6)} \equiv q_i + q'_i$

$q_i$ are the SM quarks
Flavor with $N_c > 3$

Field Content of the Flavor Sector

$$(SU(6)_{SC} \times SU(3)_A \times SU(3)_B \times SU(2)_L)_{U(1)_Y}$$

$q'_i$ partners with the $\tilde{q}_i$ fields to create new quarks at a higher scale through interactions of the form:

$$W \ni z^{Q}_{ij} Q_i \Delta^c \tilde{q}_j$$

$$\Phi \sim (6, \bar{3}, 1, 1)_0$$
$$\Phi^c \sim (\bar{6}, 3, 1, 1)_0$$
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$q'_i$ partners with the $\tilde{q}_i$ fields to create new quarks at a higher scale through interactions of the form:

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There are twelve new quarks under $SU(3)_{C'}$:

$$\begin{align*}
\Phi & \sim (6, \bar{3}, 1, 1)_0 \\
\Phi^c & \sim (\bar{6}, 3, 1, 1)_0 \\
\Delta & \sim (6, 1, \bar{3}, 1)_0 \\
\Delta^c & \sim (\bar{6}, 1, 3, 1)_0 \\
Q_i & \sim (6, 1, 1, 2)_{1/6} \\
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\tilde{q}_i & \sim (1, 1, \bar{3}, 2)_{-1/6} \\
\tilde{u}_i^c & \sim (1, 1, 3, 1)_{2/3} \\
\tilde{d}_i^c & \sim (1, 1, 3, 1)_{-1/3}
\end{align*}$$
(SU(6)_{SC} \times SU(3)_A \times SU(3)_B \times SU(2)_L)_{U(1)_Y}

W \ni y^u_{ij} Q_i H_u U^c_j + y^d_{ij} Q_i H_d D^c_j
+ x^u_{ij} \tilde{q}_i H_d \tilde{u}^c_j + x^d_{ij} \tilde{q}_i H_u \tilde{d}^c_j
+ z^Q_{ij} Q_i \Delta^c \tilde{q}_j + z^u_{ij} U_i \Delta \tilde{u}_j + z^Q_{ij} D_i \Delta \tilde{d}_j

These give mass to the SM fermions through H communicating with the technisector

Φ \sim (6, \bar{3}, 1, 1)_0
Φ^c \sim (\bar{6}, 3, 1, 1)_0
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Flavor with $N_C > 3$

Field Content of the Flavor Sector

$$(SU(6)_{SC} \times SU(3)_A \times SU(3)_B \times SU(2)_L)_{U(1)_Y}$$

$$W \ni y^u_{ij} Q_i H_u U_j^c + y^d_{ij} Q_i H_d D_j^c$$
$$+ x^u_{ij} \tilde{q}_i H_d \tilde{u}_j^c + x^d_{ij} \tilde{q}_i H_u \tilde{d}_j^c$$
$$+ z^{Q}_{ij} Q_i \Delta^c \tilde{q}_j + z^{u}_{ij} U_i \Delta \tilde{u}_j + z^{Q}_{ij} D_i \Delta \tilde{d}_j$$

These give mass to the SM fermions through $H$ communicating with the technisector.

The give an $O(M_{SUSY})$ mass to the 12 $SU(3)_{C'}$ quarks.

Φ \sim (6, \bar{3}, 1, 1)_0
Φ^c \sim (\bar{6}, 3, 1, 1)_0
Δ \sim (6, 1, \bar{3}, 1)_0
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Qi \sim (6, 1, 1, 2)_{1/6}
Ui^c \sim (\bar{6}, 1, 1, 1)_{-2/3}
Di^c \sim (\bar{6}, 1, 1, 1)_{1/3}
\tilde{q}_i \sim (1, 1, \bar{3}, 2)_{-1/6}
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\tilde{d}_i^c \sim (1, 1, 3, 1)_{-1/3}
Suppressing Flavor Violation

Flavor looks disastrous!

Since $M \gg m, \tilde{m}$, to suppress FCNCs we need $M_X^{ij} = M_X^\delta^{ij}$. 

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Suppressing Flavor Violation

Flavor looks disastrous!

Set $M_{ij}^X \equiv z_{ij}^X \langle \Delta \rangle$
and $\tilde{m}_{ij}^X \equiv x_{ij}^X \nu$

\[
\begin{pmatrix}
  u_{1}'^c & u_{2}'^c & u_{3}'^c & \tilde{u}_1 & \tilde{u}_2 & \tilde{u}_3 \\
  u_{1}' & m_u & 0 & 0 & M_{11}^Q & M_{12}^Q & M_{13}^Q \\
  u_{2}' & 0 & m_c & 0 & M_{12}^Q & M_{22}^Q & M_{23}^Q \\
  u_{3}' & 0 & 0 & m_t & M_{13}^Q & M_{23}^Q & M_{33}^Q \\
  \tilde{u}_1 & M_{11}^U & M_{21}^U & M_{31}^U & \tilde{m}_1^U & \tilde{m}_2^U & \tilde{m}_3^U \\
  \tilde{u}_2 & M_{12}^U & M_{22}^U & M_{32}^U & \tilde{m}_1^U & \tilde{m}_2^U & \tilde{m}_3^U \\
  \tilde{u}_3 & M_{13}^U & M_{23}^U & M_{33}^U & \tilde{m}_1^U & \tilde{m}_2^U & \tilde{m}_3^U 
\end{pmatrix}
\]
Suppressing Flavor Violation

Flavor looks disastrous!

Set \( M_{ij}^X \equiv z_{ij}^X \langle \Delta \rangle \)
and \( \tilde{m}_{ij}^X \equiv x_{ij}^X \nu \)

Since \( M \gg m, \tilde{m} \), to suppress FCNCs we need \( M_{ij}^X = M^X \delta_{ij} \)
Supersymmetric Conformal Technicolor with Topcolor

The Audience: Okay, now you are just messing with us...

\[
SU(3)_{tC} \times SU(3)_{\bar{C}} \times SU(2)_L \bigg)_{U(1)_Y}
\]

\[
\begin{align*}
W & \ni y_t H_u q_3 t^c + y_b H_d q_3 b^c \\
& + (y_u)_{ij} H_u q_i u_j^c + (y_d)_{ij} H_d q_i d_j^c \\
& + z_t \Phi t^c U + z_t \Phi b^c D \\
& + (z_u)_i q_i H_u U^c + (z_d)_i q_i H_d D^c \\
& + \mu_u U U^c + \mu_d D D^c
\end{align*}
\]
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\[
\left( SU(3)_{tC} \times SU(3)_{\bar{C}} \times SU(2)_L \right)_{U(1)_Y}
\]

These fields get VEVs \( \mathcal{O}(M_{\text{SUSY}}) \):

\[
\langle \Phi \rangle = \langle \Phi^c \rangle \propto \mathbf{1}_3
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\langle \Phi \rangle = \langle \Phi^c \rangle \propto 1_3
\]

Which break $SU(3)_{tC} \times SU(3)_{\bar{C}} \rightarrow SU(3)_C$

<table>
<thead>
<tr>
<th>Field</th>
<th>Multiplet</th>
<th>Notes</th>
</tr>
</thead>
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<tr>
<td>$\Phi$</td>
<td>$(3, \bar{3}, 1)_0$</td>
<td></td>
</tr>
<tr>
<td>$\Phi^c$</td>
<td>$(\bar{3}, 3, 1)_0$</td>
<td></td>
</tr>
<tr>
<td>$q_3$</td>
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<tr>
<td>$t^c$</td>
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Supersymmetric Conformal Technicolor with Topcolor

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\[(SU(3)_{tC} \times SU(3)_{\bar{C}} \times SU(2)_L)_{U(1)_Y}\]

These are the third generation quarks charged under topcolor:

- $\Phi \sim (3, \bar{3}, 1)_0$
- $\Phi^c \sim (\bar{3}, 3, 1)_0$
- $q_3 \sim (3, 1, 2)_{1/6}$
- $t^c \sim (\bar{3}, 1, 1)_{-2/3}$
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- $d^c_i \sim (1, 3, 1)_{1/3}$
- $U \sim (1, 3, 1)_{2/3}$
- $U^c \sim (1, \bar{3}, 1)_{-2/3}$
- $D \sim (1, 3, 1)_{-1/3}$
- $D^c \sim (1, \bar{3}, 1)_{1/3}$
Supersymmetric Conformal Technicolor with Topcolor

The Audience: Okay, now you are just messing with us...

\[ \left( SU(3)_{tC} \times SU(3)_{\bar{C}} \times SU(2)_L \right)_{U(1)_Y} \]

These are the first two generations of quarks

\( i = 1, 2 \)
Supersymmetric Conformal Technicolor with Topcolor

The Audience: Okay, now you are just messing with us.

$$(SU(3)_{tC} \times SU(3)_{\bar{C}} \times SU(2)_L)_{U(1)_Y}$$

These are new high scale quarks

$\Phi \sim (3, \bar{3}, 1)_0$

$\Phi^c \sim (\bar{3}, 3, 1)_0$

$q_3 \sim (3, 1, 2)_{1/6}$

$t^c \sim (\bar{3}, 1, 1)_{-2/3}$

$b^c \sim (\bar{3}, 1, 1)_{1/3}$

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\[( SU(3)_{tC} \times SU(3)_{\bar{C}} \times SU(2)_L )_{U(1)_Y} \]

These are new high scale quarks

They have dirac masses of \( \mathcal{O}(M_{SUSY}) \)

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These are new high scale quarks

They have dirac masses of \( \mathcal{O}(M_{\text{SUSY}}) \)

Through interactions with \( t^c \) and \( b^c \), they communicate mixing between the 3rd and first two generations of quarks
Supersymmetric Conformal Technicolor with Topcolor

The Audience: Okay, now you are just messing with us...

\[
\left( SU(3)_t \times SU(3)_{\bar{t}} \times SU(2)_L \right)_{U(1)_Y}
\]

\[
W \ni \begin{aligned}
& y_t H_u q_3 t^c + y_b H_d q_3 b^c \\
+ & (y_u)_{ij} H_u q_i u_j^c + (y_d)_{ij} H_d q_i d_j^c \\
+ & z_t \Phi t^c U + z_t \Phi b^c D \\
+ & (z_u)_{i} q_i H_u U^c + (z_d)_{i} q_i H_d D^c \\
+ & \mu_u UU^c + \mu_d DD^c
\end{aligned}
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Supersymmetric Conformal Technicolor with Topcolor

The Audience: Okay, now you are just messing with us...
We have then a mass matrix of:

\[ M_u = \begin{pmatrix} u \\ t \\ U \end{pmatrix}^T \begin{pmatrix} m_u & 0 & \delta_u \\ 0 & m_t & 0 \\ 0 & \Delta_u & \mu_u \end{pmatrix} \begin{pmatrix} u^c \\ t^c \\ U^c \end{pmatrix} \]
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FCNCs suppressed since all terms mix through the very heavy $U$ or $D$.

Still, the strongly interacting tC gluon exchange puts the SUSY scale bound into the 10s of TeV range.
Finding MCTC at the LHC

Detection of this model at the LHC is difficult, but not impossible!
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We will have light $SU(2)_{CTC}$ gauginos, our global symmetry structure is

$$SU(4) \times U(1)_\lambda \rightarrow Sp(4)$$

$\Rightarrow$ 3 physical PNGBs – $h$, $a$ and $\eta$

$h$ is a composite Higgs

$\gg$ For good S-parameter, it needs to be light (120 GeV)

$\gg$ Will look just like a SM Higgs (ILC may be able to distinguish)

$a$ is a new state which is very weakly coupled to the SM

$\gg$ For a good S-parameter, it will be heavy

$m_a \sim m_h \sin \theta$

$\gg$ Decays through anomalies or into tops

$\gg$ Pair production possibly large enough if $\sigma_{TC}$ is $\mathcal{O}(\text{TeV})$

$\eta$ is a new state which is also very weakly coupled to the SM

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- Recent developments from both theory and lattice support CTC, the superconformal symmetry is essential to the model
- This is a relatively young idea with much need for model building
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The phenomenology needs to be developed more thoroughly, but there is definitely interesting new physics there

Much more work is in progress
Thank you!