IR fixed point pattern of couplings in the MSSM+1VF

with N. McGinnis, arXiv:1812.05240
and other papers with N. McGinnis, E. Lunghi and S. Shin

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Standard model

Out of 17 dimensionless parameters:

\[ \alpha_1, \alpha_2, \alpha_3, y_t, y_b, y_\tau, \lambda_h \]

only 7 couplings are sizable

all others = 0  (in the first approximation)
In the MSSM+1VF

the values of all large couplings:

\[ \alpha_1, \alpha_2, \alpha_3, y_t, y_b, y_\tau, \lambda_h \]

can be understood from the IR fixed point structure of renormalization group equations
MSSM with a complete vectorlike family

We add to the MSSM:

\[ Q, \bar{U}, \bar{D}, L, \bar{E} + \bar{Q}, U, D, \bar{L}, E \]

or \[ 16 + \overline{16} \] in SO(10) language

We consider:

- unrelated gauge couplings at the GUT scale (fundamental scale)
- unrelated Yukawa couplings at the GUT scale:
- universal Yukawa c. of vectorlike fields at the GUT scale: \( Y_V \)
- common scale for superpartners: \( M_{SUSY} \) (and zero A-terms)
- common scale for vectorlike matter: \( M_V \)

in this talk we identify the two scales: \( M_{SUSY} = M_V \equiv M \)
Big picture

GUT scale

$\sim 3 \times 10^{16}$ GeV

MSSM+1VF

few TeV

Random unrelated boundary conditions:

$\alpha_1(M_G), \alpha_2(M_G), \alpha_3(M_G) \in [0.1, 0.3]$

$y_t(M_G), y_b(M_G), y_{\tau}(M_G), Y_V(M_G) \in [1, 3]$

(larger values of couplings do not affect results significantly)

Higgs quartic given by gauge couplings at any scale:

$$\lambda_h(Q) \equiv \frac{g_2^2(Q) + (3/5)g_1^2(Q)}{4} \cos^2 2\beta$$

the plots assume: $\tan \beta = 40$
Big picture

GUT scale
\( \sim 3 \times 10^{16} \text{ GeV} \)

MSSM+1VF
few TeV

solid line are SM measured values evolved to a given scale, they include SUSY threshold corrections assuming \( \tan \beta = 40 \)

Distinctive pattern of couplings emerges
Big picture

GUT scale

\( \sim 3 \times 10^{16} \text{ GeV} \)

MSSM+1VF

few TeV

SM

EW scale

GUT: Random boundary conditions

EW: familiar pattern of couplings and masses
Predicted pattern of gauge couplings

In the MSSM+1VF:

\[ \alpha_1(M_G), \alpha_2(M_G), \alpha_3(M_G) \in [0.1, 0.3] \]

\[ M_G = 3.5 \times 10^{16} \text{ GeV}, \ M = 7 \text{ TeV} \quad \text{and} \quad \tan \beta = 40 \]

\[ \text{--- --- universal b.c.} \quad \text{--- ---} \quad \text{M optimized for } \alpha_3 \]

\[ 20\% \text{ variations of } M \quad \text{--- ---} \quad \text{and all couplings} \quad \text{--- ---} \]

\[ \alpha_i^{-1}(Q) = \frac{b_i}{2\pi} \ln \frac{M_G}{Q} + \alpha_i^{-1}(M_G) \]
Evolution of top, bottom and tau Y.c.

In the MSSM+1VF:

common IR fixed points remain good approximations for a large range of boundary conditions

very effective IR fixed point behavior
Predicted pattern of fermion masses

In the MSSM+1VF:

\[ \alpha_1(M_G), \alpha_2(M_G), \alpha_3(M_G) \in [0.1, 0.3], \ y_t(M_G), y_b(M_G), y_\tau(M_G), Y_V(M_G) \in [1.3] \]

\[ M_G = 3.5 \times 10^{16} \text{ GeV}, \ M = 7 \text{ TeV} \text{ and } \tan \beta = 40 \]

- - - universal b.c. \quad \text{\textcolor{orange}{\quad Y_V optimized for $m_t$}}

20% variations of $M$ and all couplings

SUSY corrections at $M$ assume all superpartners at the same scale, zero A-terms and $\mu = -\sqrt{2}M_{\text{SUSY}}$ for top-bottom-tau Yukawa c. unification, see the talk of N. McGinnis
In the MSSM+1VF

For large range of b.c. there is a narrow range of $M$ within which all the couplings in the MSSM+1VF meet the corresponding parameters in the SM:
Optimizing parameters related to scales

For random unrelated (or unified) parameters:

\[ \alpha_1(M_G), \alpha_2(M_G), \alpha_3(M_G) \in [0.1,0.3] \]
\[ y_t(M_G), y_b(M_G), y_\tau(M_G), Y_V(M_G) \in [1,3] \]

three parameters,

\[ M_G, M, \tan \beta, \]

can be optimized so that none of the seven observables is more than 25% (or 15%) from the measured values.

Further optimizing \( Y_V \) to obtain the required overall scale of Yukawa couplings, all 7 observables are within 11% (or 7.5%) from their measured values.
Combined signatures of heavy Higgses and vectorlike fermions
Heavy Higgses in vectorlike quark decays

Large (QCD) production rates:

\[ gg \rightarrow t_4 t_4 \]
\[ t_4 \rightarrow H t , H^\pm b \]

\[ gg \rightarrow b_4 b_4 \]
\[ b_4 \rightarrow H b , H^\pm t \]

even tiny couplings that mix VQ with SM quarks make them decay, and decays through heavy Higgses easily dominate especially at large \( \tan \beta \)

close to 100% BRs to heavy Higgses, final states: 6t, 4t2b, 2t4b, 6b

Conclusions

In the MSSM+1VF with vectorlike matter and superpartners at a multi-TeV scale:

\[ \alpha_1, \alpha_2, \alpha_3, y_t, y_b, y_\tau, \lambda_h \]

can be understood from the IR fixed point structure of the RGEs

- just one example, similar scenarios might have other interesting features and consequences
- 1st and 2nd generations? \( \rightarrow \) different models for fermion masses
- motivation for more complex UV embeddings besides simple SU(5) or SO(10), e.g. Pati-Salam, flipped SU(5), …
- part of the spectrum might be within the reach of LHC and combined signatures of heavy Higgses and VQ and VL are very promising