Yukawa Unification in SUSY SO(10) GUT

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based on the work with Marek Olechowski and Stefan Pokorski

preliminary results
For a given generation all matter fermions, including $\nu_R$, sit in one 16 dim. representation of SO(10).

Both MSSM Higgs doublets are in the 10 dim. representation of SO(10).

Yukawa interactions are given by

$$W = h_{16 \ 10 \ 16}$$

which imply unification of $t - b - \tau$ Yukawa coupling at $M_{\text{GUT}}$. 
Explaining $(g - 2)_\mu$ anomaly and Yukawa unification

Yukawa unification prefers $\mu < 0$ but usually $\mu > 0$ is considered.

Why?

$(g - 2)^{SM}_\mu$ more than $3\sigma$ below experimental value.

$(g - 2)^{SUSY}_\mu \sim \text{sgn}(\mu M_2) \Rightarrow (g - 2)_\mu$ prefers $\mu > 0$ for universal gaugino masses

but

Universal gaugino masses are not obligatory in SUSY GUTs

Our Strategy

Consider $\mu < 0$ and non-universal gaugino masses with $M_2 < 0$
The model

\[ \mu < 0 \]

- **Non-universal scalar masses:**
  \[
  m_{H_d}^2 = m_{10}^2 + 2D \\
  m_{H_u}^2 = m_{10}^2 - 2D \\
  m_{Q,U,E}^2 = m_{16}^2 + D \\
  m_{D,L}^2 = m_{16}^2 - 3D
  \]

- **Non-universal gaugino masses generated by** $F$-term transforming as **54** dim. representation of $SO(10)$:
  \[
  M_1 = -\frac{1}{2}m_{1/2} \\
  M_2 = -\frac{3}{2}m_{1/2} \\
  M_3 = m_{1/2}
  \]

- **Universal trilinear couplings:** $A_U = A_D = A_E = A_0$
  
  5 parameters + $\tan \beta$
Methodology

The soft SUSY breaking masses are imposed at the GUT scale and run down to the electroweak scale with RGE code SOFTSUSY. We impose the condition of REWSB, neutral LSP, particle mass bounds and the experimental constraints for the following observables:

- the relic abundance of dark matter $\Omega_{DM} h^2$
- $a_\mu \equiv (g-2)_\mu/2$
- $\text{BR}(b \to s\gamma)$
- $\text{BR}(B_s \to \mu^+ \mu^-)$

which we calculate using MicrOMEGAs.

We have performed random scan for the following ranges of parameters:

\begin{align*}
0 \leq m_{16} &\leq 2000 \text{ GeV} & 0.1 \leq m_{10}/m_{16} &\leq 2 & -3 \leq A_0/m_{16} &\leq 3 \\
0 \leq m_{1/2} &\leq 2000 \text{ GeV} & 0 \leq D/m_{16}^2 &\leq 0.3 & 40 \leq \tan \beta &\leq 55
\end{align*}
Yukawa unification ($R \approx 1$) can be obtained for a very wide ranges of parameters but majority of points with good yukawa unification excluded by $b \to s\gamma$. 
Strong correlation between $(g - 2)_\mu$ and $b \to s\gamma$

For the points not excluded by $b \to s\gamma$, $(g - 2)_\mu$ typically very small

How to disentangle $(g - 2)_\mu$ from $b \to s\gamma$?

We have identified 2 classes of solutions with good yukawa unification, consistent with all the experimental constraints (including $b \to s\gamma$) with large SUSY contribution to $(g - 2)_\mu$
Solution 1

- **Large $D$-terms** to push up $m_{H^\pm}$ and suppress Higgs contribution to $BR(b \to s\gamma)$
- $A_t \approx 0$ at $M_{EW}$ (this require large positive $A$-terms at $M_{GUT}$) to suppress chargino-stop mixing contribution to $BR(b \to s\gamma)$ without suppressing chargino contribution to $(g - 2)_\mu$
- Bino-like LSP with the relic abundance satisfying WMAP bound due to stau coannihilations

$(g - 2)_\mu$ within 2σ from exp. value (1σ relaxing Higgs mass bound)
Solution 2

- $m_{1/2} \ll m_{16} \Rightarrow$ light gluinos (500-700 GeV)
- Large chargino mixing ($M_2 \approx \mu$ at $M_{EW}$) which results in negative chargino contribution to $\text{BR}(b \to s\gamma)$
- Bino-like LSP with non-negligible higgsino component which allows for resonant annihilations through $h^0$ or $Z$ bosons

$(g - 2)_{\mu}$ within $2\sigma$ from exp. value
   ($1\sigma$ relaxing Higgs mass bound)
Yukawa coupling unification in SUSY SO(10) consistent with all the phenomenological constraints is much more natural for $\mu < 0$.

- Proper REWSB requires non-universal scalar masses at $M_{\text{GUT}}$ which is generic in the SO(10) GUT $\rightarrow D$-term splitting, RG running between $M_{\text{Pl}}$ and $M_{\text{GUT}}$
- Non-universal gaugino masses with $M_2 < 0$, as required by $(g-2)_\mu$ constraint, can be generated by the $F$-term in 54 rep. of SO(10)
- $(g-2)_\mu$ can be disentangled from $b \rightarrow s\gamma$ and compatible with the experimental value at $1\sigma$ level. Upper limit for $(g-2)_\mu$ is set by the LEP bound on $m_{h^0}$.

Yukawa unification in SO(10) with light SUSY spectrum:

Light gluinos for the early LHC
Backup slides
Solution 1: typical spectrum

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Solution 2: typical spectrum

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Sources of non-universal scalar masses

**RG running from the Planck scale**

In gravity mediation soft SUSY breaking terms are supposed to be generated around $M_{Pl}$.

Running from the Planck scale to the GUT scale splits 10 and 16. We parameterize this effect by setting $m_{10}$ for Higgses and $m_{16}$ for squarks at $M_{GUT}$.

**D-term contribution**

When the gauge symmetry is broken and its rank is reduced, soft scalar masses acquire new contribution from $D$-terms of the broken U(1) which is proportional to charges of the broken U(1).

For $SO(10) \rightarrow G_{SM}$:

\[
\begin{align*}
    m_{H_d}^2 &= m_{10}^2 + 2D \\
    m_{H_u}^2 &= m_{10}^2 - 2D \\
    m_{Q,U,E}^2 &= m_{16}^2 + D \\
    m_{D,L}^2 &= m_{16}^2 - 3D
\end{align*}
\]
Gaugino masses in SUGRA can arise from dimension 5 operator:

\[ \mathcal{L} \supset - \frac{F^{ab}}{2M_{\text{Planck}}} \lambda^a \lambda^b + \text{c.c.} \]

\[ \langle F^{ab} \rangle \] must transform as a singlet under the SM gauge group but can be in a non-singlet representation of SO(10)

Non-zero gaugino masses arise from \( F^{ab} \) representations in the symmetric part of the direct product of the adjoint representation:

\[
(45 \times 45)_S = 1 + 54 + 210 + 770
\]

If \( \langle F^{ab} \rangle \) transforms as 54, gaugino masses are determined by:

\[
M_1 : M_2 : M_3 = -\frac{1}{2} : -\frac{3}{2} : 1
\]

\( M_2 < 0 \Rightarrow \mu < 0 \) can be consistent with \((g - 2)_\mu\) constraint!

\[ \text{Martin, 2009} \]