Messenger Yukawa Alignment and Misalignment in Flavored Gauge Mediated Supersymmetry Breaking Models with Higgs-Messenger Multiplets

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PHENO2014

Based on: L. Everett and T. Garon, 1405.xxxx

The standard Minimal GMSB lore

Introduce pairs of $\mathbf{5}$ and $\bar{\mathbf{5}}$ of SU(5), which develop a vev, M, and an F-term vev, F. When they integrate out, at M, we get gaugino masses at one loop and scalar mass squareds at two loops proportional to $\frac{1}{(4\pi)^2}\frac{F}{M}$ and $\frac{1}{(4\pi)^4}\frac{F^2}{M^2}$.

We like it because:

- Flavor blind
- Not super sensitive to UV physics
- Possibly low scale

But A-terms are suppressed and so it's difficult to get the Higgs mass high enough with light superpartners.

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[0] Dine, Nelson, Shirman 1995; Dine, Nelson, Nir, Shirman 1996; Giudice and Rattazzi 1998; and many others

The newer FGM lore

We can think about a **5** as really a **3** and a **2**, with the **2** having the same quantum numbers as an MSSM Higgs.

We couple the **2**s to matter supermultiplets through Yukawa couplings. These new couplings are parametrically aligned with the MSSM couplings and the messengers develop vevs just like in gauge mediation.

When the messengers integrate out we get gaugino masses at one loop, soft scalar mass squareds at two loops with corrections to the soft masses proportional to the messenger Yukawa couplings.

A terms are now generated at one loop because the messenger-Higgs can talk to directly to matter.

[0] Recently: Shadmi and Szabo 2012, Abdullah et. al 2012, Evans and Shih 2013

Putting flavor in FGM models

We want to control these couplings.

We were inspired by some work by Perez, Ramond and Zhang (1209.6071) which placed the SU(2) doublet messenger and the electroweak Higgs doublet into a multiplet of some family symmetry $\mathcal{G}_F$. They found that through breaking this family symmetry they could get patterns where the messenger Yukawas are misaligned. (Caveats: 2 Families, B/μ problem,...)

Let's introduce a family symmetry $\mathcal{G}_F$ of the form

$$\mathcal{G}_F = \mathcal{G}_f \otimes \mathcal{G}_h \quad (1)$$

where $\mathcal{G}_f$ is some traditional family symmetry and $\mathcal{G}_h$ controls our Higgs multiplets. We take $\mathcal{G}_h = \mathcal{S}_3$ for concreteness.

[0] Perez, Ramond, Zhang 2012

The Yukawa sector

We introduce $\mathcal{G}_h$ multiplets $\mathcal{H}_u$ and $\mathcal{H}_d$ like

$$\mathcal{H}_u = \begin{pmatrix} \mathcal{H}_{u1} \\ \mathcal{H}_{u2} \end{pmatrix} = \mathcal{R}_u \begin{pmatrix} H_u \\ \Phi_u \end{pmatrix}, \quad \mathcal{H}_d = \begin{pmatrix} \mathcal{H}_{d1} \\ \mathcal{H}_{d2} \end{pmatrix} = \mathcal{R}_d \begin{pmatrix} H_d \\ \Phi_d \end{pmatrix} \tag{2}$$

and flavons $\{\phi, \Delta^{(1)}, \Delta^{(2)}\}$ charged under $\mathcal{G}_h$ giving rise to the nonrenormalizable superpotential

$$W_Y = \frac{1}{\Lambda} y_u Q\overline{u}(\phi\mathcal{H}_u) + \frac{1}{\Lambda} y_d Q\overline{d}(\phi\mathcal{H}_d) + \frac{1}{\Lambda} y_e L\overline{e}(\phi\mathcal{H}_d) \tag{3}$$

leading to effective couplings

$$\begin{aligned} W_Y = {} & Y_u Q\overline{u}H_u + Y_d Q\overline{d}H_d + Y_e L\overline{e}H_d \\ & + Y'_u Q\overline{u}\Phi_u + Y'_d Q\overline{d}\Phi_d + Y'_e L\overline{e}\Phi_d \end{aligned} \tag{4}$$

The Higgs/Messenger sector and the μ/B_μ problem

We assume Higgs/messenger couplings like

$$W_H = \lambda_{\mathbf{1}}\Delta^{(1)}(\mathcal{H}_u\mathcal{H}_d) + \lambda_{\mathbf{2}}(\Delta^{(2)}\mathcal{H}_u\mathcal{H}_d) \quad (5)$$

where at some high scale $\left\langle \lambda_2\Delta^{(2)} \right\rangle = v \begin{pmatrix} \sin\vartheta \\ \cos\vartheta \end{pmatrix} + \theta^2 F \begin{pmatrix} \sin\rho \\ \cos\rho \end{pmatrix}$.
We can rewrite as

$$= \mathcal{H}_u \mathbb{M} \mathcal{H}_d + \theta^2 \mathcal{H}_u \mathbb{F} \mathcal{H}_d \quad (6)$$

where we've imposed $[\mathbb{M}, \mathbb{F}] = 0$ to suppress one loop graphs.

B/μ problem solved by fine-tuning things such that $\det \mathbb{F} \sim 0$.

An example, $\mathcal{G}_F = \underbrace{\mathcal{A}_4 \times \mathcal{A}_4}_{\mathcal{G}_f} \times \underbrace{\mathcal{S}_3}_{\mathcal{G}_h}$

The Yukawas are a function of the flavon couplings and vevs $\langle \phi \rangle$, and the Higgs rotations.

Aligned Yukawas:

$$Y_u \sim \begin{pmatrix} 0 & & \\ & 0 & \\ & & 1 \end{pmatrix}, \qquad Y_u' \sim \begin{pmatrix} 0 & & \\ & 0 & \\ & & 1 \end{pmatrix}. \tag{7}$$

We could also get misaligned models with Yukawas like

$$Y_u \sim \begin{pmatrix} 0 & & \\ & 0 & \\ & & 1 \end{pmatrix}, \qquad Y_u' \sim \begin{pmatrix} 1 & & \\ & 1 & \\ & & 0 \end{pmatrix} \tag{8}$$

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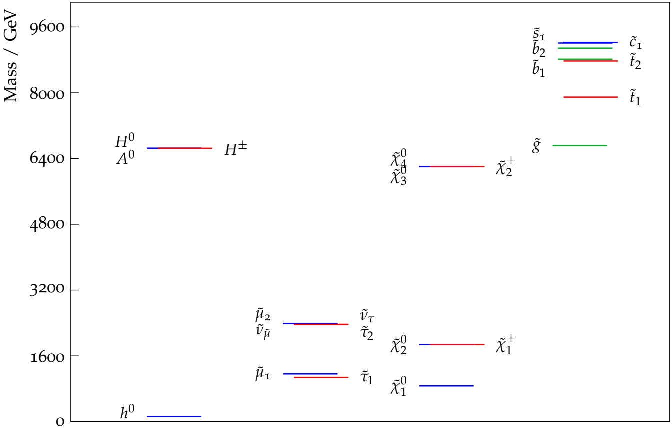
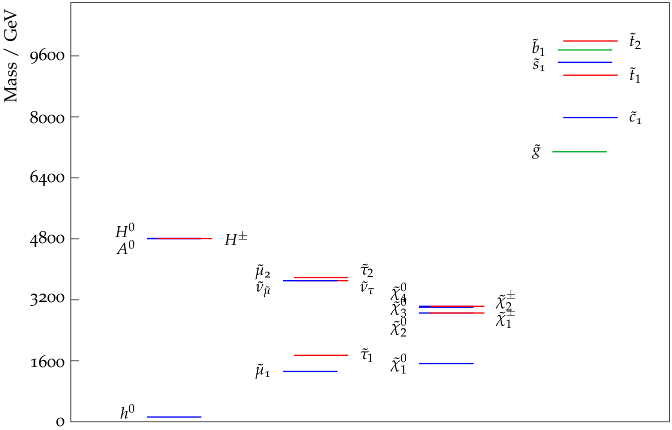
[0] The misaligned model is like in Perez, Ramond, Zhang 2012.

An aligned spectra



Aligned spectra at $M = 10^6$ GeV, $\frac{F}{M} = 3 \times 10^5$, $N = 1$, and $\tan\beta = 10$.

A misaligned spectra



Seesaw spectra at $M = 10^6$ GeV, $\frac{F}{M} = 1.1 \times 10^6$, $N = 1$, and $\tan\beta = 10$.

Phenomenology

Aligned models tend to

- large corrections to the stop squark
- sneutrino NLSP
- $\frac{F}{M}$ can change radically depending on the size of the messenger Yukawas producing different spectra

Misaligned models

- look more like minimal GMSB
- large corrections to the first two generation masses
- slepton NLSP
- scharm tends to be the lightest squark.

Conclusions and future directions

We've seen that FGM models are attractive in light of the measurement of the Higgs mass. They can be extended by thinking about adding family symmetries of the form $\mathcal{G}_F = \mathcal{G}_f \otimes \mathcal{G}_h$, to give us control over the messenger Yukawa couplings. These new models can have distinct spectra, like our misaligned model, and seem to be okay with flavor bounds at lowest order.

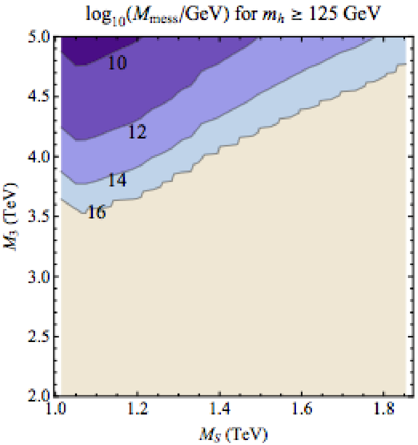
We are still at the beginning stages though. . .

Thanks!

Questions?

Extra slides

Why we need large A-terms



If A-terms are initially negligible then we need high scales to get the Higgs mass right in minimal GMSB models with light stops.

[0]From Draper et. al. 2011

Charges in the $\mathcal{A}_4 \times \mathcal{A}_4 \times \mathcal{S}_3$ model

	Q	$\bar{u}$	$\bar{d}$	L	$\bar{e}$	$\mathcal{H}_{u/d}$	ϕ	Δ_1	Δ_2	$T_{3u/d}$
$\mathcal{A}_4$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$
$\mathcal{A}'_4$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$
$\mathcal{S}_3$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$
$U(1)_R$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0	0	0	1
$\mathcal{Z}_7$	ω^3	ω	ω	ω^3	ω	ω^6	ω^4	ω^2	ω^2	ω^2
$\mathcal{Z}_3$	ω^2	ω	ω	ω^2	ω	1	1	1	1	1