Exploring Grand Unification Scenarios

A.P. Morais[1] D.J. Miller[1]

[1]School of Physics and Astronomy
University of Glasgow, Scotland, UK

August 14, 2012

Supersymmetry 2012, Peking University, Beijing

University of Glasgow

Introduction: *The Idea of Grand Unification*

- The Standard Model of Strong and Electroweak interactions is described by the gauge group $G_{SM} = SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$
- The main idea is to embed G_{SM} into a larger simple group
  - $SU(N)$, $SO(2N)$, $SO(2N+1)$, Sp_{2N}, G_2, F_4, E_6, E_7, E_8
- We will consider standard $SU(5)$ and $SO(10)$ candidates

Our Aim

- Most of current work assuming (unjustified) universal parameters at the GUT scale (cMSSM)
  - Hard to get viable points (125 GeV Higgs, light stops, dark matter relic density...)
  - Highly fine tuned
  - Some work done for non-universal gauginos [Caron et. al., 1202.5288]
- **We show that it is possible to get plenty of viable points with non-universal $\mathbf{SU(5)}$ masses, keeping universal gauginos**
  - $m_{\overline{5}}$, m_{10}, $m_{\overline{5}'}$ and $m_{5'}$ instead of a single m_0

University of Glasgow

$SU(5)$ embedding of G_{SM}: *The* $\overline{\mathbf{5}} \oplus \mathbf{10}$, $\mathbf{5}'$ *and* $\overline{\mathbf{5}}'$ *reps*

- The matter content of G_{SM} is unified in a $\overline{\mathbf{5}} \oplus \mathbf{10}$
- The two Higgs $SU(2)$ doublets are unified in a $\mathbf{5}'$ and a $\overline{\mathbf{5}}'$
  - Doublet-triplet splitting problem assumed to be solved by some mechanism (e.g. orbifold compactification) [Kawamura, 0012125]

The $\overline{\mathbf{5}}$ superpartners

$$\overline{\mathbf{5}} \to (\mathbf{1},\mathbf{2})_{-\frac{1}{2}} \oplus \left(\overline{\mathbf{3}},\mathbf{1}\right)_{\frac{1}{3}} = \widetilde{L} \oplus \widetilde{d}_R^*$$

The $\mathbf{10}$ superpartners

$$\mathbf{10} \to (\mathbf{1},\mathbf{1})_1 \oplus \left(\overline{\mathbf{3}},\mathbf{1}\right)_{-\frac{2}{3}} \oplus (\mathbf{3},\mathbf{2})_{\frac{1}{6}} = \widetilde{e}_R^* \oplus \widetilde{u}_R^* \oplus \widetilde{Q}_L$$

The $\mathbf{5}'$ Higgs

$$\mathbf{5}' \to (\mathbf{1},\mathbf{2})_{\frac{1}{2}} \oplus \left(\mathbf{3},\mathbf{1}\right)_{-\frac{1}{3}} = H_u \oplus (T_u)$$

The $\overline{\mathbf{5}}'$ Higgs

$$\overline{\mathbf{5}}' \to (\mathbf{1},\mathbf{2})_{-\frac{1}{2}} \oplus \left(\overline{\mathbf{3}},\mathbf{1}\right)_{\frac{1}{3}} = H_d \oplus (T_d)$$

$SO(10)$ embedding of G_{SM}: *The* $\mathbf{16}$ *and* $\mathbf{10}$ *reps*

Maximal subalgebra of $SO(10)$

$SO(10) \to SU(5) \otimes U(1)_x$

$\mathbf{16}$ and $\mathbf{10}$ branching rules

$\mathbf{10} \to \mathbf{5}_2 \oplus \overline{\mathbf{5}}_{-2}$
$\mathbf{16} \to \mathbf{10}_{-1} \oplus \overline{\mathbf{5}}_3 \oplus \mathbf{1}_{-5}$

From the branching rules of $SU(5)$ down to G_{SM} we see that:

- $\mathbf{10}$ contains the $SU(5)$ Higgs doublets and the colored Higgs triplets
- $\mathbf{16}$ contains the full $SU(5)$ superpartners and an extra singlet $\mathbf{1}_5$
- Extra abelian gauge group $U(1)_x$

Right handed neutrino/sneutrino

$\mathbf{1}_5 \to (\mathbf{1},\mathbf{1})_{(0,\ 5)} = \tilde{N}_R$

- **A $SO(10)$ GUT naturally contains a right-handed neutrino/sneutrino**

University of Glasgow

Soft Supersymmetry Breaking Terms

- If SUSY exists it has to be an exact symmetry spontaneously broken (SSB) in a **Hidden sector** [Martin, 9709356]
- Many breaking scenarios proposed
- Parametrize the unknown realistic scenario of SSB
  - Introduce terms that explicitly break supersymmetry
  - Couplings should be of positive mass dimensions $\longrightarrow$ **renormalizable theory**, and given at the **low scale**
  - **SOFT TERMS**

Generic soft SUSY Lagrangian

$$\mathscr{L}_{soft} = -\left(\frac{1}{2}M_{ab}\lambda^a\lambda^b + \frac{1}{6}a^{ijk}\phi_i\phi_j\phi_k + \frac{1}{2}b^{ij}\phi_i\phi_j + t^i\phi_i\right) + h.c. - \left(m^2\right)^i{}_j\phi^{j*}\phi_i$$

University of Glasgow

Higgs and Sfermion Soft Masses: *1-Loop RGE example*

Third Generation and Higgs Soft Masses RGE

$$16\pi^2 \frac{dm^2_{\tilde{Q}_3}}{dt} = X_t + X_b - \frac{32}{3}g_3^2M_3^2 - 6g_2^2M_2^2 - \frac{2}{15}g_1^2M_1^2 + \frac{1}{5}g_1^2S$$
$$16\pi^2 \frac{dm^2_{\tilde{t}_R}}{dt} = 2X_t - \frac{32}{3}g_3^2M_3^2 - \frac{32}{15}g_1^2M_1^2 - \frac{4}{5}g_1^2S$$
$$16\pi^2 \frac{dm^2_{\tilde{b}_R}}{dt} = 2X_b - \frac{32}{3}g_3^2M_3^2 - \frac{8}{15}g_1^2M_1^2 + \frac{2}{5}g_1^2S$$
$$16\pi^2 \frac{dm^2_{\tilde{L}_3}}{dt} = X_\tau - 6g_2^2M_2^2 - \frac{6}{5}g_1^2M_1^2 - \frac{3}{5}g_1^2S$$
$$16\pi^2 \frac{dm^2_{\tilde{\tau}_R}}{dt} = 2X_\tau - \frac{24}{5}g_1^2M_1^2 + \frac{6}{5}g_1^2S$$
$$16\pi^2 \frac{dm^2_{\tilde{N}_3}}{dt} = 2X_\nu$$
$$16\pi^2 \frac{dm^2_{H_d}}{dt} = 3X_b + X_\tau - 6g_2^2M_2^2 - \frac{6}{5}g_1^2M_1^2 - \frac{3}{5}g_1^2S$$
$$16\pi^2 \frac{dm^2_{H_u}}{dt} = 3X_t + X_\tau - 6g_2^2M_2^2 - \frac{6}{5}g_1^2M_1^2 + \frac{3}{5}g_1^2S$$

- $X_t = 2y_t^2\left(m^2_{H_u} + m^2_{\tilde{Q}_3} + m^2_{\tilde{t}_R} + A_t^2\right)$
- $X_b = 2y_b^2\left(m^2_{H_d} + m^2_{\tilde{Q}_3} + m^2_{\tilde{b}_R} + A_b^2\right)$
- $X_\tau = 2y_\tau^2\left(m^2_{H_d} + m^2_{\tilde{L}_3} + m^2_{\tilde{\tau}_R} + A_\tau^2\right)$
- $X_\nu = 2y_\nu^2\left(m^2_{H_u} + m^2_{\tilde{L}_3} + m^2_{\tilde{N}_3} + A_\nu^2\right)$
- $a_i = y_iA_i$

- S is a D-term contribution
  - $S \equiv Tr(Ym^2) = m^2_{H_u} - m^2_{H_d} + \sum_{generations}\left(m^2_{\tilde{Q}_L} - 2m^2_{\tilde{u}_R} + m^2_{\tilde{d}_R} - m^2_{\tilde{L}_L} + m^2_{\tilde{e}_R}\right)$
  - $\frac{dS}{dt} = \frac{66}{5}\frac{\alpha_1}{4\pi}S \Rightarrow S(t) = S(t_G)\frac{\alpha_1(t)}{\alpha_1(t_G)}$

Standard CMSSM or mSUGRA Boundary Conditions

- Common scalar mass: $m^2_{\tilde{Q}_L}(t_G) = m^2_{\tilde{u}_R}(t_G) = m^2_{\tilde{d}_R}(t_G) = m^2_{\tilde{L}_L}(t_G) = m^2_{\tilde{e}_R}(t_G) = \mathbf{m_0^2}$
- Common Higgs mass: $m^2_{H_u}(t_G) = m^2_{H_d}(t_G) = (\mathbf{m_0^2} + \mu^2)$
- Since $S(t_G) = 0$, then $S(t)$ is identically 0 at all scales
- Common gaugino mass: $M_1^2(t_G) = M_2^2(t_G) = M_3^2(t_G) = \mathbf{M_{1/2}^2}$
- Common trilinear coupling: $a_t(t_G) = a_b(t_G) = a_\tau(t_G) = \mathbf{a_0}$
- Universal generations: $m_0^{(1,2,3)} = \mathbf{m_0}$
- **Left with 5 unkown parameters:** $\tan\beta,\ \mathbf{sign}(\mu),\ \mathbf{m_0},\ \mathbf{M_{1/2}},\ \mathbf{a_0}$

University of Glasgow

$SU(5)$ Grand Unification: *Boundary Conditions*

- Why universal soft terms? $\rightarrow$ **Simple and clean solutions**
- However $\rightarrow$ **Not clear which mechanism breaks SUSY**
  - Soft parameters highly (SUSY breaking) model dependent
  - **No reason for universal $\mathbf{M_{1/2}}$, $\mathbf{A_0}$, $\mathbf{m_0}$ ...**

Common $m_{\mathbf{10}}$ for matter in a $\mathbf{10}$

$$m^2_{\tilde{Q}_L}(t_G) = m^2_{\tilde{u}_R}(t_G) = m^2_{\tilde{e}_R}(t_G) = m^2_{\mathbf{10}}$$

Common $m_{\bar{\mathbf{5}}}$ for matter in a $\bar{\mathbf{5}}$

$$m^2_{\tilde{L}_L}(t_G) = m^2_{\tilde{d}_R}(t_G) = m^2_{\bar{\mathbf{5}}}$$

Higgs soft masses unrelated

$m^2_{H_u}(t_G) = m^2_{\mathbf{5}'}$ and $m^2_{H_d}(t_G) = m^2_{\bar{\mathbf{5}}'}$

S-term non zero

$$S(t_G) = m^2_{\mathbf{5}'} - m^2_{\bar{\mathbf{5}}'}$$

Decoupling generations

No reason for universal masses/trilinears within different generations

$$m_{\bar{5}}^{(1,2)} = K_{\bar{5}}\, m_{\bar{5}}^{(3)}$$
$$m_{10}^{(1,2)} = K_{10}\, m_{10}^{(3)}$$
$$1 \leq K_{\mathbf{R}} \leq 10$$

Trilinear couplings $(a_i \equiv y_i A_i)$

$$a_u H_u \tilde{u}_R \tilde{Q}_L \xrightarrow{SU(5)} a_{\bar{5}'}\, \mathbf{\bar{5}'} \cdot \mathbf{10} \cdot \mathbf{10}$$
$$a_d H_d \tilde{d}_R \tilde{Q}_L \xrightarrow{SU(5)} a_{5'}\, \mathbf{5'} \cdot \mathbf{\bar{5}} \cdot \mathbf{10}$$
$$a_e H_d \tilde{e}_R \tilde{L} \xrightarrow{SU(5)} a_{5'}\, \mathbf{5'} \cdot \mathbf{10} \cdot \mathbf{\bar{5}}$$

At GUT scale: $a_{u0} = a_{\bar{5}'}$ and $a_{d0} = a_{e0} = a_{5'}$

Gauginos (adjoint rep): $\mathscr{L}_{G-K} = -\frac{1}{M_p} F_{ab} \lambda^a \otimes \lambda^b \xrightarrow{\langle F_{ab} \rangle} M_{ab} \lambda^a \lambda^b$

$\mathbf{24} \otimes \mathbf{24} = \mathbf{1} \oplus \mathbf{24} \oplus \mathbf{75} \oplus \mathbf{200}$

Universal $M_{1/2}$ at GUT scale only if $F_{ab} \in \mathbf{1} \rightarrow F_{ab} = F_0 \delta_{ab} \rightarrow \langle F_{ab} \rangle = F_0$

If $F_{ab} \in \mathbf{24}, \mathbf{75}, \mathbf{200}$ or combinations $\longrightarrow$ non-universal gaugino mass

19 FREE PARAMETERS

$\mathbf{m^i_{\bar{5}}}$, $\mathbf{m^i_{10}}$, $\mathbf{M^{\alpha}_{1/2}}$, $\mathbf{m_{\bar{5}'}}$, $\mathbf{m_{5'}}$, $\mathbf{a^i_{\bar{5}'}}$, $\mathbf{a^i_{5'}}$, $\tan\beta$, $\mathbf{sign}(\mu)$

$\alpha, i = 1,2,3$

University of Glasgow

$SU(5)$ Parameter Space Scan: *Strategy*

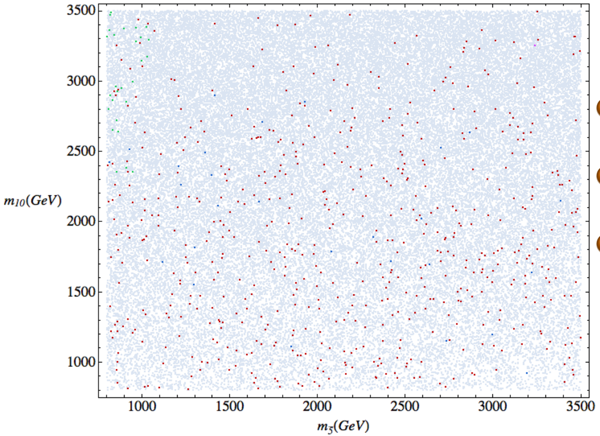
1. Universal trilinear couplings $\mathbf{a_0}$, universal gauginos $\mathbf{M_{1/2}}$ and universal generations $\mathbf{m_{\bar{5}}}$ and $\mathbf{m_{10}}$
   - **8 free parameters**
2. $SU(5)$ trilinear couplings $\mathbf{a_{\bar{5}'}}$, $\mathbf{a_{5'}}$, universal gauginos $\mathbf{M_{1/2}}$ and non-universal generations $\mathbf{m_{\bar{5}}^{(1,2)}} = \mathbf{K_{\bar{5}}\ m_{\bar{5}}^{(3)}}$, $\mathbf{m_{10}^{(1,2)}} = \mathbf{K_{10}\ m_{10}^{(3)}}$
   - $1 \leq K_{\mathbf{R}} \leq 10$
   - **11 free parameters (first and second generation trilinears negligible)**

Low Scale Constraints

- Higgs mass: $m_{h^0} \in [122.6\ ,\ 127.0]$ GeV (ATLAS + CMS)
- First and second generation sfremions: $m_{\tilde{f}_{1,2}} > 1.4$ TeV (ATLAS + CMS)
- Gluino mass: $M_{\tilde{g}} > 800$ GeV (ATLAS + CMS)
- $4 \leq \tan\beta \leq 30$
- $sign(\mu) = +$
- Dark matter relic density: $0.0941 < \Omega h^2 < 0.131$ (WMAP)

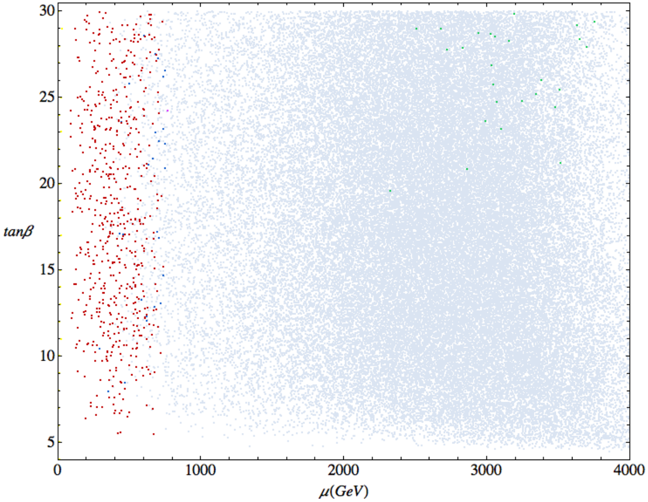
- Spectrum calculator: SOFTSUSY (v3.3.0)
  - 2-loop RGE and 2-loop radiative corrections
- Relic density calculator: micrOMEGAs (v2.4.5)

$(m_{\overline{5}}\ ,\ m_{10})$ - Plane Scan: Scenario 1



1. Blue points: $\tilde{\chi}_1^0$ DM within RD bounds
2. Red points: $\tilde{\chi}_1^0$ DM with RD below bounds
3. Light blue points: $\tilde{\chi}_1^0$ DM with RD above bounds (ruled out)

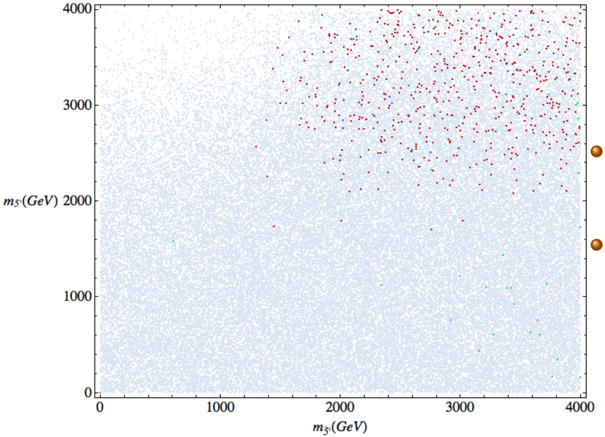
$(\mu\ ,\ \tan\beta)$ - Plane Scan: Scenario 1



- Small $\mu \rightarrow$ Higgsino dominated DM
- Large $\mu \rightarrow$ Bino dominated DM

$\left(m_{\bar{5}'}\,,\, m_{5'}\right)$ - Plane Scan: Scenario 1

Note first that $\mu^2 = \frac{1}{2}\left[\tan 2\beta \left(m_{H_u}^2 \tan\beta - m_{H_d}^2 \cot\beta\right) - M_Z^2\right]$

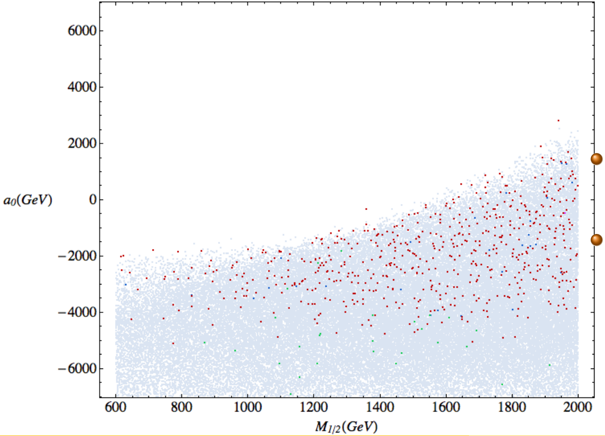


- $\left(m_{H_u}^2 \tan\beta - m_{H_d}^2 \cot\beta\right) << 0 \Rightarrow$ large μ
- $\left(m_{H_u}^2 \tan\beta - m_{H_d}^2 \cot\beta\right) < 0 \Rightarrow$ small μ

University of Glasgow

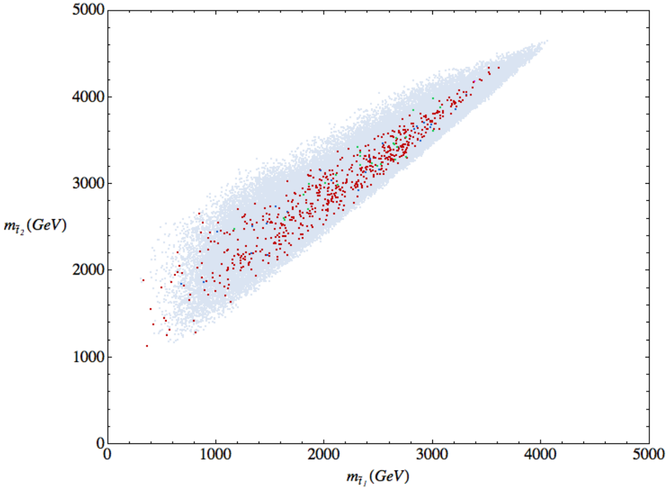
$(M_{1/2}\ ,\ a_0)$ - Plane Scan: Scenario 1

One loop correction to m_{h^0} has the contribution $2\log\frac{m_{\tilde{t}}^2}{m_t^2}+\frac{X_t^2}{m_{\tilde{t}}^2}\left(1-\frac{X_t^2}{12m_{\tilde{t}}^2}\right)$, $X_t = A_t - \mu\cot\beta$

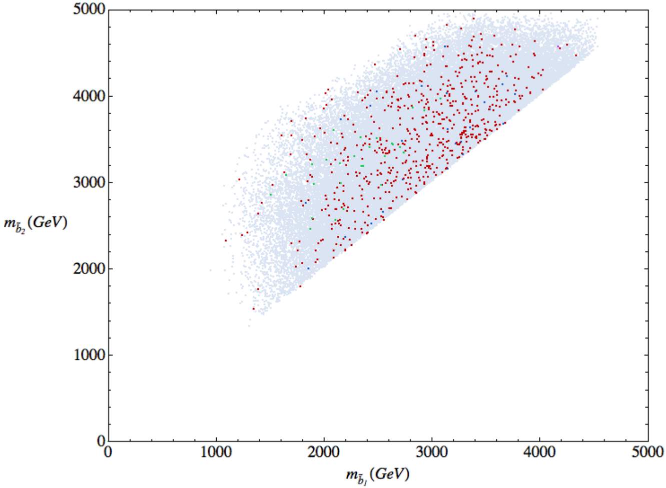


- Large X_t if $A_t << 0$ (favours 125 GeV h^0)
- Larger $m_{\tilde{t}}$ for larger $M_{1/2}$ (favours 125 GeV h^0)

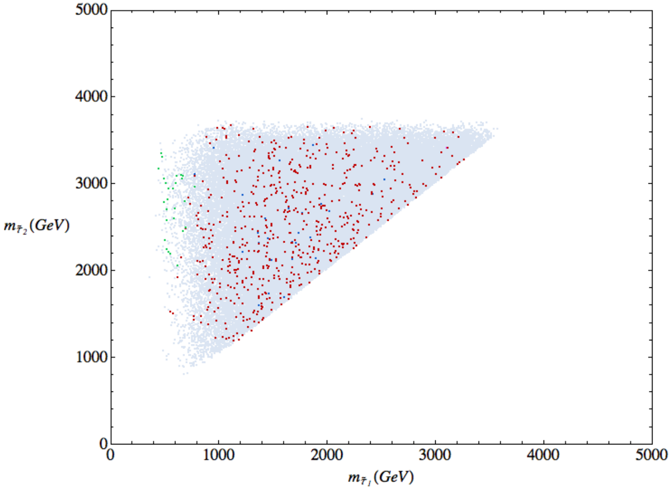
Stops: Scenario 1



Sbottoms: Scenario 1

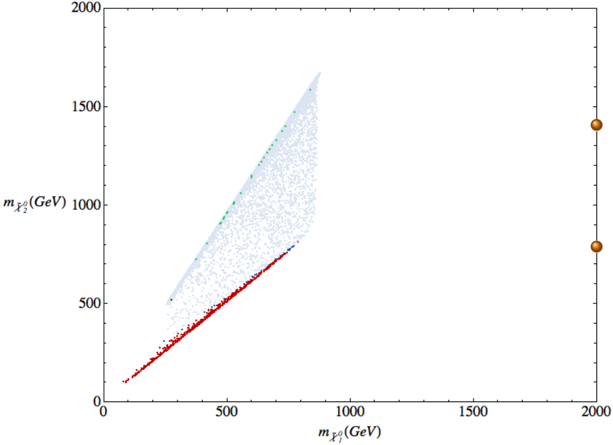


Staus: Scenario 1



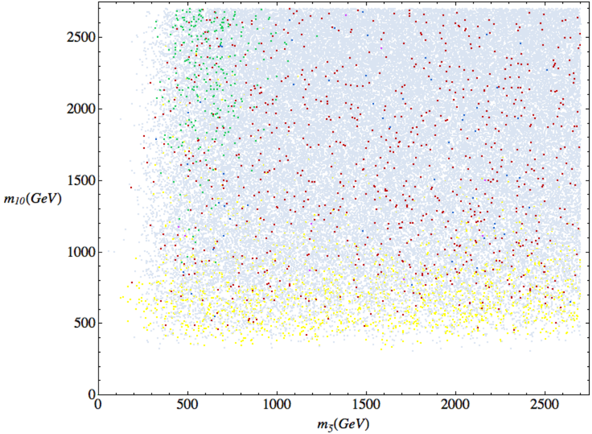
Neutralinos: Scenario 1

For universal gauginos, EW scale relation: $M_3 : M_2 : M_1 = 6 : 2 : 1$



- Higgsino dominated DM:
  - $\tilde{\chi}^0_{1,2} \approx \left(\tilde{H}^0_u \pm \tilde{H}^0_d\right) / \sqrt{2}$
  - $M_{\tilde{\chi}^0_1} \approx M_{\tilde{\chi}^0_2}$
- Bino dominated DM
  - $\tilde{\chi}^0_1 \approx \tilde{B}$, $\tilde{\chi}^0_2 \approx \tilde{W}^0$
  - $M_{\tilde{\chi}^0_1} \approx \frac{1}{2} M_{\tilde{\chi}^0_2}$

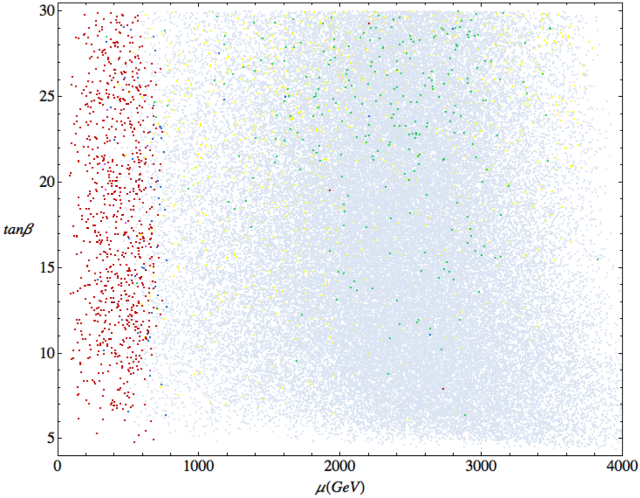
$(m_{\overline{5}}\ ,\ m_{10})$ - Plane Scan: Scenario 2



1. Yellow points: Charged LSP (ruled out)

- $\tilde{L}_3 \subset \overline{5} \Rightarrow \tilde{\nu}_L$ LSP when $m_{\overline{5}} \to$ small
- m_{10} small favours charged LSP, $\tilde{\tau}_1 (\approx \tilde{\tau}_R)$
- White region $\to$ excluded by LHC

$(\mu\ ,\ \tan\beta)$ - Plane Scan: Scenario 2

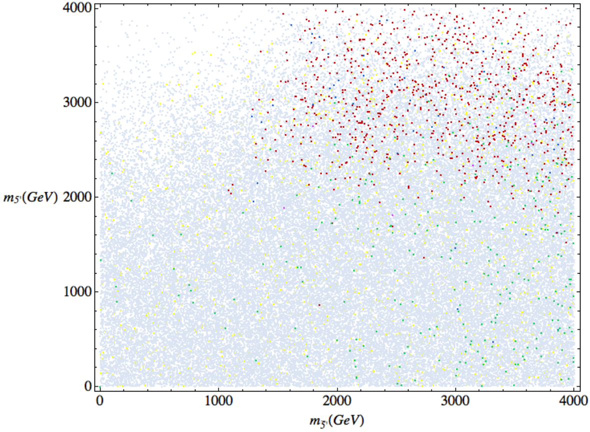


- Small $\mu \rightarrow$ Higgsino dominated DM
- Large $\mu \rightarrow$ Bino dominated DM

University of Glasgow

$\left(m_{\bar{5}'}\ ,\ m_{5'}\right)$ - Plane Scan: Scenario 2

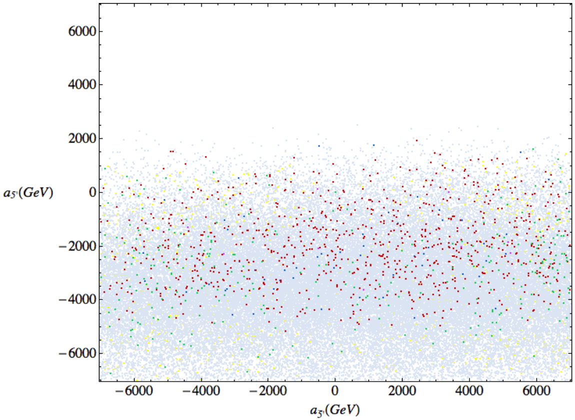
Note first that $\mu^2 = \frac{1}{2}\left[\tan 2\beta\left(m^2_{H_u}\tan\beta - m^2_{H_d}\cot\beta\right) - M_Z^2\right]$



- $\left(m^2_{H_u}\tan\beta - m^2_{H_d}\cot\beta\right) << 0 \Rightarrow$ large μ
- $\left(m^2_{H_u}\tan\beta - m^2_{H_d}\cot\beta\right) < 0 \Rightarrow$ small μ

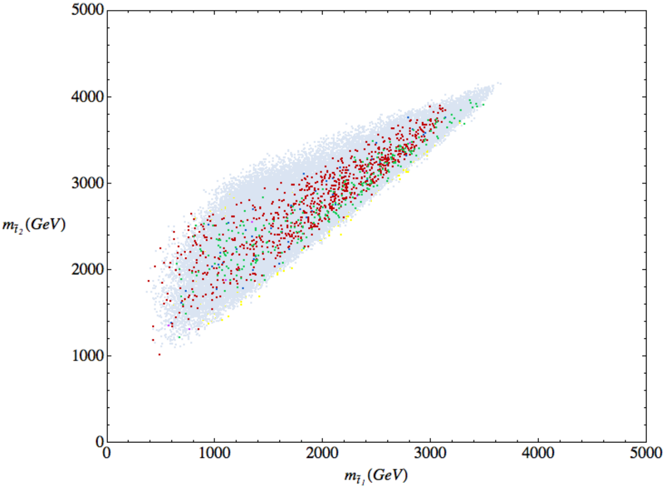
$\left(a_{\overline{5}'}\ ,\ a_{5'}\right)$ - Plane Scan: Scenario 2

One loop correction to m_{h^0} has the contribution $2\log\frac{m_{\tilde{t}}^2}{m_t^2}+\frac{X_t^2}{m_{\tilde{t}}^2}\left(1-\frac{X_t^2}{12m_{\tilde{t}}^2}\right)$, $X_t = A_t - \mu\cot\beta$

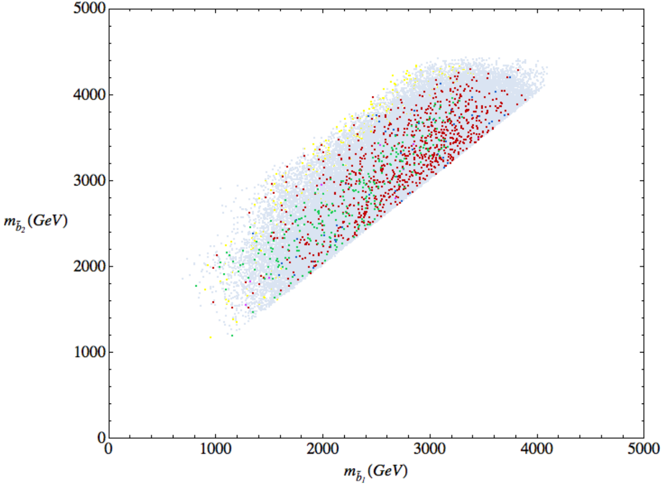


- Large X_t if $A_t << 0$ (favours 125 GeV h^0)

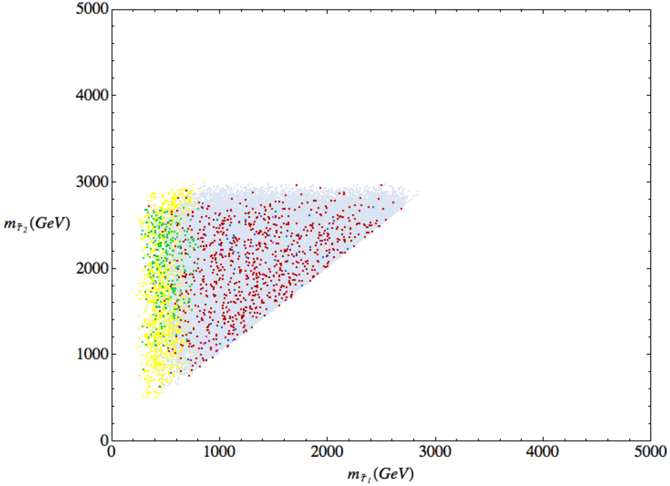
Stops: Scenario 2



Sbottoms: Scenario 2

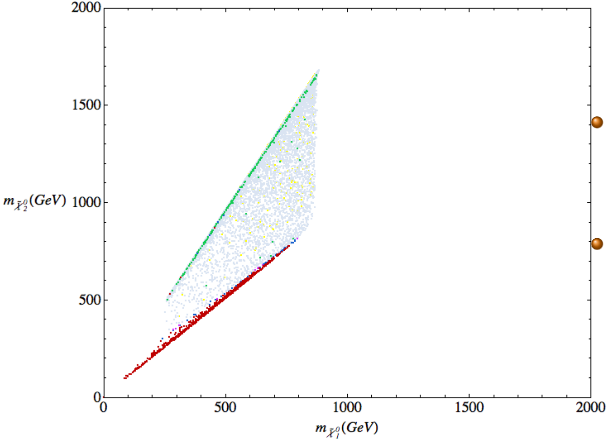


Staus: Scenario 2



Neutralinos: Scenario 2

For universal gauginos, EW scale relation: $M_3 : M_2 : M_1 = 6 : 2 : 1$



- Higgsino dominated DM:
  - $\tilde{\chi}^0_{1,2} \approx \left(\tilde{H}^0_u \pm \tilde{H}^0_d\right)/\sqrt{2}$
  - $M_{\tilde{\chi}^0_1} \approx M_{\tilde{\chi}^0_2}$
- Bino dominated DM
  - $\tilde{\chi}^0_1 \approx \tilde{B}$, $\tilde{\chi}^0_2 \approx \tilde{W}^0$
  - $M_{\tilde{\chi}^0_1} \approx \frac{1}{2} M_{\tilde{\chi}^0_2}$

University of Glasgow

$SO(10)$ Grand Unification: *Boundary Conditions*

WORK IN PROGRESS...

- Breaking $SO(10) \to SU(5) \otimes U(1)_x \to G_{SM}$ the rank is reduced from 5 to 4
  - D-term contributions from the additional $U(1)_x$ of the form $\Delta m_a^2 = -\sum_k Q_{ka} g_k^2 D_k$
    [Kolda and Martin, 9503445]
- Consider that the Higgs are embedded in a **10** of $SO(10)$

Common sfermion mass $m_{\mathbf{16}}$

$$m^2_{\tilde{Q}_L}(t_G) = m^2_{\tilde{u}_R}(t_G) = m^2_{\tilde{e}_R}(t_G) = m^2_{\mathbf{16}} + g^2_{10} D$$
$$m^2_{\tilde{L}_L}(t_G) = m^2_{\tilde{d}_R}(t_G) = m^2_{\mathbf{16}} - 3g^2_{10} D$$
$$m^2_{\tilde{N}_e}(t_G) = m^2_{\mathbf{16}} + 5g^2_{10} D$$

Common Higgs mass $m_{\mathbf{10}}$

$$m^2_{\tilde{H}_u}(t_G) = m^2_{\mathbf{10}} - 2g^2_{10} D$$
$$m^2_{\tilde{H}_d}(t_G) = m^2_{\mathbf{10}} + 2g^2_{10} D$$

- $S(t_G) = -4g^2_{10} D$

Decoupling generations

$$m_{16}^{(1,2)} = K_{16}\, m_{16}^{(3)}$$
$$1 \leq K_{\mathbf{R}} \leq 10$$

Trilinear couplings unified $(a_i \equiv y_i\, A_i)$

$$a_u H_u \tilde{u}_R \tilde{Q}_L \xrightarrow{SO(10)} a_{10}\ \mathbf{10}\cdot\mathbf{16}_R\cdot\mathbf{16}_L$$
$$a_d H_d \tilde{d}_R \tilde{Q}_L \xrightarrow{SO(10)} a_{10}\ \mathbf{10}\cdot\mathbf{16}_R\cdot\mathbf{16}_L$$
$$a_e H_d \tilde{e}_R \tilde{L} \xrightarrow{SO(10)} a_{10}\ \mathbf{10}\cdot\mathbf{16}_R\cdot\mathbf{16}_L$$

Gauginos (adjoint rep): $\mathscr{L}_{G-K} = -\frac{1}{M_p} F_{ab}\lambda^a \otimes \lambda^b \xrightarrow{\langle F_{ab}\rangle} M_{ab}\lambda^a\lambda^b$

$\mathbf{45}\otimes\mathbf{45} = \mathbf{1}\oplus\mathbf{54}\oplus\mathbf{210}\oplus\mathbf{770}$

Universal $M_{1/2}$ at GUT scale only if $F_{ab}\in\mathbf{1} \to F_{ab} = F_0\delta_{ab} \to \langle F_{ab}\rangle = F_0$

If $F_{ab}\in\mathbf{54},\mathbf{210},\mathbf{770}$ or combinations $\longrightarrow$ non-universal gaugino mass

13 FREE PARAMETERS

$\mathbf{m^i_{16}}$, $\mathbf{g^2_{10}D}$, $\mathbf{M^{\alpha}_{1/2}}$, $\mathbf{m_{10}}$, $\mathbf{a^i_{10}}$, $\tan\beta$, $\mathbf{sign}(\mu)$

$\alpha, i = 1,2,3$

Summary and Conclusions

- Review of the $SU(5)$ and $SO(10)$ G_{SM} embedding
- Studied the $SU(5)$ and $SO(10)$ boundary conditions
- Scan on the $SU(5)$ parameter space
  - LHC bounds and Dark Matter constrains
- **Plenty of viable points for $100 \leq \mu \leq 800$ GeV (Higgsino dominated DM)**
- Fine tuning estimate: [Athron, Miller, 0705.2241]
  - Scenario 1: $\Delta_1 \approx 106.1$
  - Scenario 2: $\Delta_2 \approx 70.7$ (improved)
- **Non univerality of the scalar masses favours good points**
- Relaxing further constraints, eg. gaugino masses, might improve further (work in progress...)

University of Glasgow