Kahler - Independent G_2 Fluxless Vacua and their Phenomenology

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B. Acharya, KB, G. Kane, P. Kumar, D. Vaman, hep-th/0606262

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Introduction and motivation

Why do we study 4-dim String/M theory vacua?

- Non-Abelian gauge symmetry
- Chiral fermions
- Hierarchical Yukawa couplings
- Dynamical supersymmetry breaking
- Gauge coupling unification

Great! But can we make genuine predictions even in principle?

- By compactifying to 4D, we obtain a multitude of scalar fields – moduli, parameterizing internal metric deformations, brane positions, etc.
- Their masses must be large enough to be compatible with observations (BBN => $M_{mod} > O(10)TeV$)
- Subtlety:

$$f_{QCD} = \underset{\text{heavy}\ \nearrow}{\frac{4\pi}{g_3^2(M)}} + i\,\underset{\nwarrow\ \text{light}}{\frac{\theta_{QCD}(M)}{2\pi}}$$

- In String/M theory all masses and couplings are functions of the moduli vevs
- Once the moduli are stabilized, all couplings are completely fixed and are computable in principle
- Can we stabilize all moduli so that we can make predictions?

- In particular, can String/M theory *naturally* explain the hierarchy between the electroweak scale $M_Z=90\ GeV$ and Planck scale $M_{Plank}\sim10^{19}\ GeV$?

Strong hints in favor of low scale SUSY from bottom up:

- Radiative Electroweak Symmetry Breaking naturally occurs in the MSSM (large top Yukawa drives $m_{H_u}^2 < 0$)
- MSSM gauge coupling unification
- However, while supersymmetry alone can stabilize the hierarchy, it still does not explain it!

Standard lore in 1985: strong hidden sector gauge dynamics may generate a potential for the moduli and break supersymmetry at a small scale

- Fluxless G_2 compactifications of M theory can *naturally* implement this good old idea from top down!

B. Acharya, KB, hep-th/0810.3285
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M theory on G_2 manifolds

- Consider M theory compactifications on singular 7-dim manifolds X with G_2 holonomy (required for $\mathcal{N}$=1 SUSY)

- The Riemannian metric $g(X)$ can be expressed in terms of the associative 3-form Φ as

$$g_{ij} = (\det s)^{-\frac{1}{9}} s_{ij},$$

where $$s_{ij} = \frac{1}{144} \Phi_{ikn} \Phi_{jlm} \Phi_{rst} \varepsilon^{knlmrst}, \;\; \varepsilon^{12\ldots7} = +1$$

- Expand Φ in terms of basis harmonic 3-forms

$$\Phi = \sum_{i=1}^{N} s_i \phi_i, \quad \phi_{\mathrm{i}} \in H^3(X, Z), \; N = b^3(X)$$

- Unlike CY, there is only one type of geometric moduli:

$$z_i = t_i + i s_i, \quad i = 1,\ldots,N; \quad N = b_3(X)$$

Axions
(periods of the 3-form C_3,
transform under a shift symmetry)

periods of the associative 3-form Φ
(fluctuations of the metric)

- This PQ-type shift symmetry guarantees that in the absence of fluxes the entire superpotential is purely non-perturbative => exponential hierarchies are natually expected!

- Non-Abelian gauge fields are localized on three-dimensional submanifolds $Q \in X$ along which there is an orbifold singularity. Acharya. hep-th/9812205, hep-th/0011089

- Example: locally, M-theory on $R^{3,1}\times\overbrace{Q\times(C_2/Z_N)}^{X}$ is the 11-dim SUGRA coupled to a 7-dim SU(*N*) gauge theory on $R^{3,1}\times Q$.

  ↖ associative (supersymmetric) 3-cycle

- Chiral fermions are localized at point-like isolated singularities $p\in X$. Atiyah-Witten. hep-th/0107177, Acharya-Witten. hep-th/0109152

- A particle localized at *p* will be charged under the gauge group supported along the associative three-cycle *Q* if $p\in Q$

Bulk Kahler potential

Beasley-Witten: hep-th/0203061; Acharya, Denef, Valandro: hep-th/0502060

$$K = -3\ln(4\pi^{1/3}V_7)$$

- We know that the 7-dim volume V_7 is a homogeneous function of the moduli s_i of degree 7/3

$$\sum_{i=1}^{N} s_j \frac{\partial V_7}{\partial s_i} = \frac{7}{3} \quad \Rightarrow \quad \sum_{i=1}^{N} s_j \frac{\partial K}{\partial s_i} = -7; \; \sum_{i,j=1}^{N} s_i s_j \frac{\partial^2 K}{\partial s_i \partial s_j} = 7$$

- These properties and everything that follows from them are all we use! In particular, no specific choice of the 7-dim volume needs to be made in order to compute the soft SUSY breaking terms!

- In earlier work

B. Acharya, KB, G. Kane, P. Kumar and J. Shao, hep-ph/0801.0478
B. Acharya, KB, G. Kane, P. Kumar and J. Shao, hep-th/0701034,
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we assumed a specific N-parameter family of the 7-dim volumes consistent with G_2 holonomy

$$V_7 = \prod_{i=1}^{N} s_i^{n_i}\,, \text{where } \sum_{i=1}^{N} n_i = \frac{7}{3}$$

- We then also assumed a canonical Kahler potential for charged chiral matter

$$\tilde{K} = \bar{\phi}\phi$$

- In B. Acharya, KB hep-th/0810.3285, presented here, we redid the entire analysis with no such assumptions

Kahler potential for matter fields

- Because chiral matter is localized at points in the seven extra dimensions, we expect that the corresponding kinetic terms should be “largely independent of bulk moduli fields”

- A single conical singularity gives only N of $SU(N)$ which gives a trivial superpotential

- When $W=0$ there is a one-to one correspondence between holomorphic gauge-invariant operators (HGIO) and D-flat directions Taylor, Luty, hep-th/9506098

- One cannot construct any HGIO from a single N => no D-flat directions => no local moduli

Matter Kahler metric from dim reduction

- The physics of a conical singularity in M-theory does not involve any new scale, aside from the 11d Planck scale so the natural frame is the 11d Einstein frame.
- Lagrangian density in 11d frame

$$L \sim M_{11}^{9}\sqrt{g_{11}}R + \delta_7 \wedge \partial_M \bar{\phi}\, \partial_N \phi \, g^{MN} \kappa(s_i)\sqrt{g_{11}} + \ldots$$

Peaked at the position of the matter multiplet

where $$\sum_{i=1}^{N} s_i \frac{\partial \kappa}{\partial s_i} = 0$$

Kinetic term is “largely independent of bulk moduli”

- Integrating over X gives

$$L \sim V_7 M_{11}^{9}\sqrt{g_4}R + \kappa(s_i) g^{\mu\nu}\partial_\mu \bar{\phi}\, \partial_\nu \phi \sqrt{g_4} + \ldots$$

- Weil rescaling into the 4d Einstein frame gives

$$L \sim m_p^2 \sqrt{g_E} R_E + \frac{\kappa(s_i)}{V_7} g_E^{\mu\nu} \partial_\mu \bar{\phi} \partial_\nu \phi \sqrt{g_E} + \ldots$$

- The kinetic term is non-trivial in the 4d Einstein frame – the standard frame in which we define the Kahler potential.

- Read off the Kahler potential from the kinetic term

$$\tilde{K} = \kappa(s_i) \frac{\bar{\phi}\phi}{V_7}$$

Matter Kahler metric from the finiteness of the physical (normalized) Yukawa couplings

- In $\mathcal{N}$=1 D=4 supergravity

$$|Y_{\alpha\beta\gamma}| = e^{K/2}\,|Y'_{\alpha\beta\gamma}|\left(\tilde{K}_\alpha\tilde{K}_\beta\tilde{K}_\gamma\right)^{-1/2} \sim |Y'_{\alpha\beta\gamma}|\left(V_7^3\tilde{K}_\alpha\tilde{K}_\beta\tilde{K}_\gamma\right)^{-1/2}$$

where (in M-theory on G_2) the superpotential Yukawa is

$$|Y'_{\alpha\beta\gamma}| \sim e^{-2\pi V_{\alpha\beta\gamma}}\,, V_{\alpha\beta\gamma} = \sum_{i=1}^{N} m_i^{\alpha\beta\gamma} s_i$$

- There are well-defined local models where manifold X is non-compact , i.e. $V_7 \to \infty \Rightarrow m_{pl}/M_{11} \to \infty$

$Y_{\alpha\beta\gamma}$ is finite $\Rightarrow K_\alpha \sim K_\beta \sim K_\beta \sim \dfrac{1}{V_7}$

Kahler potential for the visible sector matter

- For the visible sector matter fields, the Kahler potential may generally include a tree-level interaction term with the hidden sector

$$\tilde{K} = \tilde{K}_{\alpha\bar{\beta}} Q^{\alpha} \overline{Q}^{\bar{\beta}} = \frac{\kappa_{\alpha\bar{\beta}}(s_i) Q^{\alpha} \overline{Q}^{\bar{\beta}}}{V_7} \left(1 + c(s_i) \frac{\phi\bar{\phi}}{3V_7} \right)$$

- In the above we assumed that the flavor structure of $\tilde{K}_{\alpha\bar{\beta}}$ is completely determined by the matrix $\kappa_{\alpha\bar{\beta}}(s_i)$. Here this form is motivated by the suppression of the FCNCs from the bottom up. Another way to suppress FCNCs is to assume that $c(s_i) \approx 0$.

- Expand the fundamental associative three-form Φ in a basis of harmonic three-forms $\{\phi_i\}$

$$\Phi = \sum_{i=1}^{b_3(X)} s_i \phi_i , \quad \phi_i \in H^3(X,Z)$$

- Choose the basis of $\{\phi_i\}$ such that for all Poincare dual four-cycles $\{\beta_i\}$ the periods of *Φ are positive definite

$$\int_{\beta_\mathrm{i}} * \Phi > 0, \quad \forall \beta_i , \text{where } \ \beta_i = PD_X(\phi_i) \in H_4(X)$$

Then, we can ensure that all four-cycle volumes are positive because

$$\mathrm{Vol}(\beta_i) \geq \int_{\beta_\mathrm{i}} * \Phi > 0$$

- Consider an associative three-cycle Q

$$\mathrm{Vol}(Q) = \int_Q \Phi = \sum_{i=1}^{b_3(X)} s_i \int_Q \phi_i = \sum_{i=1}^{b_3(X)} s_i N_i$$

- Key point: we implicitly assume that we study any G_2 manifold X containing an associative three-cycle Q supporting a gaugino condensate, such that in the above basis of harmonic three-forms $\{\phi_i\}$ the integers specifying the homology of Q are all positive definite

$$N_i = \int_Q \phi_i > 0$$

Moduli stabilization and SUSY breaking

- Superpotential is generated by strong dynamics in the hidden sectors (PQ symmetry => W is non-pert.)

$$W = A_1 \phi^a e^{i b_1 f} + A_2 e^{i b_2 f} + \ldots$$

Integers specifying the homology of the hidden sector 3-cycle

where the gauge kinetic function $f = \sum_{i=1}^{N} N_i z_i$

Most economical way to fix moduli and get dS vacua !

All F-terms will have the same phase. Important for CP!

- An effective meson field $\phi \equiv \sqrt{2\hat{Q}\tilde{\hat{Q}}} = \phi_0 e^{i\theta}$

- For $SU(N_c)$ and $SU(M)$ hidden sector gauge groups and $N_f = 1$ flavor:

$$b_1 = \frac{2\pi}{P}, \quad b_2 = \frac{2\pi}{M}, \quad a = -\frac{2}{P}, \quad \text{where} \quad P = N_c - 1$$

- Inverse Kahler metric (first consider $\kappa(s_i)=1$):

$$K^{i\bar{j}}=\frac{4s_i s_{\bar{j}}}{3a_{\bar{j}}}\frac{(\Delta^{-1})^{i\bar{j}}}{1+\frac{\phi_0^2}{3V_7}};K^{i\bar{\phi}}=i\frac{2}{3}\frac{s_i\bar{\phi}}{1+\frac{\phi_0^2}{3V_7}};K^{\phi\bar{\phi}}=V_7\left(1+\frac{7}{3}\frac{1}{1+\frac{\phi_0^2}{3V_7}}\frac{\phi_0^2}{3V_7}\right)$$

"angular" (scale-invariant) coordinates on the moduli space

↓

$$a_i\equiv-\frac{1}{3}s_i\frac{\partial K}{\partial s_i}\qquad\sum_{i=1}^{N}a_i=\frac{7}{3}\qquad\sum_{\bar{j}=1}^{N}(\Delta^{-1})^{i\bar{j}}a_{\bar{j}}=a_i\qquad\sum_{i=1}^{N}(\Delta^{-1})^{i\bar{j}}=1$$

These contraction properties are completely general and are crucial for our ability to minimize the scalar potential and perform explicit computations of the soft terms!

$\mathcal{N}$=1 D=4 SUGRA scalar potential

$$
\begin{aligned}
V = \frac{e^{\frac{\phi_0^2}{V_7}}}{64\pi V_7^3}\Bigg[& \frac{4}{3}\sum_{i=1}^{N}\sum_{\bar{j}=1}^{N}\frac{s_i s_{\bar{j}} N_i N_{\bar{j}}}{a_{\bar{j}}}\frac{(\Delta^{-1})^{i\bar{j}}}{1+\frac{\phi_0^2}{3V_7}}(b_1 A_1 \phi_0^a e^{-b_1\vec{N}\cdot\vec{s}} - b_2 A_2 \phi_0^a e^{-b_2\vec{N}\cdot\vec{s}})^2 \\
& + 4\vec{N}\cdot\vec{s}(b_1 A_1 \phi_0^a e^{-b_1\vec{N}\cdot\vec{s}} - b_2 A_2 \phi_0^a e^{-b_2\vec{N}\cdot\vec{s}})(A_1 \phi_0^a e^{-b_1\vec{N}\cdot\vec{s}} - A_2 \phi_0^a e^{-b_2\vec{N}\cdot\vec{s}}) \\
& + 7(b_1 A_1 \phi_0^a e^{-b_1\vec{N}\cdot\vec{s}} - b_2 A_2 \phi_0^a e^{-b_2\vec{N}\cdot\vec{s}})^2\left(1+\frac{\phi_0^2}{3V_7}\right) - 3(A_1 \phi_0^a e^{-b_1\vec{N}\cdot\vec{s}} - A_2 \phi_0^a e^{-b_2\vec{N}\cdot\vec{s}})^2 \\
& - \frac{4}{3}\left(\frac{(b_1 A_1 \phi_0^a e^{-b_1\vec{N}\cdot\vec{s}} - b_2 A_2 \phi_0^a e^{-b_2\vec{N}\cdot\vec{s}})}{1+\frac{\phi_0^2}{3V_7}}\vec{N}\cdot\vec{s} + \frac{7}{2}(A_1 \phi_0^a e^{-b_1\vec{N}\cdot\vec{s}} - A_2 \phi_0^a e^{-b_2\vec{N}\cdot\vec{s}})\right) \\
& \times\left(a A_1 \phi_0^a e^{-b_1\vec{N}\cdot\vec{s}} + \frac{\phi_0^2}{V_7}(A_1 \phi_0^a e^{-b_1\vec{N}\cdot\vec{s}} - A_2 \phi_0^a e^{-b_2\vec{N}\cdot\vec{s}})\right) \\
& + \frac{V_7}{\phi_0^2}\left(1+\frac{7}{3}\frac{1}{1+\frac{\phi_0^2}{3V_7}}\frac{\phi_0^2}{3V_7}\right)\left(a A_1 \phi_0^a e^{-b_1\vec{N}\cdot\vec{s}} + \frac{\phi_0^2}{V_7}(A_1 \phi_0^a e^{-b_1\vec{N}\cdot\vec{s}} - A_2 \phi_0^a e^{-b_2\vec{N}\cdot\vec{s}})\right)^2\Bigg]
\end{aligned}
$$

- Minimize the potential with respect to the moduli and the meson to obtain a system of N+1 coupled equations

- Solve in the limit when the volume V_Q of the hidden sector associative cycle Q is large

- Moduli vevs: $s_i = \frac{a_i}{N_i}\frac{3}{7}V_Q$ where $V_Q \approx \frac{1}{2\pi}\frac{PM}{M-P}\ln\left(\frac{MA_1\phi_0^a}{PA_2}\right)$

- Parameters a_i satisfy a system of N equations: $\left.\frac{\partial K}{\partial s_i}\right|_{s_i=\frac{a_i}{N_i}} + 3N_i = 0$

Integers specifying the homology of the hidden sector 3-cycle Q

- 7-dim volume is fixed at: $V_7 = V_Q^{7/3}\left(\frac{3}{7}\right)^{7/3} \times V_7(s_i)\Big|_{s_i=\frac{a_i}{N_i}}$

- Alternatively, introducing a basis of dual variables

$$\tau_i \equiv \frac{\partial V_7}{\partial s_i} = \frac{1}{3}\int_X \phi_i \wedge *\Phi = \frac{1}{3}\int_{\beta_i} *\Phi$$

- We find upon minimizing the scalar potential

$$\tau_i = N_i \frac{7V_7}{3V_Q} > 0, \quad \Leftrightarrow \quad *\Phi = \alpha \cdot PD_X\left(Q\right), \quad 0 < \alpha \in R$$

Fixed by the supergravity scalar potential

The co-associative four-form $*\Phi$ is dynamically fixed by the homology of Q!

- Recasting the volume V_7 in terms of τ_i we can express:

$$s_i = \frac{4V_Q}{7}\frac{\partial}{\partial \tau_i}\ln V_7(\tau_k)\Big|_{\tau_k = N_k}$$

Integers specifying the homology of the hidden sector 3-cycle Q

- In Type IIB even more explicit: $\tau_i = \frac{\tau_D}{3}\frac{\partial}{\partial n_i}\ln\sum d_{ljk}n_l n_j n_k$

K.B, V. Braun, P. Kumar and S. Raby: hep-th 1003.1982

- In Type IIB K.B, V. Braun, P. Kumar and S. Raby: hep-th/1003.1982

$$t_i = \frac{n_i \tau_D^{1/2}}{\sqrt{3 \sum d_{ijk} n_i n_j n_k}}, \quad \tau_i = \frac{\tau_D}{3} \frac{\partial}{\partial n_i} \ln \sum d_{ljk} n_l n_j n_k, \quad V_{CY} = \frac{\tau_D^{3/2}}{3\sqrt{3 \sum d_{ijk} n_i n_j n_k}}$$

- Explicit three-parameter example (hep-th/1003.1982)

$$\tau_1 = \frac{6}{30}\tau_D, \quad \tau_2 = \frac{11}{30}\tau_D, \quad \tau_3 = \frac{13}{30}\tau_D, \quad t_1 = t_2 = t_3 = \frac{\tau_D^{1/2}}{3\sqrt{5}}, \quad V_{CY} = \frac{\tau_D^{3/2}}{9\sqrt{5}}$$

- At the minimum all Kahler moduli are controlled by a single parameter τ_D ! In G_2 this is true for all moduli!

- This approach to moduli fixing is highly constraining and therefore potentially predictive

- Key point:

To find the soft supersymmetry breaking parametrs we do not need to know the explicit values of a_i and s_i ! The following general contraction properties are all we need to know!

$$\sum_{i=1}^{N} a_i = \frac{7}{3}, \qquad \sum_{\bar{j}=1}^{N} (\Delta^{-1})^{i\bar{j}} a_{\bar{j}} = a_i, \qquad \sum_{i=1}^{N} (\Delta^{-1})^{i\bar{j}} = 1$$

- Potential at the minimum in the leading order as a function of the meson vev

$$V_0 \approx \left[\left(\frac{2}{M-P} + \frac{\phi_0^2}{V_7} \right)^2 + \frac{14}{P_{eff}} \left(1 - \frac{2}{3(M-P)} \right) \left(\frac{2}{M-P} + \frac{\phi_0^2}{V_7} \right) - 3 \frac{\phi_0^2}{V_7} \right] \frac{V_7}{\phi_0^2} m_{3/2}^2$$

$$\frac{\partial V_0}{\partial \phi_0^2} = 0 \,\&\, V_0 = 0 \quad \Rightarrow \quad \frac{\phi_0^2}{V_7} \approx \frac{2}{M-P} + \frac{7}{P_{eff}} \left(1 - \frac{2}{3(M-P)} \right) + O\left(\frac{1}{P_{eff}^2} \right)$$

$$V_0 = 0 \quad \Rightarrow \quad P_{eff} \approx \frac{14(3(M-P)-2)}{9(M-P) - 6\sqrt{6(M-P)}}$$

where $P_{eff} \equiv P \ln\left(\frac{MA_1 \phi_0^a}{PA_2} \right)$ such that $V_Q \approx \frac{1}{2\pi} \frac{P_{eff} M}{M-P}$

$$V_Q > 0 \,\&\, M > P \Rightarrow P_{eff} > 0 \Rightarrow M - P \geq 3$$

- For $M-P=3$ we obtain $P_{eff}\approx 61.65$, $\frac{\phi_0^2}{V_7}\approx 0.75$, $s_i\approx 1.4\frac{a_i}{N_i}M$
- Can we actually tune $P_{eff}\equiv P\ln\left(\frac{MA_1\phi_0^a}{PA_2}\right)\approx 62$?
- Recall $A_1=\tilde{C}Pe^{-\frac{S_1'}{2P}};A_2=\tilde{C}Me^{-\frac{S_2'}{2M}}$
- When the 3-cycle is a lens space S^3/Z$_q$, the KK thresholds

Ray-Singer torsions

are: $S'_{SU(N)}=-2N\overbrace{\ln q}+2(N-2)\overbrace{\ln\left(4\sin^2(4\pi mw/q)\right)}$

$$\Rightarrow\qquad P_{eff}\approx P\ln\left(\frac{\left(4\sin^2(4\pi nl/q)\right)^{\frac{M-2}{M}}}{\left(4\sin^2(4\pi mw/q)\right)^{\frac{P-1}{P}}}\right)$$

P_{eff}	P	M	q	l	w	n	m
61.3	10	13	99	12	25	1	1
61.9	20	23	17	6	4	1	1
64.2	27	30	11	3	5	1/2	1/2

- Perturbative corrections may help fine tune the CC

$$\delta V_0^{1-loop} = \frac{1}{32\pi^2} Str \sum_i (-1)^{2J_i} (2J_i + 1) m_i^2 M_{11}^2 + \ldots$$

- From non-Abelian *SU(N)* and *U(1)* gauginos:

$$\delta V_0^{SU(N_i)} = -\frac{1}{16\pi^2} N_i^2 \lambda_i^2 (N_i, \underset{\nwarrow}{w_i}) m_{3/2}^2 M_{11}^2, \;\; \delta V_0^{U(1)} = -\frac{1}{16\pi^2} \lambda_i^2 (\vec{w}_i) m_{3/2}^2 M_{11}^2$$

discrete Wilson line winding numbers

- Vary discrete Wilson lines to scan over all N_i and w_i

in all hidden sectors => Fluxless discretuum !

- When M-$P=3$ and the CC is tuned $P_{eff} \approx 60$, the volume of the hidden sector cycle is

$$V_Q = \operatorname{Im} f = \sum_{i=1}^{N} N_i s_i = \frac{MP_{eff}}{6\pi} \approx \frac{10M}{\pi}$$

the contributions of the leading condensates are fixed!

$$\delta W_0 \sim e^{-\frac{2\pi}{M}V_Q} \approx e^{-20}$$

- Consider another rigid 3-cycle Y, supporting an SU(M`) gauge group. Its volume is also proportional to M !

$$V_Y = \sum_{i=1}^{N} N_i' s_i = \frac{3}{7} V_Q \sum_{i=1}^{N} \frac{N_i' a_i}{N_i} = M \times O(1)$$

- The extra contributions to the superpotential can be suppressed relative to the leading ones when $M >> M$`

$$\delta W_{extra} \sim e^{-\frac{2\pi}{M'}V_Y} \approx e^{-2\pi\frac{M}{M'}\times O(1)} << \delta W_0$$

- Gravitino mass is fixed once coarse tuning is done

$$m_{3/2} = m_{pl} e^{\frac{\phi_0^2}{2V_7}} \frac{\left|P-M\right| C_2}{8\sqrt{\pi} V_7^{3/2}} e^{-\frac{P_{eff}}{M-P}} \approx 9\times 10^5 (TeV) \frac{C_2}{V_7^{3/2}}$$

- Extract V_7 from $\frac{1}{8\pi m_{pl}^2} = \frac{\alpha_{GUT}^3 V_{Q_{vis}}^{7/3} L(Q_{vis})^{2/3}}{32\pi^2 M_{GUT}^2 V_7}$

Friedmann and Witten, hep-th/0211269

- For typical values $\alpha_{GUT}^{-1} = V_{Q_{vis}} \approx 25,\ M_{GUT} \approx 2\times 10^{16} GeV$

- Obtain $V_7 \approx 137.4 \times L(Q_{vis})^{2/3}$, where $L(Q_{vis}) = 4\sin^2\left(5\pi w/q\right)$

q	2	3	4	4	6	6	6
w	1	1, 2	1, 3	2	1, 5	2, 4	3
V_7	549.6	594.5	549.6	872.4	453.7	943.7	1143.2
$m_{3/2}/C_2$	70 TeV	62 TeV	70 TeV	35 TeV	93 TeV	31 TeV	23 TeV

- Moduli: $M_1 \approx O(200-300)\times m_{3/2}, \quad m_i \approx O(1)\times m_{3/2} < 2\times m_{3/2}$

- $m_{3/2}$ ~*O(10)TeV* => moduli are heavy enough to decay before BBN. Non-standard cosmology: large entropy production at late times, but before BBN; dark matter is generated non-thermally. When the LSP is mostly Wino => relic density is compatible with observation (Gordy's talk) Acharya, et.al, hep-ph/0804.0863, astro-ph/0908.2430

- Axions (B. Acharya, KB, P. Kumar: hep-th/1004.5138, Piyush's talk): to fix all axions we must include the truncated non-perturbative contributions

$$m_1 \approx O(200-300)\times m_{3/2}, \quad m_i^2 \approx O(1)\frac{m_{pl}^2 m_{3/2}}{f_i^2} e^{K/2} e^{-b_i V_i}, \; i=1,\ldots,N$$

- The entropy dilution due to late time moduli decays allows decay constants f_i much closer to the GUT scale

Generalizing to the case when $\kappa(s_i) \neq const$

- The main difference is in the moduli vevs

$$s_i \approx \frac{1}{N_i}\left(a_i + c_i\frac{\phi_c^2}{3}r\right)\frac{3}{7}V_Q$$

where, $r \approx \frac{3}{2}$ and the vev of the canonically normalized meson $\phi_c^2 \equiv \frac{\kappa(s_i)}{V_7}\phi_0^2 \approx \frac{2}{M-P} + \frac{7}{P_{eff}}\left(1 - \frac{2}{3(M-P)}\right)$ is the same as when $\kappa(s_i)=1$. Parameters a_i , c_i can be found from

$$s_i \left.\frac{\partial K}{\partial s_i}\right|_{s_i=\frac{1}{N_i}\left(a_i+c_i\frac{\phi_c^2}{3}r\right)} + 3a_i = 0; \quad s_i \left.\frac{\partial \ln\kappa}{\partial s_i}\right|_{s_i=\frac{1}{N_i}\left(a_i+c_i\frac{\phi_c^2}{3}r\right)} - c_i = 0$$

- Use the general contraction rules to obtain

$$e^{K/2}F^{k}\approx -i2s_{k}\frac{1}{P_{eff}}\left(1+\frac{2}{\phi_{c}^{2}\left(M-P\right)}+O\left(\frac{1}{P_{eff}}\right)\right)\times m_{3/2}m_{pl}$$

$$e^{K/2}F^{\phi}\approx \phi\left(1-\frac{7}{3P_{eff}}\right)\left(1+\frac{2}{\phi_{c}^{2}\left(M-P\right)}+O\left(\frac{1}{P_{eff}}\right)\right)\times m_{3/2}m_{pl}$$

- Notice two key properties of the F-terms:

$$F^{i}\approx s_{i}\times const,\quad \text{and}\quad F^{i}<<F^{\phi}$$

- When computing the soft terms use homogeneity:

$$\sum_{i}F^{i}\partial_{i}\frac{\kappa_{\alpha\beta}}{V_{7}}\approx const\times\sum_{i}s_{i}\partial_{i}\frac{\kappa_{\alpha\beta}}{V_{7}}=-\frac{7}{3}\frac{\kappa_{\alpha\beta}}{V_{7}}\times const$$

Summary of the soft SUSY breaking terms

$$m_{1/2}^{tree} \approx -\frac{1}{P_{eff}}\left(1+\frac{2}{\phi_c^2\left(M-P\right)}+\frac{\delta}{P_{eff}}\right)\times m_{3/2} << m_{3/2}, \text{since } P_{eff} \approx 60$$

$$m_{1/2}^{1-loop} \approx \frac{\alpha_{GUT}}{4\pi}\left(\left(3C_a-\sum_{\alpha}C_a^{\alpha}\right)K_1+\frac{2}{3}K_2\sum_{\alpha}C_a^{\alpha}\right)\times m_{3/2}$$

$$A_{\alpha\beta\gamma}^{tree} \approx \left(K_2+\frac{4\pi}{P_{eff}}\left(1+\frac{2}{\phi_c^2\left(M-P\right)}\right)V_{Q_{\alpha\beta\gamma}}\right)\times m_{3/2}$$

$$A_a^{1-loop} \approx -\frac{1}{16\pi^2}\gamma_a K_1\times m_{3/2}$$

Volume of the cycle $Q_{\alpha\beta\gamma}$ that connects three co-dimension seven singularities supporting charged chiral matter

$$m_{\alpha}^2 \approx (1-c)\left(m_{3/2}^2-\frac{7}{3}\left(m_{1/2}^{tree}\right)^2\right)$$

$$K_1 \equiv 1-\frac{1}{3}\left(1+\frac{2}{\phi_c^2\left(M-P\right)}\right)\left(\phi_c^2+\frac{7}{P_{eff}}\right), \quad K_2 \equiv \left(1+\frac{2}{\phi_c^2\left(M-P\right)}\right)(1-c)\phi_c^2$$

Computation of soft SUSY breaking terms

- Since we stabilized the moduli we can compute the terms in the soft-breaking lagrangian

Nilles: Phys. Rept. 110 (1984) 1, Brignole et.al.: hep-th/9707209

- Tree-level gaugino masses

$$M_{1/2} = m_p \frac{e^{\hat{K}/2} F^n \partial_n f_{sm}}{2i \, \mathrm{Im} \, f_{sm}}$$

where the SM gauge kinetic function

$$f_{sm} = \sum_{i=1}^{N} N_i^{sm} z_i$$

Integers specifying the homology of the visible sector 3-cycle

- Use the expressions for the F-terms to compute

$$M_{1/2} \approx -\frac{e^{-i\gamma_W}}{P_{eff}}\left(1+\frac{2}{\phi_c^2(M-P)}+\frac{\delta}{P_{eff}}\right)\times m_{3/2}$$

- The tree-level gaugino mass is always suppressed for the entire class of dS vacua obtained in our model

$$V_0 = 0 \,\&\, M - P = 3 \Rightarrow P_{eff} \approx 61.65$$

$$\Rightarrow M_{1/2} \approx -e^{-i\gamma_W}(0.031 + 0.00026\times\delta)\times m_{3/2}$$

- Depending on N_i^{sm} we find typically $|\delta| \leq O(1-10)$
- Vary $61 \leq P_{eff} \leq 62 \Rightarrow -O(m_{3/2}m_{pl})^2 < V_0 < +O(m_{3/2}m_{pl})^2$
- However, $M_{1/2}$ stays virtually inert!

- Anomaly mediated gaugino masses:

Gaillard et. al.: hep-th/09905122, Bagger et. al.: hep-th/9911029

$$(M)_a^{am} = -\frac{g_a^2}{16\pi^2}\left[-\left(3C_a - \sum_\alpha C_a^\alpha\right)e^{\hat{K}/2}\overline{W} + \left(C_a - \sum_\alpha C_a^\alpha\right)e^{\hat{K}/2}F^m K_m + 2\sum_\alpha C_a^\alpha e^{\hat{K}/2}F^m \partial_m \ln\tilde{K}_\alpha\right]$$

- Use $\ln\tilde{K}_\alpha \approx \frac{1}{3}\hat{K} + (c-1)\kappa(s_i)\frac{\phi\bar{\phi}}{3V_7} + const$

$$(M)_a^{am} \approx -\frac{\alpha_{GUT}}{4\pi}\left[-\left(3C_a - \sum_\alpha C_a^\alpha\right)\left(1 - \frac{1}{3}\left(1 + \frac{2}{(M-P)\phi_c^2}\right)\left(\phi_c^2 + \frac{7}{P_{eff}}\right)\right)\right.$$

$$\left. + (c-1)\left(1 + \frac{2}{(M-P)\phi_c^2}\right)\frac{2\phi_c^2}{3}\sum_\alpha C_a^\alpha\right]e^{-i\gamma_w} \times m_{3/2}$$

- In the limit $c \rightarrow 1$ Konishi anomaly contribution vanishes. In this case we obtain a particular example of mirage pattern for gaugino masses

- Assume a SUSY GUT broken to MSSM
- Require zero CC at tree-level and $M-P=3$ to obtain tree-level plus anomaly gaugino masses:

$$M_1 \approx e^{-i\gamma_w}\left(-(0.031+0.00026\times\delta)\eta+\alpha_{GUT}\left(-0.225+0.523(1-c)\right)\right)\times m_{3/2}$$

$$M_2 \approx e^{-i\gamma_w}\left(-(0.031+0.00026\times\delta)\eta+\alpha_{GUT}\left(-0.034+0.555(1-c)\right)\right)\times m_{3/2}$$

$$M_3 \approx e^{-i\gamma_w}\left(-(0.031+0.00026\times\delta)\eta+\alpha_{GUT}\left(0.102+0.476(1-c)\right)\right)\times m_{3/2}$$

- From KK threshold corrections $\eta = 1-\frac{5g^2_{GUT}}{8\pi^2}\tau_\omega$

  Friedmann and Witten, hep-th/0211269

- Ray-Singer torsion $\tau_\omega = \ln(4\sin^2(5\pi w/q))$
- $\alpha_{GUT} \approx 1/25$ is fixed from gauge coupling unification
- For the case when *c=0*, the Konishi anomaly is large such that the tree-level and anomaly partially cancel

- μ - problem

$$\overset{\text{physical}}{\mu} = \left(\frac{\overline{W}}{|W|} e^{\hat{K}/2} \overset{\text{in superpotential}}{\mu'} + \overbrace{m_{3/2} Z - e^{\hat{K}/2} F^{\overline{m}} \partial_{\overline{m}} Z}^{\text{from Kahler potential (Giudice-Masiero)}} \right) (\tilde{K}_{H_u} \tilde{K}_{H_d})^{-1/2}$$

where $Z(z_i, \bar{z}_i, \phi, \bar{\phi})$ originates from $\delta\tilde{K} = \overbrace{Z(z_i, \bar{z}_i, \phi, \bar{\phi}) H_u H_d}^{\text{Invariant under } \mathbf{F}} + h.c.$

- μ\` -parameter can vanish if the G_2 manifold has a discrete symmetry **F**. Also used to solve the doublet-triplet splitting problem

Witten, hep-ph/0201018

- Since $Z(z_i, \bar{z}_i, \phi, \bar{\phi})$ is unknown $\mu \equiv Z_{eff}^1 m_{3/2}, B\mu \equiv Z_{eff}^2 m_{3/2}^2$
- If $Z_{eff}^{1,2} \sim O(1)$ then typically expect $\mu \sim O(m_{3/2})$
- Heavy higgsinos and $\tan\beta \sim O(1)$

From Higgs-Higgsino loops, at the weak scale get an extra contribution to M_1 and M_2.

Pierce, et.al, hep-ph/9606211; Gherghetta et.al, hep-ph/9904378; Arkani-Hamed, et.al hep-ph/0601041

$$\Delta M_{1,2} \approx \frac{\alpha_{1,2}}{4\pi} \frac{\mu \sin(2\beta)}{\left(1 - \frac{\mu^2}{m_A^2}\right)} \ln \frac{\mu^2}{m_A^2} \approx \frac{\alpha_{1,2}}{4\pi} \mu = \frac{\alpha_{1,2}}{4\pi} Z_{eff}^1 m_{3/2}$$

used that $\tan\beta \approx O(1)$ and $\frac{\mu^2}{m_A^2} \approx 1$

When $\mu \sim O(1) m_{3/2}$, such contributions can change the type of the LSP, depending on the sign of μ !

- In $\mathcal{N}=1$ D=4 sugra, the unnormalized scalar masses:

$$m'^{2}_{\alpha\bar{\beta}} \approx \tilde{K}_{\alpha\bar{\beta}}(m^{2}_{3/2}+V_{0})-e^{\hat{K}}F^{n}\overline{F}^{\overline{m}}(\partial_{n}\partial_{\overline{m}}\tilde{K}_{\alpha\bar{\beta}}-\partial_{n}\tilde{K}_{\alpha\bar{\gamma}}\tilde{K}^{\bar{\gamma}\delta}\partial_{\overline{m}}\tilde{K}_{\delta\bar{\beta}})$$

- In our construction we obtain (using homogeneity)

$$m'^{2}_{\alpha\bar{\beta}} \approx (1-c)\left(m^{2}_{3/2}-\frac{7}{3}\left(m^{tree}_{1/2}\right)^{2}\right)\tilde{K}_{\alpha\bar{\beta}} \Rightarrow m_{\alpha} \approx (1-c)^{1/2}m_{3/2}$$

- For generic values of *c* the scalars are very heavy

- Tree-level mass vanishes in the limit *c=1* – get tachyons in the scalar spectrum.

- We restrict our analysis to the values of *c* when

$$\frac{1}{16\pi^{2}} << \frac{m_{\alpha}}{m_{3/2}}$$

- Trilinear couplings:

$$A^{tree}_{\alpha\beta\gamma} = \frac{\overline{W}}{|W|} e^{\hat{K}/2} F^{m} \left(K_m Y'_{\alpha\beta\gamma} + \partial_m Y'_{\alpha\beta\gamma} - \left(\tilde{K}^{\delta\bar{\rho}} \partial_m \tilde{K}_{\bar{\rho}\alpha} Y'_{\delta\beta\gamma} + (\alpha \leftrightarrow \beta) + (\alpha \leftrightarrow \gamma) \right) \right)$$

$$Y'_{\alpha\beta\gamma} = C_{\alpha\beta\gamma} e^{i 2\pi \sum_{i=1}^{N} m_i^{\alpha\beta\gamma} z_i}$$

Membrane instanton volume: $V_{Q^{\alpha\beta\gamma}} = \sum_{i=1}^{N} m_i^{\alpha\beta\gamma} s_i$

$$\tilde{A}^{tree}_{\alpha\beta\gamma} \equiv \frac{A^{tree}_{\alpha\beta\gamma}}{Y'_{\alpha\beta\gamma}} \approx m_{3/2} e^{-i\gamma_W} \left(1 + \frac{2}{(M-P)\phi_c^2} \right) \left((1-c)\phi_c^2 + \frac{4\pi}{P_{eff}} \overset{\uparrow}{V}_{Q^{\alpha\beta\gamma}} \right)$$

Anomaly: $$\tilde{A}^{AM}_{a} = -\frac{1}{16\pi^2} \gamma_a \left(e^{\hat{K}/2} \overline{W} - \frac{1}{3} e^{\hat{K}/2} F^n K_n \right) + \frac{(1-c)}{16\pi^2} X_a m_{3/2}$$

Gaillard-Nelson. hep-th/0004170

$$\tilde{A}^{AM}_{t} \approx -\frac{e^{-i\gamma_w}}{16\pi^2} \left(-\frac{46}{5} g^2_{GUT} + 6Y_t^2 + Y_b^2 \right) \left(1 - \frac{1}{3} \left(1 + \frac{2}{(M-P)\phi_c^2} \right) \left(\phi_c^2 + \frac{7}{P_{eff}} \right) \right) m_{3/2}$$

$$\tilde{A}^{AM}_{b} \approx -\frac{e^{-i\gamma_w}}{16\pi^2} \left(-\frac{44}{5} g^2_{GUT} + Y_t^2 + 6Y_b^2 + Y_\tau^2 \right) \left(1 - \frac{1}{3} \left(1 + \frac{2}{(M-P)\phi_c^2} \right) \left(\phi_c^2 + \frac{7}{P_{eff}} \right) \right) m_{3/2}$$

$$\tilde{A}^{AM}_{\tau} \approx -\frac{e^{-i\gamma_w}}{16\pi^2} \left(-\frac{24}{5} g^2_{GUT} + 3Y_b^2 + 4Y_\tau^2 \right) \left(1 - \frac{1}{3} \left(1 + \frac{2}{(M-P)\phi_c^2} \right) \left(\phi_c^2 + \frac{7}{P_{eff}} \right) \right) m_{3/2}$$

- Total trilinear couplings for *M-P=3* and zero CC:

$$\tilde{A}_t \approx e^{-i\gamma_w}\left(1.5(1-c)-0.003\left(-\frac{46}{5}g_{GUT}^2+6Y_t^2+Y_b^2\right)\right)\times m_{3/2}$$

$$\tilde{A}_b \approx e^{-i\gamma_w}\left(1.5(1-c)-0.003\left(-\frac{44}{5}g_{GUT}^2+Y_t^2+6Y_b^2+Y_\tau^2\right)\right)\times m_{3/2}$$

$$\tilde{A}_\tau \approx e^{-i\gamma_w}\left(1.5(1-c)-0.003\left(-\frac{24}{5}g_{GUT}^2+3Y_b^2+4Y_\tau^2\right)\right)\times m_{3/2}$$

- We assumed that the third generation Yukawas arise from colliding singularities and thus dropped the volume terms

Friedmann and Witten, hep-th/0211269
Atiyah-Witten. hep-th/0107177

- For generic values of *0<c<1*: $\tilde{A}_{t,b,\tau} \sim O(1)\times m_{3/2}$

Electroweak Symmetry Breaking

- In most models REWSB is accommodated but not predicted, i.e. one picks $\tan\beta$ and then finds μ, which give the experimental value of M_Z

- Recall $\mu \equiv Z^1_{eff} m_{3/2}, B\mu \equiv Z^2_{eff} m^2_{3/2}$

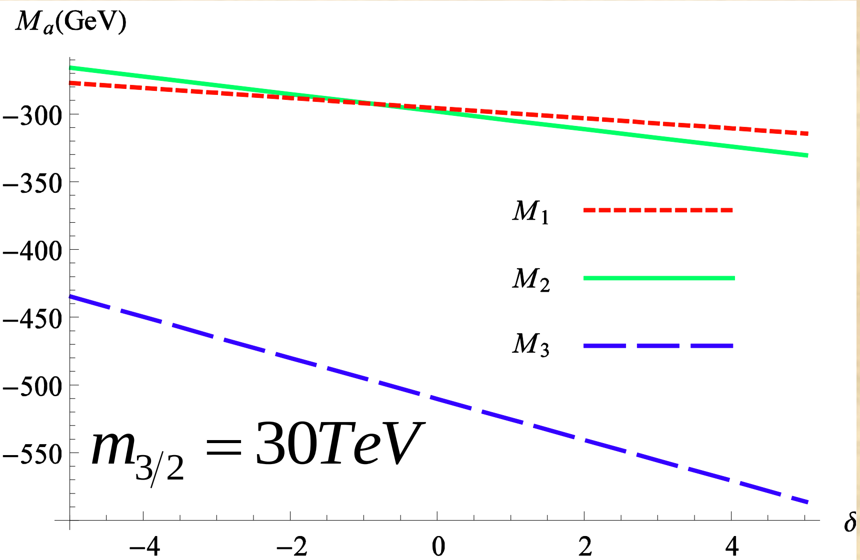
- Radiative EWSB is generic in our construction for a large range of values $0.1 < Z^{1,2}_{eff} < 3$

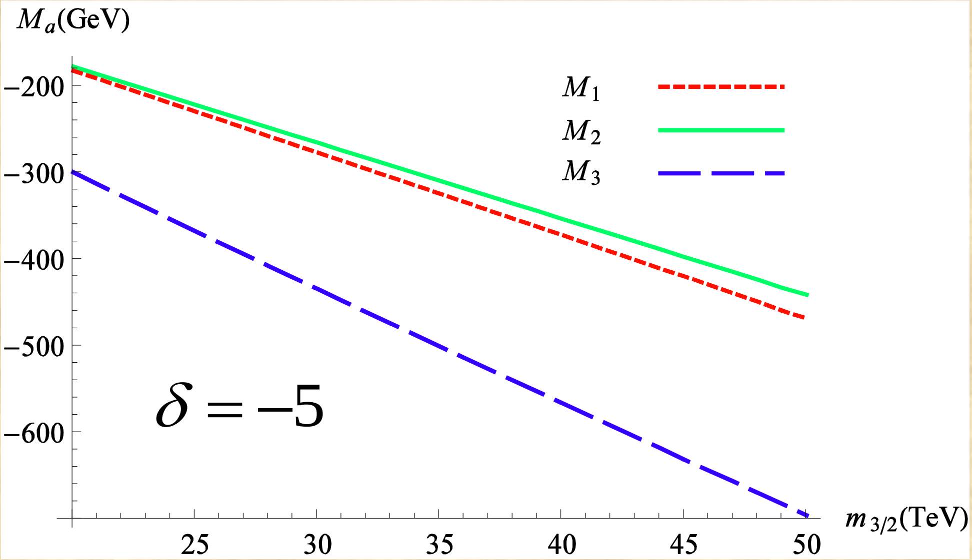
- However, generically get $M_Z \sim O(m_{3/2})$

- Getting $M_Z \approx 91 GeV$ requires fine tuning up to 0.01% level

Gaugino masses at the EW scale

(generated by SOFTSUSY package)





$$\tan\beta = 2.6, c = 0, \mu < 0, \eta = 1$$

- Pure Wino LSP is rapidly excluded as c is increased
- For typical values 0 < *c* < 1 get pure Bino LSP
- In the limit *c*=1, for large tan β can have light higgsinos mixing with gauginos

Benchmark spectra (masses are in GeV)

GUT scale input

$m_{3/2}$	20000	20000	20000	20000	30000	50000	30000
δ	-5	-3	0	-5	5	-5	-5
c	0	0	0	0.1	0.5	1/2	0
$\tan\beta$	3	2.65	2.65	3	3	2.5	3
μ	-12023	-13430	-13468	-11041	-10367	-33962	+17578
LSP	Wino	W+B	Bino	Bino	Bino	Wino	Bino
M_1	182	188	195	200	446	464	275
M_2	179	189	201	212	578	428	262
M_3	307	330	359	377	1113	663	429
$m_{\tilde{g}}$	463	495	535	558	1518	987	645
$m_{\tilde{\chi}_1^0}$	168.7	173.7	181	189	434	381.2	294
$m_{\tilde{\chi}_2^0}$	170	174	188	207	611	426	357
$m_{\chi_1^\pm}$	168.8	174	188	207	611	381.4	357
$m_{\tilde{t}_1}$	9077	8740	8711	8884	11191	22878	14213
$m_{\tilde{b}_1}$	15325	15241	15234	14625	16788	38479	23233
m_h	116.6	114.3	114.5	116.2	115.7	114.7	114.5

Approximately sequestered limit

- Express $c = 1 - \left(\frac{m_\alpha}{m_{3/2}} \right)^2$. GUT scale input: $m_{3/2}, m_\alpha, \eta, \delta, \tan\beta$

Can set $\eta = 1$

- Recast the soft terms as

$$M_1 \approx e^{-i\gamma_w} m_{3/2} \left(-(0.031 + 0.00026 \times \delta)\eta + \alpha_{GUT} \left(-0.225 + 0.523 (m_\alpha / m_{3/2})^2 \right) \right)$$

$$M_2 \approx e^{-i\gamma_w} m_{3/2} \left(-(0.031 + 0.00026 \times \delta)\eta + \alpha_{GUT} \left(-0.034 + 0.555 (m_\alpha / m_{3/2})^2 \right) \right)$$

$$M_3 \approx e^{-i\gamma_w} m_{3/2} \left(-(0.031 + 0.00026 \times \delta)\eta + \alpha_{GUT} \left(0.102 + 0.476 (m_\alpha / m_{3/2})^2 \right) \right)$$

$$\tilde{A}_t \approx e^{-i\gamma_w} m_{3/2} \left(1.5 (m_\alpha / m_{3/2})^2 - 0.003 (-(46/5) g_{GUT}^2 + 6 Y_t^2 + Y_b^2) \right)$$

$$\tilde{A}_b \approx e^{-i\gamma_w} m_{3/2} \left(1.5 (m_\alpha / m_{3/2})^2 - 0.003 (-(44/5) g_{GUT}^2 + Y_t^2 + 6 Y_b^2 + Y_\tau^2) \right)$$

$$\tilde{A}_\tau \approx e^{-i\gamma_w} m_{3/2} \left(1.5 (m_\alpha / m_{3/2})^2 - 0.003 (-(24/5) g_{GUT}^2 + 3 Y_b^2 + 4 Y_\tau^2) \right)$$

- Used SOFTSUSY to get the EW scale spectrum and then fed the output into micrOMEGAs to get the thermal relic density

Approximately sequestered limit (δ=2, η=1, all masses are in GeV)

Point	1	2	3	4	5	6
$m_{3/2}$	8000	16000	16000	16000	30000	50000
m_{α}	800	800	800	1200	2000	2000
$\tan\beta$	42.00	43.00	38.00	42.80	43.10	37.80
M_{GUT}	2.6x10^{16}	2.0x10^{16}	2.0x10^{16}	2.0x10^{16}	1.7x10^{16}	1.4x10^{16}
μ	297.2	532.9	538.1	516.7	847.3	1411.2
$\Omega_c h^2$	0.114	0.115	0.118	0.116	0.112	0.115
M_1	**134.1**	**274.7**	**274.5**	**275.6**	**530.2**	**898.4**
M_2	203.9	413.4	412.8	413.5	784.0	1316.1
M_3	505.2	980.8	979.4	970.2	1746.2	2840.4
$m_{\tilde{g}}$	574.2	1053.2	1053.8	1072.5	1909.7	3008.0
$m_{\tilde{\chi}_1^0}$	130.2	270.8	270.7	272.1	525.8	891.1
$m_{\tilde{\chi}_2^0}$	193.8	408.3	409.3	408.8	779.4	1327.2
$m_{\tilde{\chi}_3^0}$	308.1	539.4	545.2	524.3	854.9	1419.4
$m_{\tilde{\chi}_4^0}$	332.0	562.7	567.5	551.0	896.4	1456.2
$m_{\tilde{\chi}_1^\pm}$	194.6	412.1	412.9	411.6	781.5	1333.3
$m_{\tilde{\chi}_2^\pm}$	330.6	558.9	564.3	547.6	891.1	1450.6
$m_{\tilde{d}_L}, m_{\tilde{s}_L}$	924.4	1223.8	1223.3	1499.7	2571.4	3326.5
$m_{\tilde{u}_L}, m_{\tilde{c}_L}$	920.2	1219.3	1218.6	1495.7	2566.3	3318.5
$m_{\tilde{b}_1}$	667.1	929.0	974.8	1125.9	1980.7	2756.8
$m_{\tilde{t}_1}$	577.6	838.1	840.9	986.4	1737.4	2379.8
$m_{\tilde{e}_L}, m_{\tilde{\mu}_L}$	818.0	875.5	875.3	1248.7	2101.1	2277.5
$m_{\tilde{\nu}_{eL}}, m_{\tilde{\nu}_{\mu L}}$	814.0	872.0	871.8	1246.2	2100.1	2277.3
$m_{\tilde{\tau}_1}$	669.0	688.9	722.5	1011.6	1699.8	1868.5
$m_{\tilde{\nu}_{\tau L}}$	749.0	807.9	821.8	1148.5	1939.2	2158.3
$m_{\tilde{d}_R}, m_{\tilde{s}_R}$	912.8	1184.9	1184.5	1470.5	2512.0	3192.1
$m_{\tilde{u}_R}, m_{\tilde{c}_R}$	914.9	1194.5	1193.9	1477.8	2527.2	3225.6
$m_{\tilde{b}_2}$	733.7	992.0	1032.1	1193.2	2060.8	2813.1
$m_{\tilde{t}_2}$	714.8	1003.1	1026.6	1164.8	2004.4	2781.8
$m_{\tilde{e}_R}, m_{\tilde{\mu}_R}$	809.2	835.9	836.0	1223.4	2048.4	2134.5
$m_{\tilde{\tau}_2}$	755.4	816.3	829.7	1152.5	1940.2	2159.6
m_{h_0}	111.4	115.0	115.1	115.7	119.3	121.7
m_{H_0}	426.5	444.6	637.3	653.3	1140.7	1774.5
m_{A_0}	426.4	444.6	637.2	653.2	1140.6	1774.5
$m_{H^\pm}$	435.4	452.6	642.4	658.4	1143.4	1775.8
$\tilde{A}_t$	445.5	810.5	830.3	829.5	1485.9	2397.4
$\tilde{A}_b$	561.2	954.2	1079.2	1014.4	1811.7	3112.4
$\tilde{A}_\tau$	159.9	192.7	272.2	257.2	473.0	864.9

Conclusions

- Generalized the previous construction by relying only on the most basic property of the bulk Kahler potential

- Presented a very general form of the Kahler potential for chiral matter and used it in the construction

- All moduli are stabilized by the potential generated by the strong gauge dynamics in the hidden sector. The superpotential is very simple, contains only two terms!

- Supersymmetry is broken spontaneously via F-terms (no antibranes are needed for uplifting)

- Constrained $m_{3/2} \sim O(10)\ TeV$ from CC=0
- Demonstrated via explicit computations that the soft breaking terms are independent of the detailed microscopic structure of the Kahler potential
- Gauginos are always light: $M_{1,2,3} \sim O(100\text{-}1000)\ GeV$
- Gauge coupling unification and REWSB are generic
- The little hierarchy problem leads to 0.01% tuning
- Typical spectrum: light gauginos and heavy scalars and higgsinos, Bino LSP is generic but can be Wino
- Approximately sequestered limit - all superpartners are light. For $28 < \tan\beta < 43$ the LSP can have a large higgsino component

Related work

- Found a robust solution to the Strong CP problem and realization of the String Axiverse, (Piyush's talk)
(K.B. with Bobby Acharya and Piyush Kumar; hep-th/1004.5138)

- Constructed a new class of compactifications in Type IIB on CY orientifolds, completely analogous to the M-theory models described here. Found explicit CY examples that implement the idea. (K.B with Volker Braun, Piyush Kumar and Stuart Raby: hep-th 1003.1982)

Things to do in the future

- Find a good argument/derivation for sequestering
- Yukawa couplings and neutrino masses
- Inflation (probably need to know the details of $V_7(s_i)$)