On Moduli Stabilization in M-Theory on Singular G_2 and its Phenomenology

Mahdi Torabian

International Center for Theoretical Physics, Trieste

Planck 2010, CERN, June 1, 2010

In collaboration with B. S. Acharya, In preparation

Motivations

It's been noticed that 4 dimensional vacua of M-Theory compactified on singular G_2 manifolds offer

a practical framework for studying physics beyond the Standard Model

[Acharya; Atiyah; Friedmann; Witten, '01, '02]

✓ The key elements of low scale physics are localized at singularities in the compactification manifold. In particular, non-Abelian gauge symmetry arises via co-dim 4 orbifold singularity. Wherever this 3-fold in G_2 develops co-dim 7 singularities, the symmetry gets enhanced by one rank and charged chiral fermions can be supported at conical singularities.

✓ In a bottom-up approach, through Geometric Engineering successful local models have been constructed.

[for recent works see Bourjaily '08,'09]

Motivations

It's been noticed that 4 dimensional vacua of M-Theory compactified on singular G_2 manifolds offer

a practical framework for studying physics beyond the Standard Model

✓ However, there are some elements we don't see directly at low scale physics:

- Supersymmetry → must be dynamically broken
- Moduli fields → must be stabilized
- Ubiquitous $U(1)$'s → must be spontaneously broken

✓ There must be a good Mechanism, in a top-down approach, to get rid of these extras but still keep their virtues for low scale physics.

Q: Which Mechanism is a good one?

Motivations

It's been noticed that 4 dimensional vacua of M-Theory compactified on singular G_2 manifolds offer

a practical framework for studying physics beyond the Standard Model

as such, must EXPLAIN the scale of the Standard Model

✓There must also be a dynamics to generate and stabilize the Hierarchy.

We take the "Hierarchical Scales" as the guiding principle.

In G_2-construction we use "strong gauge dynamics" as *the* Mechanism:

$$\Lambda \sim m_{Pl} e^{-2\pi/b_0\alpha}$$

[Witten, '81]

IDEA: to study 4-dimensional vacua of M-Theory with Hierarchical scales, SUSY and $U(1)$'s broken, moduli stabilized.

WISH: to make a general prediction for a large subset of vacua.

Outline

1. Motivations
2. Review of previous results in G_2 construction
3. A more general framework with $U(1)$ and Yukawa interactions
4. Phenomenology

Generalities

The moduli space of M-Theory on G_2 is parametrize by b^3_X coordinates

$$z_i = t_i + is_i$$

✓ The moduli must get vev's BUT not with fluxes!

× tree level contributions from fluxes lead to large $\langle W \rangle$, uninteresting Phenonemology

✓ In the absence of fluxes, ALL the moduli enjoy a PQ shift symmetry.

✓ Therefore, the only contributions to the superpotential are non-perturbative:

$$W \supset \mathit{Gaugino\ Condensates} + \mathit{Membrane\ Instantons}$$

The 1^{st} working model

[Acharya, Kane, et. al. '06, '07, '08]

$$W = Ae^{i2\pi f/Q} + B\phi^{-2/P} e^{i2\pi f/P}$$
$$K = -3\ln\left(4\pi^{1/3} V_X\right) + \frac{\bar{\phi}\phi}{V_X}$$

[Beasley,Witten '02; Bobkov, Acharya '08]

$$A, B \sim \mathcal{O}(1)\ , \quad f = \sum_i N_i z_i = \frac{\theta}{2\pi} + i\alpha_{HS}^{-1}\ , \quad V_X(s_i) = \prod_i s_i^{a_i}\ , \quad \sum_i a_i = 7/3$$

It's shown that the scalar potential generated by strong gauge dynamics

$$V = e^K\left(K^{I\bar{J}} D_I W D_{\bar{J}} \bar{W} - 3|W|^2\right)$$

- ✓ Stabilizes ALL the moduli
- ✓ Spontaneously breaks SUSY in a dS vacuum
- ✓ Dynamically generates Hierarchical Scales
- ✓ Interesting Phenomenology and Cosmology

I want to report on a more general framework

✓ A framework with another kind of interactions in the superpotential, like Yukawa type Interactions and terms with Membrane Instanton as well as the one in which extra $U(1)$ gauge symmetries are also considered.

✓ In the hope of setting up a better framework for accommodating and further explaining physics beyond the Standard Model in G_2.

A Framework with $U(1)$ and Yukawa

The Model

There exist a pure $SU(P)$ gauge theory in the HS and a $U(1)$ sector with charged matter and Yukawa interaction.

The Superpotential:

$$W = A\, e^{2\pi i f/P} \quad + \quad \lambda\, T_1 T_2 T_3\, e^{2\pi i \tilde{f}}$$

$$f = \sum_i N_i z_i = \frac{\theta}{2\pi} + i {\alpha_{HS}}^{-1} \quad , \quad \tilde{f} = \sum_i \tilde{N}_i z_i$$

$$N_i = \int_{\gamma_3^{SU(P)}} \Phi \quad , \quad \tilde{N}_i = \int_{\gamma_3^{mem}} \Phi$$

The Kahler Potential:

$$K = -3 \ln\left(4\pi^{1/3} V_X\right) + \frac{\sum_{a=1}^{3} \overline{T}_a T_a}{V_X} \, ,$$

A Framework with $U(1)$ and Yukawa

Effective SUGRA Scalar Potential

$$V = e^K \left(\sum_{i=1}^{b_X^3} F^i F_i + \sum_{a=1}^{3} F^a F_a - 3|W|^2 \right)$$

$$\begin{aligned} F_I &= D_I W = \partial_I W + W \partial_I K \\ F^I &= \sum_{\bar{J}} K^{I\bar{J}} F_{\bar{J}} \end{aligned}$$

A Framework with $U(1)$ and Yukawa

$$V = \frac{e^{\sum_a \overline{T}_a T_a / V_X}}{64\pi V_X^3} A^2 (1-x)^2 e^{-4\pi/P \sum_i N_i s_i}$$

$$\times \Bigg[\frac{4}{3} \frac{1}{1 + \frac{\sum_a \overline{T}_a T_a}{3V_X}} \sum_i \sum_{\bar{j}} \frac{1}{a_i} N_i s_i \frac{y_i}{1-x} \left(\Delta^{-1}\right)^{i\bar{j}} N_{\bar{j}} s_{\bar{j}} \frac{y_{\bar{j}}}{1-x}$$

$$+4 \frac{1}{1-x} \frac{1}{1 + \frac{\sum_a \overline{T}_a T_a}{3V_X}} \sum_i N_i s_i \frac{y_i}{x}$$

$$+ \frac{x^2}{(1-x)^2} \left(\sum_a \frac{V_X}{\overline{T}_a T_a} + \frac{7}{3} \frac{1}{1 + \frac{\sum_a \overline{T}_a T_a}{3V_X}} \right)$$

$$+ \frac{x}{1-x} \left(8 - \frac{14}{9} \frac{1}{1 + \frac{\sum_a \overline{T}_a T_a}{3V_X}} \sum_a \frac{\overline{T}_a T_a}{V_X} \right)$$

$$- \frac{4}{3} \sum_a \frac{\overline{T}_a T_a}{V_X} + \frac{7}{9} \frac{1}{1 + \frac{\sum_a \overline{T}_a T_a}{3V_X}} \sum_a \left(\frac{\overline{T}_a T_a}{V_X} \right)^2 + 4 \Bigg] .$$

A Framework with $U(1)$ and Yukawa

Minimization of the scalar potential for the Moduli

There exist metastable de Sitter solutions for the scalar potential IF for some i, $0 < i \leq b_X^3$, we have to the leading order in α_{HS}:

$$\frac{\lambda}{A} T_{01} T_{02} T_{03} e^{\sum_i (2\pi/P - 2\pi/(N_i/\tilde{N}_i)) N_i s_i} = \frac{N_i/\tilde{N}_i}{P} < 1$$

We introduce a new notation:

$$\frac{N_i}{\tilde{N}_i} = n + \mathcal{O}(\alpha_{HS})$$

We will see that $\frac{n}{P}$ becomes a relevant parameter in parametrizing the space of solutions.

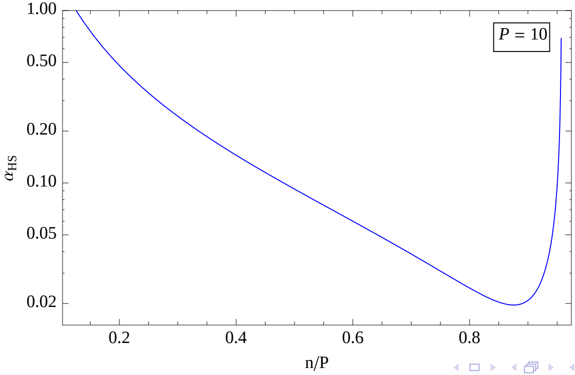
Moduli VEV's in a de Sitter Vacuum

$$
\begin{aligned}
\langle s_i \rangle &= \frac{a_i}{N_i \eta_i} \frac{3P}{4\pi} \frac{1}{P/n - 1} \ln\left(\frac{P}{n} \frac{\lambda}{A} T_{01} T_{02} T_{03} \right) \\
\left\langle \frac{\overline{T}_a T_a}{V_X} \right\rangle &= \frac{n/P}{1 - n/P} \Big(1 + \big(9/14 - n/P \big) f(n/P) \Big) ,
\end{aligned}
$$

✓ Moduli get vev's in a SUGRA-valid regime, i.e. $V_X > 1$ or $s_i > 1$.

Gauge coupling in the Hidden Sector in a de Sitter Vacuum

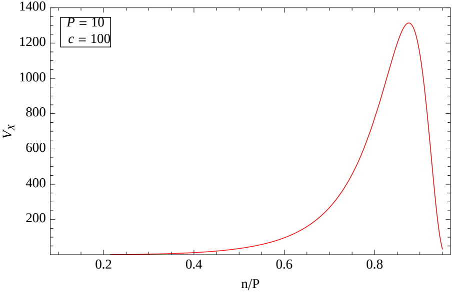
$$\alpha_{HS} = \frac{2\pi}{\eta P}\frac{1}{2}\frac{1-n/P}{n/P} \times \left(1 + \frac{n/P}{1+g(n/P)}\left(\frac{14}{9} + \frac{5}{9}(9/14 - n/P)f(n/P)\right)\right)^{-1},$$

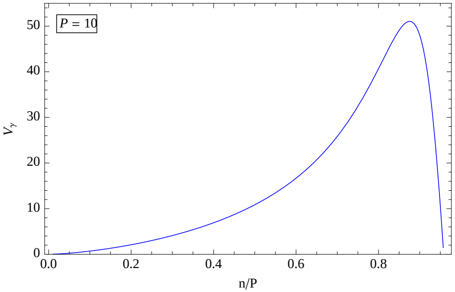


Stabilized Volumes

✓ There are two volumes, as homogeneous functions of the moduli, which control the low scale Phenomenology.

$$V_X(s_i) \sim \prod_{i=1}^{b_X^3} s_i^{a_i} \sim {\alpha_{HS}}^{-7/3} \qquad , \qquad V_{\gamma_3}(s_i) \sim \sum_{i=1}^{b_X^3} N_i s_i = {\alpha_{HS}}^{-1}$$

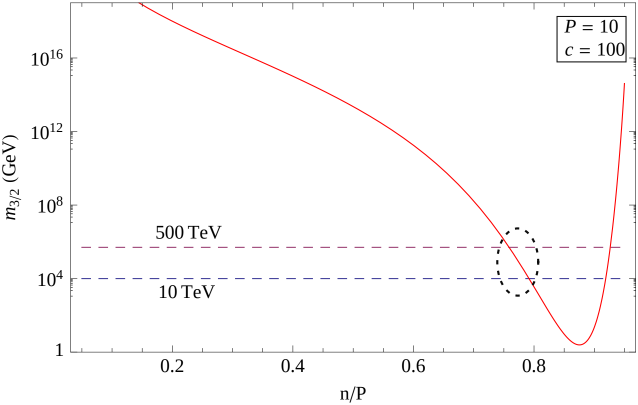




Gravitino Mass

$$m_{3/2} = m_P \cdot e^{K/(2m_P^2)} \, |W/m_P^3|$$

$$m_{3/2} = m_P \, \frac{Ac^{-3/2}}{8\pi^{1/2}} \, (1 - n/P)\left(1 + \eta \frac{n/P}{1 - n/P} \frac{\alpha_{HS} \cdot P}{2\pi}\right) \alpha_{HS}^{7/2} e^{\overline{T}_a T_a/2V_X - 2\pi/\alpha_{HS} \cdot P}$$



Moduli Masses

$$m_{IJ} = \left.\frac{\partial^2 V(\varphi)}{\partial\varphi_I \partial\varphi_J}\right|_{@min}$$

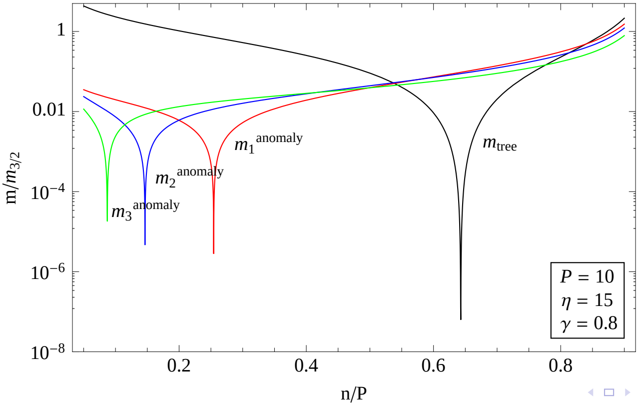
Depends on the details of the compactification manifold
However, for an explicit example, we found

$$m_{s_i} \sim \mathcal{O}(m_{3/2})$$
$$m_{T_a} \sim \mathcal{O}(m_{3/2})$$

Gaugino Masses

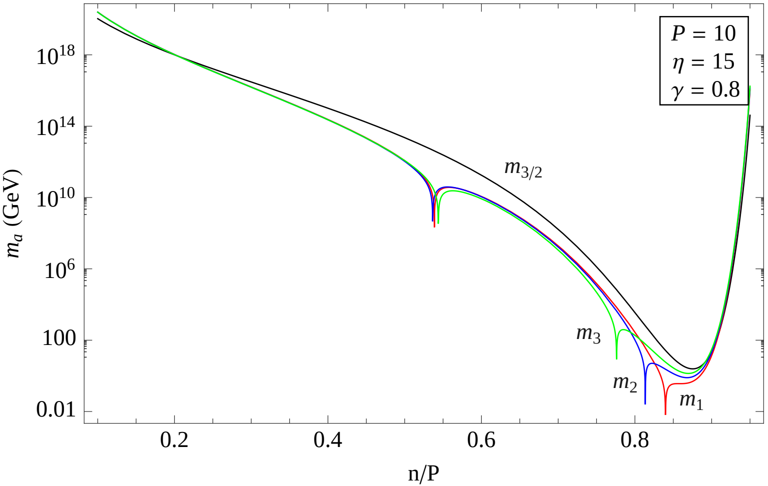
$$m_a = m_{1/2}^{\text{tree}} + m_a^{\text{threshold}}(\eta) + m_a^{\text{anomaly}}(\gamma),$$

$$m_{1/2}^{tree} = \frac{n/P}{1-n/P}\frac{\alpha_{HS}\cdot P}{2\pi}\left(\frac{2}{3}\frac{1}{1+\frac{\sum_a \overline{T}_a T_a}{3V_X}}\frac{1}{1-n/P} - \frac{5}{21} - \frac{1}{7}\frac{n/P}{1-n/P}\sum_a \frac{V_X}{\overline{T}_a T_a}\right) m_{3/2}$$



$$m_{1/2} < m_{3/2}$$

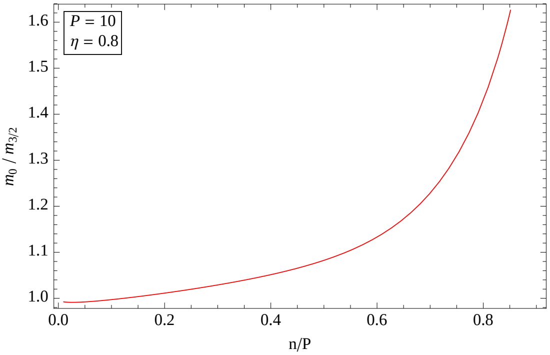
Gaugino Masses



Scalar Masses

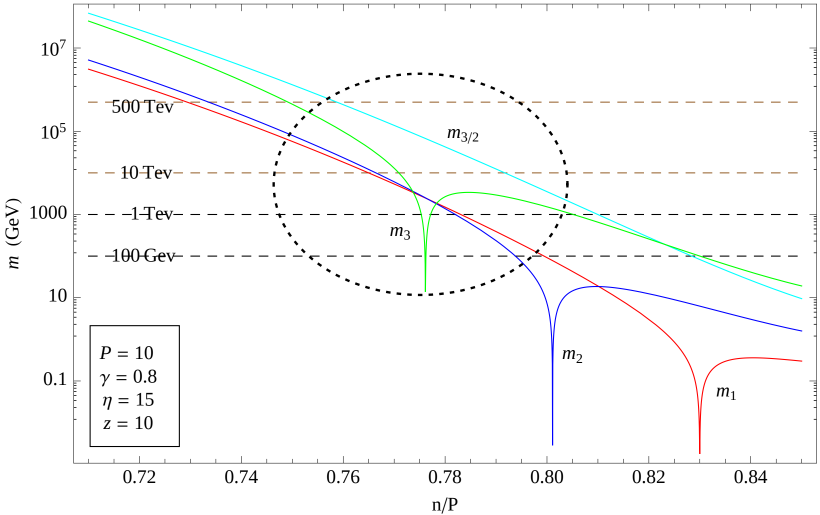
$$m^2_{\alpha\bar\beta} = \Big(m^2_{3/2} + V_0 - \sum_{I,\bar J} e^{K^{\rm HS+U_1}} F^I F^{\bar J} \partial_I \partial_{\bar J} \ln \tilde K^{\rm VS}\Big)\delta_{\alpha\bar\beta}$$

$$m_0 = \Bigg[1 + \frac{1-\gamma}{3}\sum_a \frac{\overline{T}_a T_a}{V_X}\Bigg(\frac{4}{3} + \frac{n/P}{1-n/P}\frac{V_X}{\overline{T}_a T_a} - \frac{7}{9}\frac{1}{1+\frac{\sum_a \overline{T}_a T_a}{3V_X}}\frac{3-n/P}{1-n/P} - \frac{7}{9}\frac{1}{1+\frac{\sum_a \overline{T}_a T_a}{3V_X}}\frac{\overline{T}_a T_a}{V_X}\Bigg)\Bigg]^{1/2} m_{3/2}$$



$$m_0 \sim \mathcal{O}(m_{3/2})$$

Gaugino Masses: Wino or Bino LSP



Conclusions

We've studied a more general framework in G_2 construction.

▶ Utilizing a pure gauge theory in HS which undergoes strong dynamics at low energies and a $U(1)$ sector with charged matter we could

- ✓ Stabilize ALL the moduli in a SUGRA-valid approximation,
- ✓ Spontaneously break SUSY in a dS vacuum,
- ✓ Spontaneously break extra $U(1)$ gauge symmetries,
- ✓ Generate Hierarchical Scales.

A general prediction for ALL these vacua:

- → Gaugino masses are suppressed relative to the gravitino mass.
- → Scalars are as heavy as gravitino.

$$m_{Pl} > m_{11} \gtrsim m_{GUT} > m_{SUSY} \ggg m_{3/2} \sim m_{mod} \sim m_0 \gg m_{1/2}$$

☺