Moduli Stabilization and SUSY Breaking Heterotic Orbifolds

Ben Dundee
The Ohio State University
PASCOS 2009

with Stuart Raby and Alexander Westphal
arxiv:1002.1081 (hep-th)

THE OHIO STATE UNIVERSITY DEPARTMENT OF PHYSICS

This talk

- EFTs from heterotic orbifold compactifications
- Stabilizing moduli in anti-de Sitter minima
- A Simple Model: Stabilizing moduli in (nearly) Minkowski vacua
- Low energy physics (if time---I hope so!)

EFTs from Heterotic Orbifolds

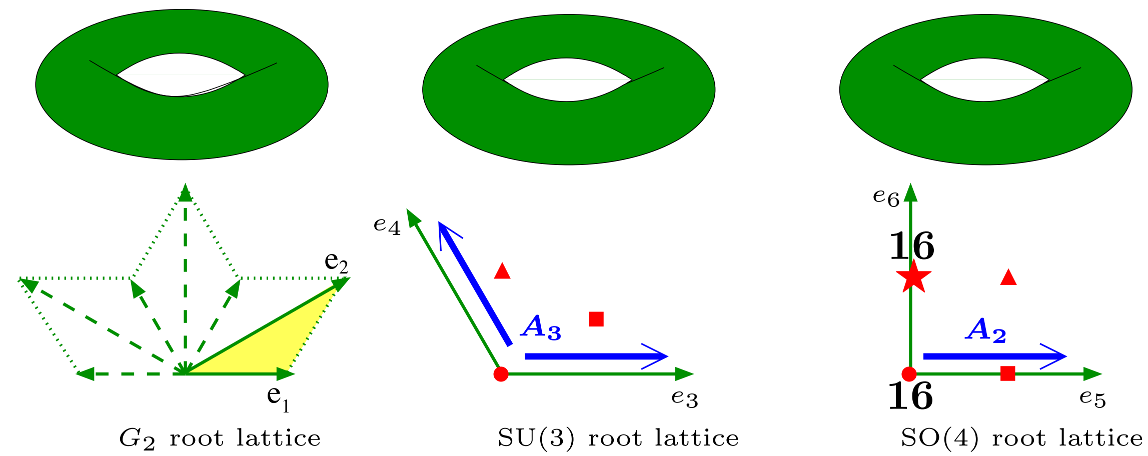
$$E_8 \otimes E_8 \rightarrow MSSM \otimes stuff$$

- Breaking such a large gauge group leaves lots of extra stuff to play with:
  - Extra gauge groups Rank 16-4 = 12
  - Lots of (non-Abelian) singlets!
  - Typically, lots of U(1)s as well (...generally broken by singlet VEVS)
  - A single anomalous, $U(1)_A$. Anomaly canceled by Green-Schwarz mechanism.
  - Superpotential is specified to all orders by string selection rules.

An Example: Mini-Landscape 1 (ML1)

$$E_8 \otimes E_8 \to MSSM \otimes SU_4 \otimes SU_2 \otimes [U_1]^8$$

Lebedev, Nilles, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter, '07



$$T^6/\mathbb{Z}_6 - \mathrm{II}$$

- ✓Good Hypercharge
- ✓MSSM spectrum
- ✓Exotics decouple
- ✓F=D=0 solutions exist
- ✓Heavy top
- ✓Unification

BD, Raby, Wingerter, '08

I will use this model as an example in what follows.

An Example: Mini-Landscape 1 (ML1)

$$E_8 \otimes E_8 \rightarrow MSSM \otimes SU_4 \otimes SU_2 \otimes [U_1]^8$$

Lebedev, Nilles, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter, '07

- ✓ Good Hypercharge
- ✓ MSSM spectrum
- ✓ Exotics decouple
- ✓ F=D=0 solutions exist
- ✓ Heavy top
- ✓ Unification

BD, Raby, Wingerter, '08

Lebedev + 6, *PRL*98 (2007)

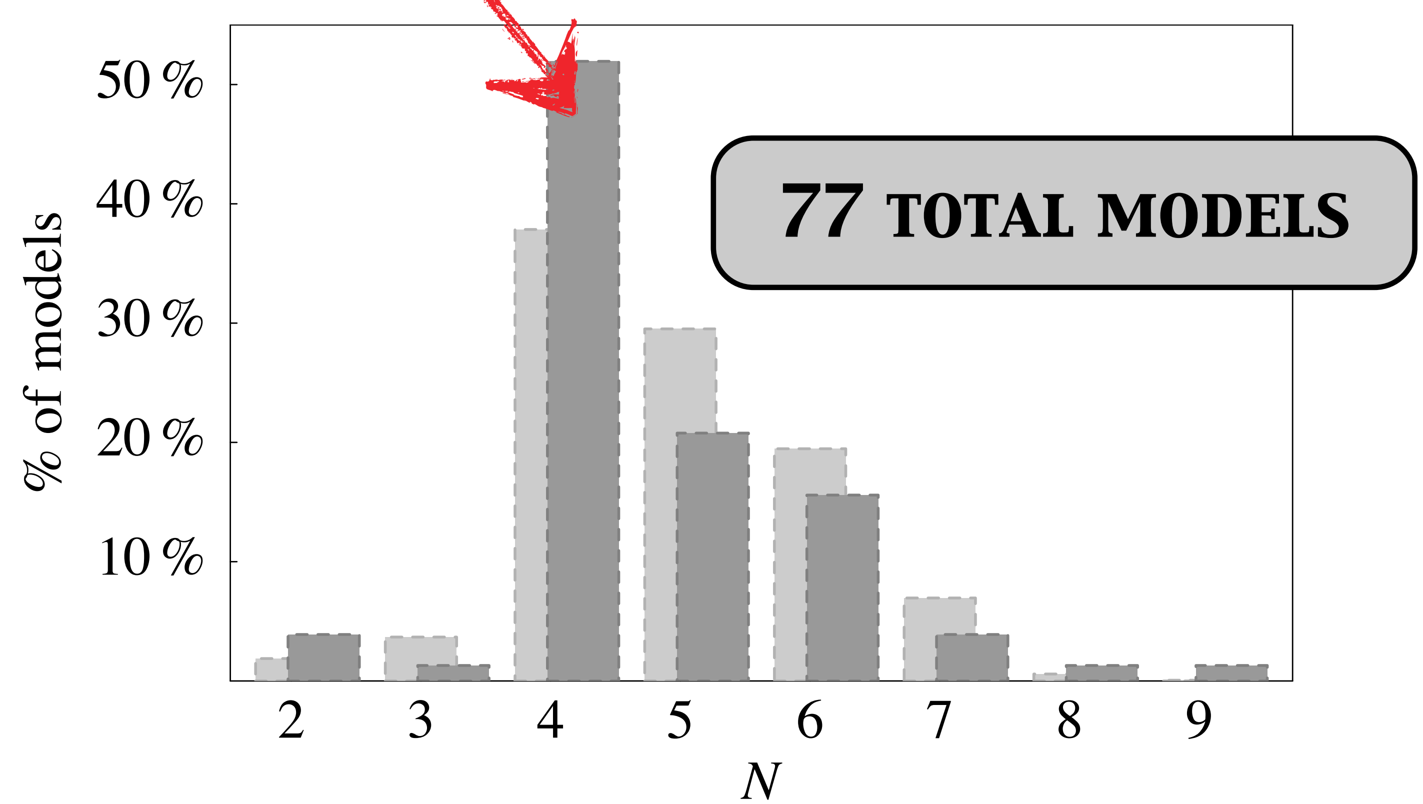


FIG. 2: As in Fig. 1 but with models of Step 8 in the foreground.

Other heterotic models have QCDs, too...

Dienes and Lennek, hep-th/0610319

group	finite sample	extracted Ω_α
U_1	99.94	95.6
SU_2	97.44	98.2
SU_3	47.84	97.6
SU_4	51.04	29.5
SU_5	7.36	41.6
$SU_{>5}$	6.60	1.72
SO_8	13.75	1.53
SO_{10}	4.83	0.21
$SO_{>10}$	2.69	0.054
$E_{6,7,8}$	0.27	0.023

QCDs in the hidden sector seem to be very generic

Table 1: Percentage of four-dimensional $\mathcal{N} = 1$ supersymmetric heterotic string models containing various gauge-group factors at least once in their total gauge groups. Here $SU_{>5}$ indicates the appearance of *any* $SU(n > 5)$ factor, while $SO_{>10}$ indicates any $SO(2n)$ group with $n \geq 6$ and $E_{6,7,8}$ signifies any of the 'E' groups. For each gauge-group factor, the 'sample' column indicates to the percentages of models exhibiting this factor across our sample of more than one million distinct models in this class. By contrast, the Ω_α column lists the corresponding values to which these percentages would "float", as extracted through Eqs. (4.7) and/or (4.9). It is clear that correcting for such probability deformations can result in abundances which are markedly different from those which appear within a finite sample.

The Moduli in Heterotic Orbifolds

- S (dilaton) sets GUT coupling constant
- T and U (volume and shape moduli) parameterize the compact dimensions
- Other singlets, including:
  - “Blow up modes”: states living at orbifold fixed points which have non-zero (left-moving) oscillator number
  - Other MSSM singlets: may carry charges under extraneous U(1)’s, and set yukawa couplings, etc.

The dilaton

$$\mathcal{L} \supset \frac{\langle S \rangle}{M_{\rm PL}} F_{\mu\nu} F^{\mu\nu}$$

$$\Rightarrow \langle S \rangle \sim \mathcal{O}\left(M_{\rm PL}\right)$$

A dimension five operator sets the gauge coupling constants in string theory. Without someway to give *S* a VEV, we won't have a good Yang-Mills sector!

Barring large threshold corrections, we need <*S*>~2.

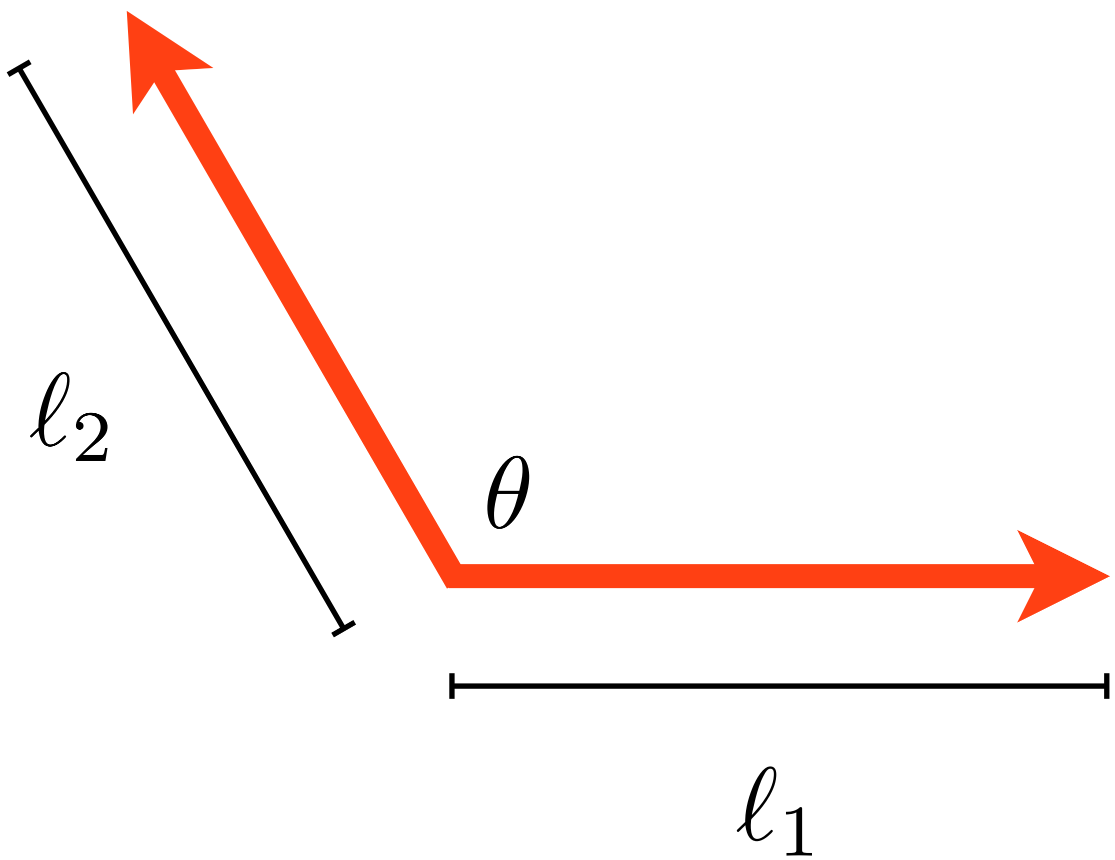
Moduli can be stabilized by radiative corrections once SUSY is broken, as the NR theorems no longer apply. This suggests :

$$\langle S \rangle \sim \Lambda_{SUSY}$$

For the dilaton, which sets the gauge coupling, this implies:

$$\Lambda_{SUSY} \sim M_{\rm PL}$$

Geometric Moduli in Orbifold Compactifications



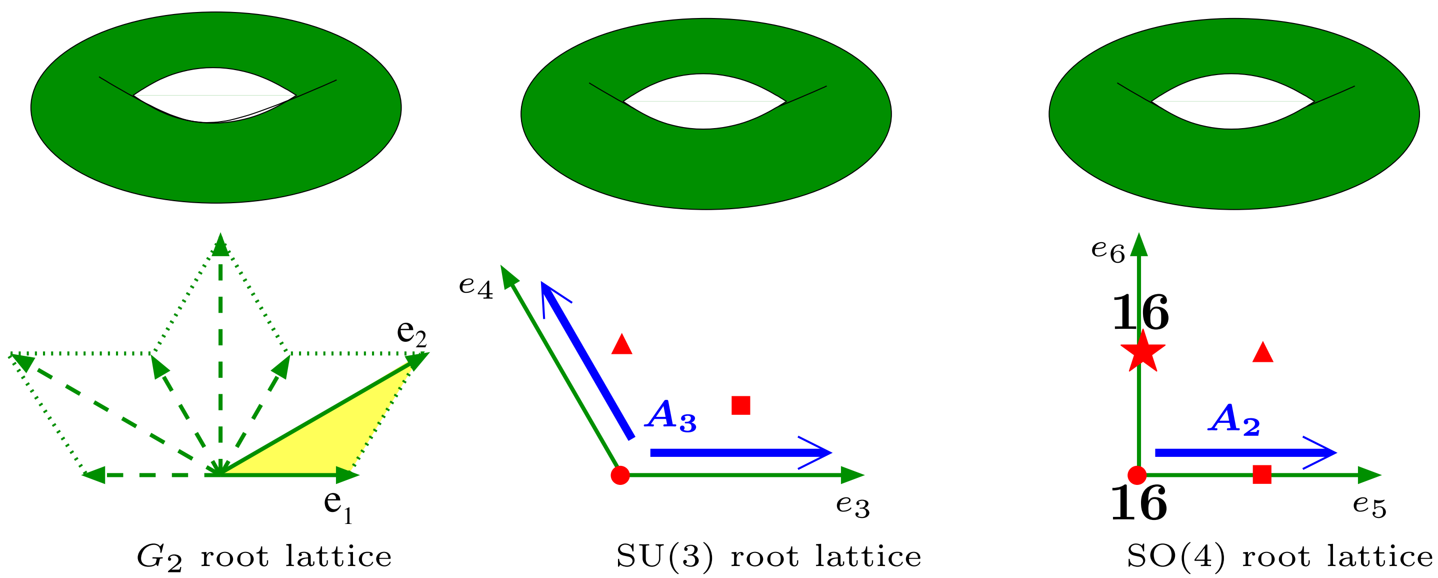
$$T \equiv \ell_1 \ell_2 \cos\theta$$

$$U \equiv \frac{\ell_2}{\ell_1} \sin\theta$$

T and U are scalar fields (moduli) which set the volume of the compact dimensions

$$T \rightarrow \frac{aT - ib}{icT + d} \qquad ad - bc = 1, \quad a, b, c, d \in \mathbb{Z}$$

An Example: Mini-Landscape 1 (ML1)



Can also have subgroups of SL(2,Z). See Love and Todd, hep-th/9606161

$$\mathrm{SL}(2,\mathbb{Z}) \otimes \mathrm{SL}(2,\mathbb{Z}) \otimes \mathrm{SL}(2,\mathbb{Z})$$

The superpotential inherits these symmetries from the UV physics...

$$\mathcal{W} \to \prod_i (c_i T^i + i d_i)\mathcal{W}$$

Raw Materials: mini-landscape EFT’s

- One or more QCD-like hidden sector. (Typically *one*, but possibly more?)
- Tons o’ singlets
- Tons o’ U(1)’s with one possibly (probably) anomalous
- F=D(=W)=0 solutions exist in the global limit (S and T dependence of W not considered)
- Modular invariance of W dictates T (and, in principle, U) dependence
- Dilaton VEV sets gauge coupling

Stabilizing Moduli

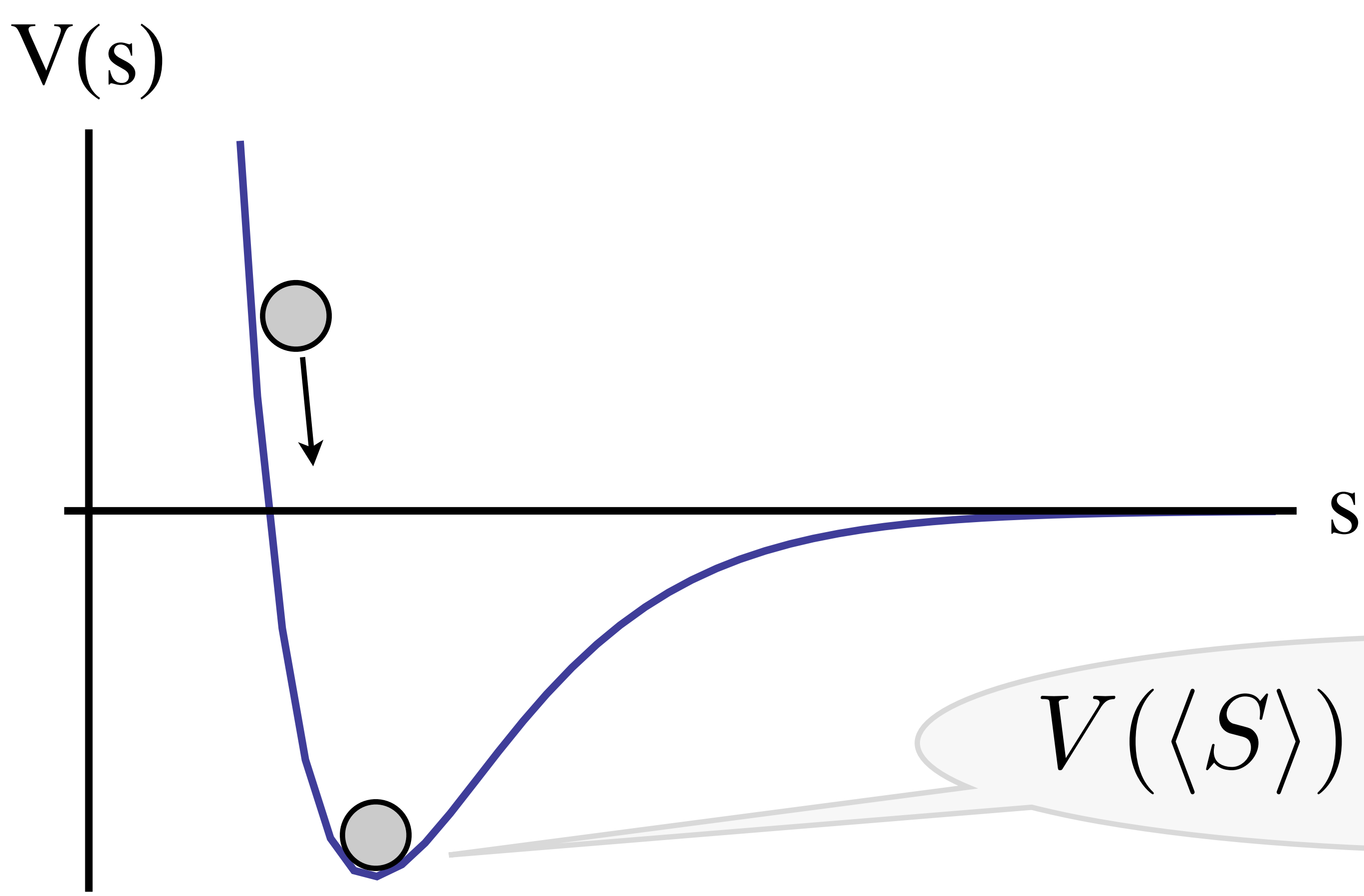
Stabilizing the Dilaton in an AdS minimum

See, for example, KKLT

$$\mathcal{W}_{\rm NP} = A e^{-\frac{24\pi^2}{b}S} + w_0$$

Origin of w0?

$$m_{3/2} \sim \langle \mathcal{W} \rangle$$
$$\Rightarrow m_{3/2} \sim w_0$$



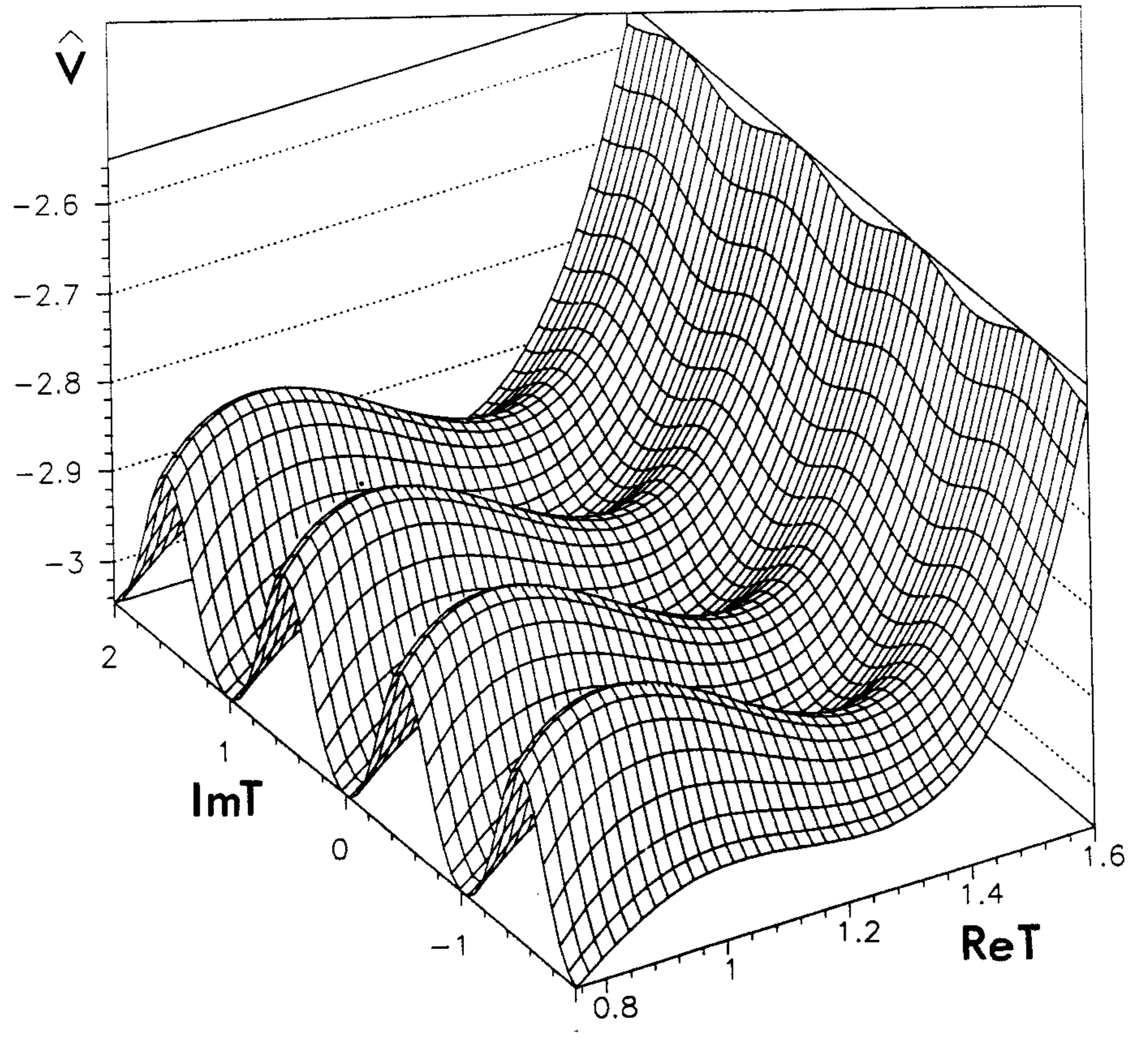
$$V(\langle S \rangle) < 0 \Rightarrow \Lambda < 0$$

Stabilizing T and U: Font, Ibanez, Lust and Quevedo

Modular Invariance implies a very specific form of W...

$$\mathcal{W}(S,T) = \frac{e^{-aS} + w_0}{\eta(T)^6}$$

Dedekind eta function

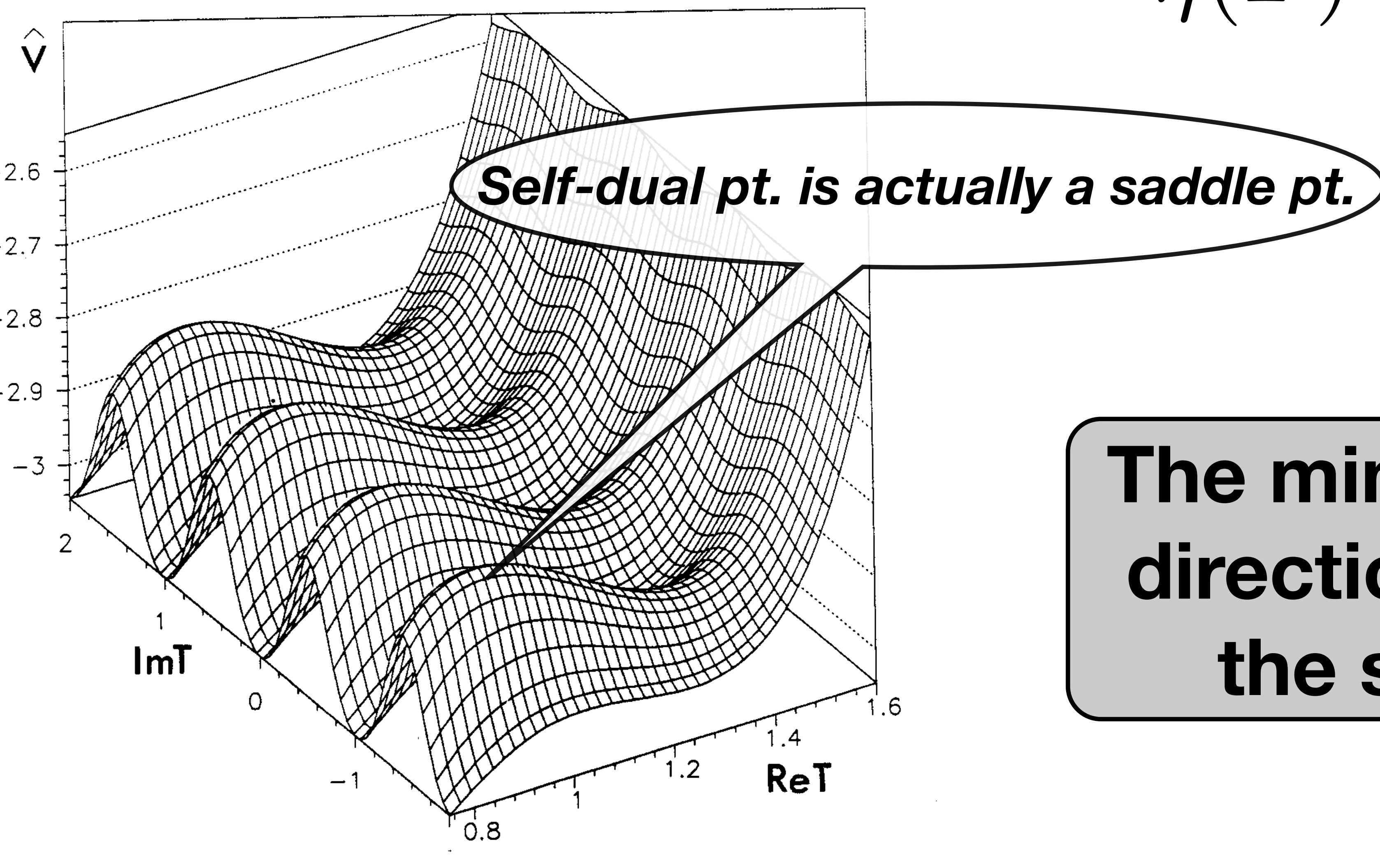


Stabilizing T and U: Font, Ibanez, Lust and Quevedo

Modular Invariance implies a very specific form of W...

$$\mathcal{W}(S,T) = \frac{e^{-aS} + w_0}{\eta(T)^6}$$

Dedekind eta function



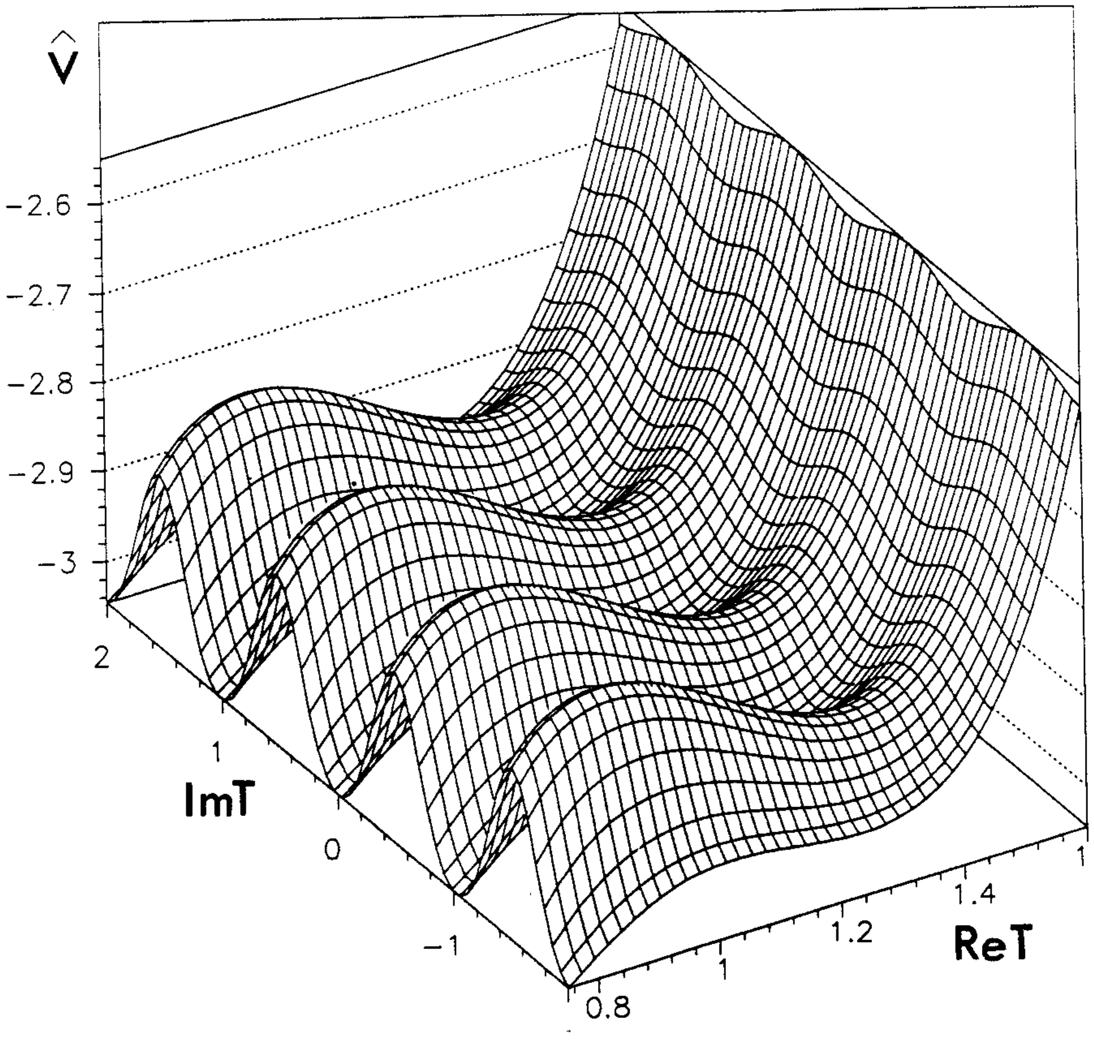
$$\Rightarrow \langle Re(T) \rangle \sim 1.23...$$

The minimum in the Re(T) direction is always “near the self-dual point”.

Stabilizing T and U: Font, Ibanez, Lust and Quevedo

Modular Invariance implies a very specific form of W...

$$\mathcal{W}(S,T) = \frac{e^{-aS} + w_0}{\eta(T)^6}$$



The problem is that the minima are anti-de Sitter:

$$\frac{V_0}{3m_{3/2}^2} \sim -0.8$$

The Good News and the Bad News

- A single gaugino condensate (+ w_0) can stabilize the dilaton (S)
- Modular invariance can stabilize T and U: $\eta(T) \approx e^{\frac{-\pi T}{12}} + \mathcal{O}(e^{-2\pi T})$

We always end up in an anti-de Sitter vacuum!

The Good News and the Bad News

- A single gaugino condensate (+ w_0) can stabilize the dilaton (S)
- Modular invariance can stabilize T and U: $\eta(T) \approx e^{\frac{-\pi T}{12}} + \mathcal{O}(e^{-2\pi T})$

We always end up in an anti-de Sitter vacuum!

A Model (arxiv:1002.1081 BD, Raby, Westphal)

Ingredients

	$\mathrm{SU}(5)$	$\mathrm{U}(1)_A$
Q	$\square$	q
$\tilde{Q}$	$\bar{\square}$	$\tilde{q}$
ϕ_1	1	$-2/r$
ϕ_2	1	$-9/r$
χ	1	$20/r$

Can also find SU(4) examples, too

A for Anomalous

Also, two moduli: S and T

A Model (arxiv:1002.1081 BD, Raby, Westphal)

$$\mathcal{K}_{\rm M} = -\log(S+\bar{S}) - 3\log(T+\bar{T})$$

Typical modular structure

$$\mathcal{K} = \mathcal{K}_{\rm M} + \frac{\bar{\phi}_2\phi_2}{(T+\bar{T})^n} +$$

$$\mathcal{W} = \mathcal{W}_{\rm NP} + \mathcal{W}_{\rm SINGLET}$$

A Model (arxiv:1002.1081 BD, Raby, Westphal)

$$\mathcal{K}_{\rm M} = -\log(S+\bar{S}) - 3\log(T+\bar{T})$$

$$\mathcal{K} = \mathcal{K}_{\rm M} + \frac{\bar{\phi}_2\phi_2}{(T+\bar{T})^n} + \text{other singlets}$$

$$\mathcal{W} = \mathcal{W}_{\rm NP} + \mathcal{W}_{\rm SINGLET}$$

Assume no modular dependence in phi initially (n=0)

A Model (arxiv:1002.1081 BD, Raby, Westphal)

$$\mathcal{K}_{\rm M} = -\log(S+\bar{S}) - 3\log(T+\bar{T})$$

$$\mathcal{K} = \mathcal{K}_{\rm M} \ldots (T+\bar{T})$$

Non-pert. piece plus singlet-singlet couplings + Wo.

$$\mathcal{W} = \mathcal{W}_{\rm NP} + \mathcal{W}_{\rm SINGLET} + \mathcal{W}_0$$

Heterotic SQCD with mass terms

$$\mathcal{W}_{\rm NP} = \mathcal{M}(\phi, T) Q\tilde{Q} + (N_c - N_f) \left(\frac{\Lambda^{3N_c - N_f}}{\det \, Q\tilde{Q}} \right)^{\frac{1}{N_c - N_f}}$$

a la Affleck, Dine, Seiberg...

$$\mathcal{M}(\phi, T) = \eta(T)^{\gamma_T} \phi^r \approx e^{\frac{\gamma_T \pi}{12}} \phi^r$$

$$\Lambda_{\rm SQCD} \sim e^{\frac{-8\pi^2}{b_{\rm SQCD}} \frac{1}{g^2}}$$

$\frac{1}{g^2} = \langle S \rangle$ *to leading order!*

Strategy: Integrate out all of the flavors and work in the pure gauge limit.

Heterotic SQCD with mass terms

$$\mathcal{W}_{\rm NP} = \mathcal{M}(\phi, T)Q\tilde{Q} + (N_c - N_f)\left(\frac{\Lambda^{3N_c - N_f}}{\det\ Q\tilde{Q}}\right)^{\frac{1}{N_c - N_f}}$$

$$\boxed{\mathcal{W}_{\rm NP}(S, T, \phi) = N_c\left(\phi^r e^{\frac{\gamma_T \pi}{12}}\right)^{N_f/N_c} e^{\frac{-8\pi^2}{N_c}S}}$$

A Model: Singlet superpotential

$$\mathcal{W}_{\mathrm{SINGLET}} = \chi\left(\phi_1^{10} + \lambda\phi_1\phi_2^2\right)$$

$$\begin{aligned} \langle\chi\rangle &= 0, \\ \langle\phi_1\rangle &= 0, \\ \langle\phi_2\rangle &= \text{arbitrary} \end{aligned}$$

Note that we have a SUSY vacuum for these singlet VEVS

$\Longrightarrow$ **In this (SUSY) vacuum,** $\langle\mathcal{W}_{\mathrm{SINGLET}}\rangle = 0$

A Model: FI D Term

$$20\,|\chi|^2 - 2\,|\phi_1|^2 - 9\,|\phi_2|^2 = \xi$$

$$\langle\chi\rangle = 0,$$
$$\langle\phi_1\rangle = 0,$$
$$\langle\phi_2\rangle = \sqrt{\frac{\xi}{9}}.$$

This solution now satisfies F = D = 0.

A Model: Scorecard

$$20\,|\chi|^2 - 2\,|\phi_1|^2 - 9\,|\phi_2|^2 = \xi$$

- ✓**SUSY QCD in hidden Sector**
- ✓**Anomalous U(1)**
- ✓**F=D=0 solutions exist**
- ✓**W=0 in the NP limit**

This solution now satisfies $F = D = 0$.

Generating w_0

$$\mathcal{W}_{\rm SINGLET} = \chi\left(\phi_1^{10} + \lambda\phi_1\phi_2^2\right)$$

The singlet superpotential is calculated to some finite order, and has an (approximate) R symmetry:

$$\begin{aligned} R(\chi) &= 2 \\ R(\phi_1) = R(\phi_2) &= 0. \end{aligned}$$

Generating w_0

$$\mathcal{W}_{\text{SINGLET}} = \chi \left(\phi_1^{10} + \lambda \phi_1 \phi_2^2\right)$$

The singlet superpotential is calculated to some finite order, and has an (approximate) R symmetry:

$$\begin{aligned} R(\chi) &= 2 \\ R(\phi_1) = R(\phi_2) &= 0. \end{aligned}$$

Explicitly broken R symmetries are a generic feature of the heterotic models, and can generate w_0:

$$\mathcal{W}_0 = e^{-bT} w_0$$

Kappl, et al., arXiv:0812.2120(hep-th)

A Specific Model

A Specific Example

$$\mathcal{W} \sim \left(A\phi^p e^{-aS}\right) e^{-b_2 T} + w_0 e^{-bT}$$

$$a = \frac{8\pi^2}{5} \qquad b = \frac{8}{125} \qquad b_2 = \frac{29\pi}{20}$$

$$A = 45 \qquad r = 15p \qquad p = \frac{2}{5}$$

$$w_0 = 62 \times 10^{-16}$$

A Specific Example

$$\mathcal{W} \sim \left(A\phi^p e^{-aS}\right) e^{-b_2 T} + w_0 e^{-bT}$$

$$\langle s \rangle \approx 2.0 \qquad \langle t \rangle \approx 1.7$$

$$\langle \sigma \rangle \approx 1.0 \qquad \langle \phi_2 \rangle \approx 0.08$$

$$\langle \chi \rangle = \langle \phi_1 \rangle = 0$$

$$F_S \approx -3.3 \times 10^{-16} \qquad F_T \approx 4.7 \times 10^{-15} \qquad F_{\phi_2} \approx 1.0 \times 10^{-16}$$

Can check that all other singlets are stabilized after SUSY breaking (see paper)

A Specific Example

$$\mathcal{W} \sim \left(A\phi^p e^{-aS}\right) e^{-b_2 T} + w_0 e^{-bT}$$

$$\langle s \rangle \approx 2.0 \qquad \langle t \rangle \approx 1.7$$

$$\langle \sigma \rangle \approx 1.0 \qquad \langle \phi_2 \rangle \approx 0.08$$

$$\langle \chi \rangle = \langle \phi_1 \rangle = 0$$

$$F_S \approx -3.3 \times 10^{-16} \qquad F_T \approx 4.7 \times 10^{-15} \qquad F_{\phi_2} \approx 1.0 \times 10^{-16}$$

A Specific Example

$$\mathcal{W} \sim \left(A\phi^p e^{-aS}\right) e^{-b_2 T} + w_0 e^{-bT}$$

$$\langle s \rangle \approx 2.0 \qquad \langle t \rangle \approx 1.7$$

$$\langle \sigma \rangle \approx 1.0 \qquad \langle \phi_2 \rangle \approx 0.08$$

$$\langle \chi \rangle = \langle \phi_1 \rangle = 0$$

$$F_S \approx -3.3 \times 10^{-16} \qquad \boxed{F_T \approx 4.7 \times 10^{-15}} \qquad F_{\phi_2} \approx 1.0 \times 10^{-16}$$

SUSY breaking “mostly” from T...

A Specific Example

$$\mathcal{W} \sim \left(A\phi^p e^{-aS}\right) e^{-b_2 T} + w_0 e^{-bT}$$

$$\langle s \rangle \approx 2.0 \qquad \langle t \rangle \approx 1.7$$

$$\langle \sigma \rangle \approx 1.0 \qquad \langle \phi_2 \rangle \approx 0.08$$

$$\langle \chi \rangle = \langle \phi_1 \rangle = 0$$

$$F_S \approx -3.3 \times 10^{-16} \qquad F_T \approx 4.7 \times 10^{-15} \qquad F_{\phi_2} \approx 1.0 \times 10^{-16}$$

SUSY breaking "mostly" from T...

A Specific Example

$$\mathcal{W} \sim \left(A\phi^p e^{-aS}\right) e^{-b_2 T} + w_0 e^{-bT}$$

$$\langle s \rangle \approx 2.0 \qquad \langle t \rangle \approx 1.7 \qquad \neq 1.234...$$

$$\langle \sigma \rangle \approx 1.0 \qquad \langle \phi_2 \rangle \approx 0.08$$

$$\langle \chi \rangle = \langle \phi_1 \rangle = 0$$

$$F_S \approx -3.3 \times 10^{-16} \qquad F_T \approx 4.7 \times 10^{-15} \qquad F_{\phi_2} \approx 1.0 \times 10^{-16}$$

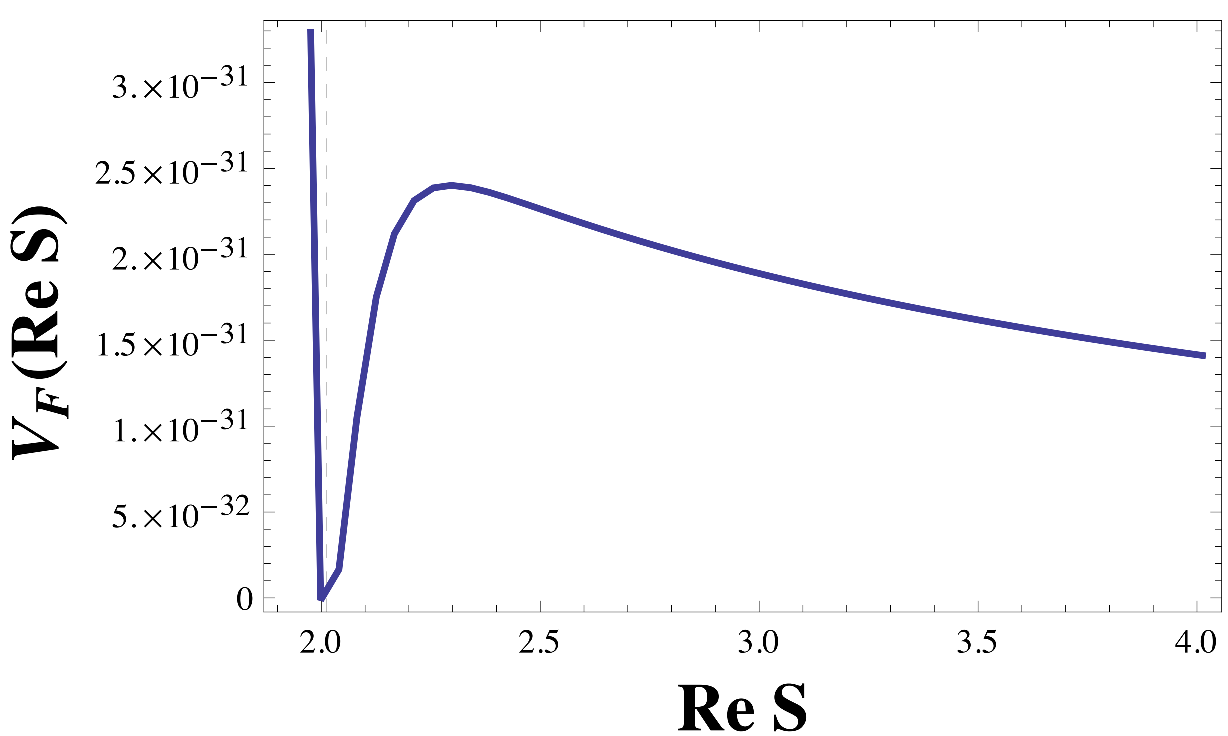
SUSY breaking "mostly" from T...

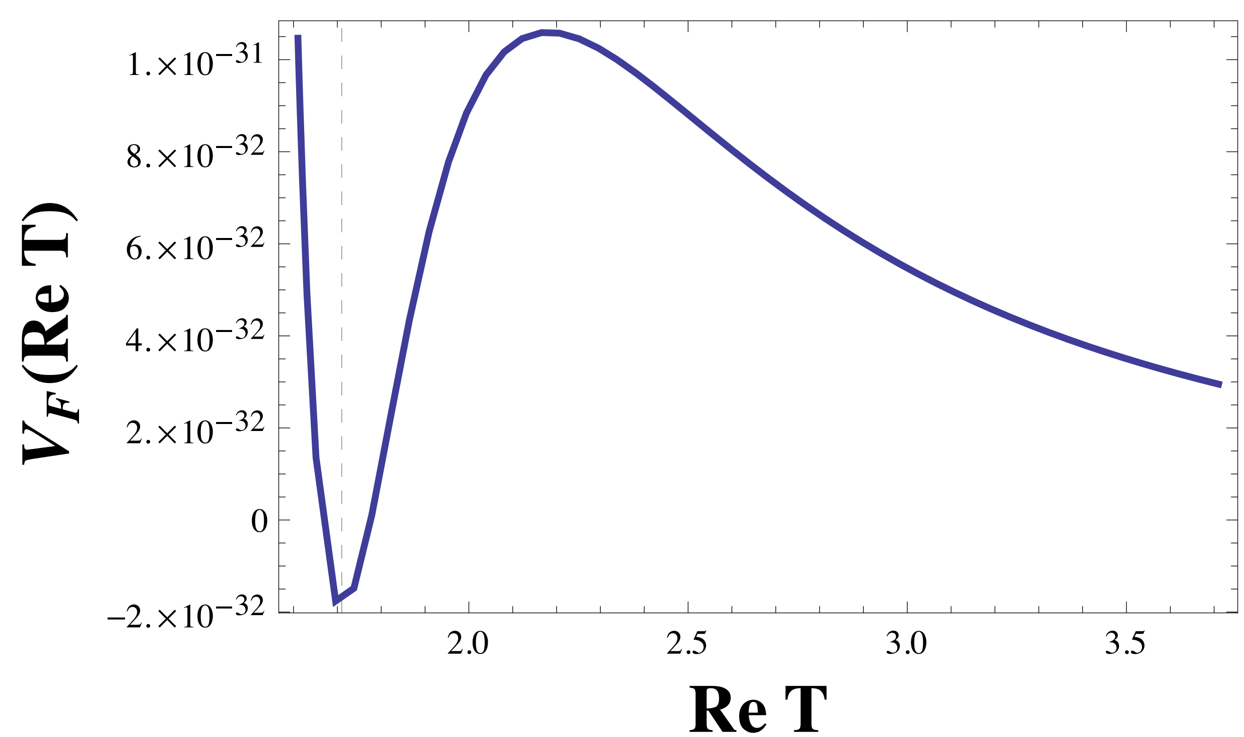
An Interesting Potential: b > 0

$$\mathcal{W} \sim \left(A\phi^p e^{-aS}\right) e^{-b_2 T} + w_0 e^{-bT}$$

The dilaton sees KKLT

The T modulus sees a Racetrack (when b > 0)





Low Energy Observables

- Derive soft masses (Brignole, Ibanez, Munoz; Minetruy, Gaillard, Nelson)
- Run with `SoftSUSYv3.1` (Allanach)
- Check other observables (FCNC, EW precision obs., WMAP data, etc.) with `micrOMEGASv2.1` (Belanger, Boudjema, Pukhov, Semenov)
  - Les Houches accords make interface easy!

ML1A as an example

	Q_A		Modular Weight $\vec{n}$	
	Gen. 1,2	Gen. 3	Gen. 1,2	Gen. 3
$\mathbf{Q}$	7/18	4/3	(5/6, 2/3, 1/2)	(0,1,0)
$\mathbf{U}^c$	7/18	2/3		(1,0,0)
$\mathbf{D}^c$	−5/18	8/9		(1/3, 2/3, 0)
$\mathbf{L}$	−5/18	4/9		(2/3, 1/3, 0)
$\mathbf{E}^c$	7/18	2/3		(1,0,0)
$\mathbf{H}^u$	−2		(0, 0, 1)	
$\mathbf{H}^d$	+2		(0, 0, 1)	

First two families come from 5b + 10 of SU(5)

Discrete family symmetry => modular weights are the same!

Idea: SUSY breaking dominated by T_3. Other T moduli have no-scale structure.

Low Energy Observables

- *Gravity mediation contribution set by gravitino mass...* $m_{3/2} \approx 1\ \mathrm{TeV}$
- *Gaugino masses given by dilaton F term...* $M_a \approx 253\ \mathrm{GeV}$
- *A terms are non-universal (some assumption req'd.)*

$$\begin{aligned} A_t &\approx 3830\ \mathrm{GeV}, \\ A_b &\approx 1788\ \mathrm{GeV}, \\ A_\tau &\approx 1788\ \mathrm{GeV}. \end{aligned}$$

Low Energy Observables: Scalar Masses

Gravity mediation contribution set by gravitino mass, but also a D term contribution!

m_{H^u}	237
m_{H^d}	247

	Gen. 1,2	Gen. 3
$m_{\tilde{q}}$	762	1051
$m_{\tilde{u}^c}$	762	1050
$m_{\tilde{d}^c}$	761	1051
$m_{\tilde{\ell}}$	761	1050
$m_{\tilde{e}^c}$	762	1050

Low Energy Observables: Observables

	Observable	
Inputs	$m_{3/2}$	1049
	$\tan\beta$	25
	$\mathrm{sgn}(\mu)$	$-$
	n_1, n_2, n_3	0,0,0
EWSB	$\mu(M_{\mathrm{SUSY}})$	-1391
	m_{h^0}	112.9
	m_{H^0}	1224
	m_{A^0}	1242
	m_{H^+}	1245
Charg./Neut.	$m_{\tilde{\chi}_1^0}$	101
	$m_{\tilde{\chi}_2^0}$	197
	$m_{\tilde{\chi}_3^0}$	1397
	$m_{\tilde{\chi}_4^0}$	-1398
	$m_{\tilde{\chi}_1^\pm}$	197
	$m_{\tilde{\chi}_2^\pm}$	140

		Gen. 1,2	Gen. 3
Squarks/Sleptons	$m_{\tilde{u}_1}$	921	114
	$m_{\tilde{u}_2}$	914	782
	$m_{\tilde{d}_1}$	924	737
	$m_{\tilde{d}_2}$	911	1052
	$m_{\tilde{e}_1}$	779	955
	$m_{\tilde{e}_2}$	766	1037
	$m_{\tilde{\nu}}$	774	1020
Other Obs.	$\delta\rho$	6.4×10^{-5}	
	$\delta(g-2)_\mu$	-5.5×10^{-10}	
	$b \to s\gamma$	2.5×10^{-4}	
	$B_s \to \mu^+\mu^-$	3.6×10^{-9}	
	m_{LMM}	117	
	m_{nLMM}	21573	

Low Energy Observables: Observables

	Observable	
Inputs	$m_{3/2}$	1049
	$\tan\beta$	25
	$\mathrm{sgn}(\mu)$	–
	n_1, n_2, n_3	0,0,0
EWSB	$\mu(M_{\mathrm{SUSY}})$	-1391
	m_{h^0}	112.9
	m_{H^0}	1224
	m_{A^0}	1242
	m_{H^+}	1245
Charg./Neut.	$m_{\tilde{\chi}_1^0}$	101
	$m_{\tilde{\chi}_2^0}$	197
	$m_{\tilde{\chi}_3^0}$	1397
	$m_{\tilde{\chi}_4^0}$	-1398
	$m_{\tilde{\chi}_1^\pm}$	197
	$m_{\tilde{\chi}_2^\pm}$	140

		Gen. 1,2	Gen. 3
Squarks/Sleptons	$m_{\tilde{u}_1}$	921	114
	$m_{\tilde{u}_2}$	914	782
	$m_{\tilde{d}_1}$	924	737
	$m_{\tilde{d}_2}$	911	1052
	$m_{\tilde{e}_1}$	779	955
	$m_{\tilde{e}_2}$	766	1037
	$m_{\tilde{\nu}}$	774	1020
Other Obs.	$\delta\rho$	6.4×10^{-5}	
	$\delta(g-2)_\mu$	-5.5×10^{-10}	
	$b \to s\gamma$	2.5×10^{-4}	
	$B_s \to \mu^+\mu^-$	3.6×10^{-9}	
	m_{LMM}	117	
	m_{nLMM}	21573	

Low Energy Observables: Observables

	Observable	
Inputs	$m_{3/2}$	1049
	$\tan\beta$	25
	$\mathrm{sgn}(\mu)$	$-$
	n_1, n_2, n_3	0,0,0
EWSB	$\mu(M_{\mathrm{SUSY}})$	-1391
	m_{h^0}	112.9
	m_{H^0}	1224
	m_{A^0}	1242
	m_{H^+}	1245
Charg./Neut.	$m_{\tilde{\chi}_1^0}$	101
	$m_{\tilde{\chi}_2^0}$	197
	$m_{\tilde{\chi}_3^0}$	1397
	$m_{\tilde{\chi}_4^0}$	-1398
	$m_{\tilde{\chi}_1^\pm}$	197
	$m_{\tilde{\chi}_2^\pm}$	140

		Gen. 1,2	Gen. 3
Squarks/Sleptons	$m_{\tilde{u}_1}$	921	114
	$m_{\tilde{u}_2}$	914	782
	$m_{\tilde{d}_1}$	924	737
	$m_{\tilde{d}_2}$	911	1052
	$m_{\tilde{e}_1}$	779	955
	$m_{\tilde{e}_2}$	766	1037
	$m_{\tilde{\nu}}$	774	1020
Other Obs.	$\delta\rho$	6.4×10^{-5}	
	$\delta(g-2)_\mu$	-5.5×10^{-10}	
	$b \to s\gamma$	2.5×10^{-4}	
	$B_s \to \mu^+\mu^-$	3.6×10^{-9}	
	m_{LMM}	117	
	m_{nLMM}	21573	

Low Energy Observables: Observables

	Observable	
Inputs	$m_{3/2}$	1049
	$\tan\beta$	25
	$\text{sgn}(\mu)$	–
	n_1, n_2, n_3	0,0,0
EWSB	$\mu(M_{\text{SUSY}})$	-1391
	m_{h^0}	112.9
	m_{H^0}	1224
	m_{A^0}	1242
	m_{H^+}	1245
Charg./Neut.	$m_{\tilde{\chi}_1^0}$	101
	$m_{\tilde{\chi}_2^0}$	197
	$m_{\tilde{\chi}_3^0}$	1397
	$m_{\tilde{\chi}_4^0}$	-1398
	$m_{\tilde{\chi}_1^\pm}$	197
	$m_{\tilde{\chi}_2^\pm}$	140

		Gen. 1,2	Gen. 3
Squarks/Sleptons	$m_{\tilde{u}_1}$	921	114
	$m_{\tilde{u}_2}$	914	782
	$m_{\tilde{d}_1}$	924	737
	$m_{\tilde{d}_2}$	911	1052
	$m_{\tilde{e}_1}$	779	955
	$m_{\tilde{e}_2}$	766	1037
	$m_{\tilde{\nu}}$	774	1020
Other Obs.	$\delta\rho$	6.4×10^{-5}	
	$\delta(g-2)_\mu$	-5.5×10^{-10}	
	$b \to s\gamma$	2.5×10^{-4}	
	$B_s \to \mu^+\mu^-$	3.6×10^{-9}	
	m_{LMM}	117	
	m_{nLMM}	21573	

Low Energy Observables: Observables

	Observable	
Inputs	$m_{3/2}$	1049
	$\tan\beta$	25
	$\mathrm{sgn}(\mu)$	–
	n_1, n_2, n_3	0,0,0
EWSB	$\mu(M_{\mathrm{SUSY}})$	-1391
	m_{h^0}	112.9
	m_{H^0}	1224
	m_{A^0}	1242
	m_{H^+}	1245
Charg./Neut.	$m_{\tilde{\chi}_1^0}$	101
	$m_{\tilde{\chi}_2^0}$	197
	$m_{\tilde{\chi}_3^0}$	1397
	$m_{\tilde{\chi}_4^0}$	-1398
	$m_{\tilde{\chi}_1^\pm}$	197
	$m_{\tilde{\chi}_2^\pm}$	140

		Gen. 1,2	Gen. 3
Squarks/Sleptons	$m_{\tilde{u}_1}$	921	114
	$m_{\tilde{u}_2}$	914	782
	$m_{\tilde{d}_1}$	924	737
	$m_{\tilde{d}_2}$	911	1052
	$m_{\tilde{e}_1}$	779	955
	$m_{\tilde{e}_2}$	766	1037
	$m_{\tilde{\nu}}$	774	1020
Other Obs.	$\delta\rho$	6.4×10^{-5}	
	$\delta(g-2)_\mu$	-5.5×10^{-10}	
	$b \to s\gamma$	2.5×10^{-4}	
	$B_s \to \mu^+\mu^-$	3.6×10^{-9}	
	m_{LMM}	117	
	m_{nLMM}	21573	

Conclusions

- The major obstacle to realistic heterotic orbifold compactifictions is currently the moduli stabilization problem

- We have shown, under very general considerations, how this may be addressed using only a single gauge condensate and the assumption of modular invariance

- Interesting low energy physics!

- Parameter space scans? Cosmology?