Stability Walls in Heterotic Theories Part 2

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arXiv:0903.5088 [hep-th]

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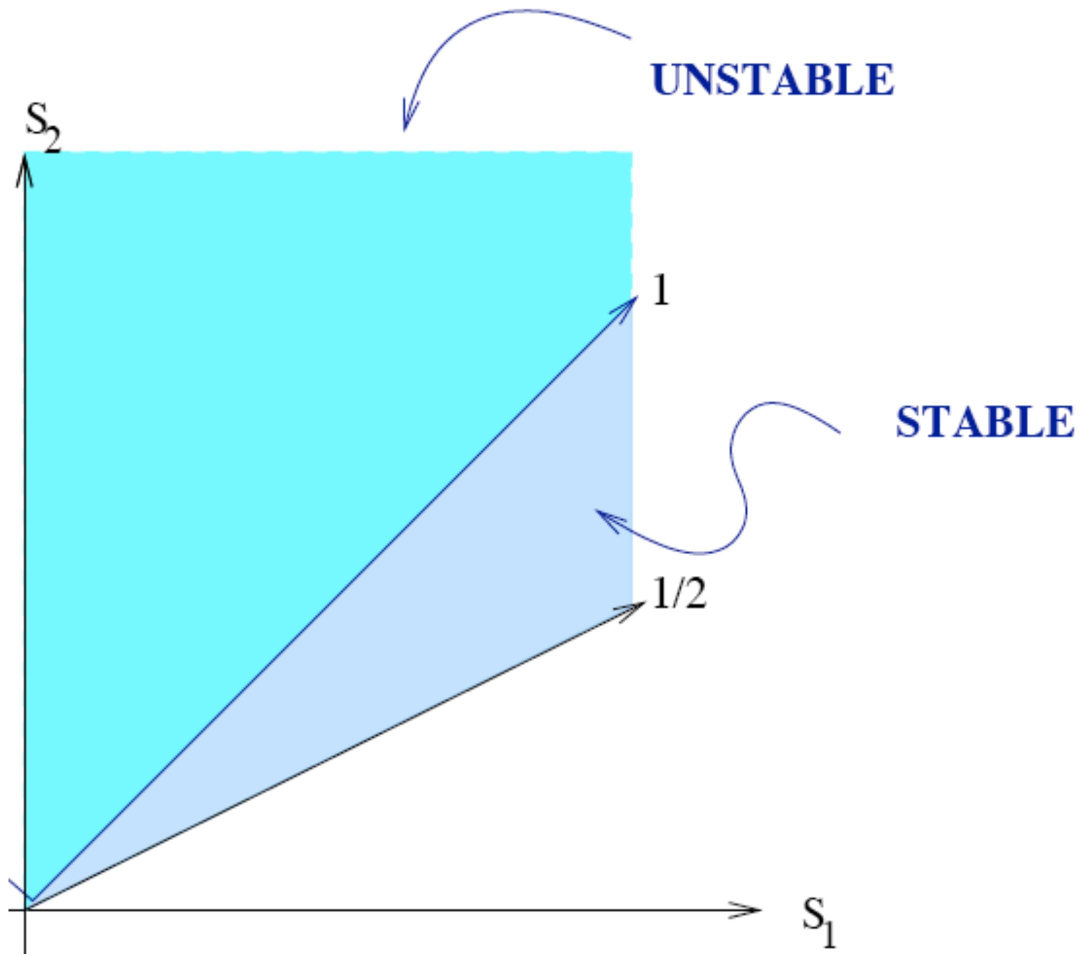
Effective Field Theory



An example: the Kahler cone is the region above the line of slope one half.

Bundle is stable below the line of slope one.

- On the line the system is supersymmetric iff the sequence $0 \longrightarrow \mathcal{F} \longrightarrow \mathcal{V} \longrightarrow \mathcal{K} \longrightarrow 0$ splits.

In other words $\mathcal{V} = \mathcal{F} \oplus \mathcal{K}$ on the line of slope one.

Structure group of $\mathcal{V}$:-

$$SU(3) \longrightarrow S[U(2) \times U(1)] \sim SU(2) \times U(1)$$

Resulting visible sector gauge group:-

$$E6 \longrightarrow E6 \times U(1)$$

So on the boundary of the stable region in Kahler moduli space, and at the "split locus" in bundle moduli space, we pick up an extra low energy U(1).

We are going to work out the EFT for fluctuations about such a locus in moduli space - including this extra U(1).

Matter Content:

Matter descending from higher D gauge fields:

$$E8 \supset E6 \times SU(2) \times U(1)$$

$$\begin{aligned} \mathbf{248} &= (\mathbf{1},\mathbf{1})_0 + (\mathbf{1},\mathbf{2})_{-3} + (\mathbf{1},\mathbf{2})_3 + (\mathbf{1},\mathbf{3})_0 + (\mathbf{78},\mathbf{1})_0 \\ &\quad + (\mathbf{27},\mathbf{1})_2 + (\mathbf{27},\mathbf{2})_{-1} + (\overline{\mathbf{27}},\mathbf{1})_{-2} + (\overline{\mathbf{27}},\mathbf{2})_1 \end{aligned}$$

As usual: $H^1 \longrightarrow \text{scalars}$ and $H^0 \longrightarrow \text{vectors}$

Representation	Cohomology	Physical $U(1)$charge	Dimension of Cohomology
$(\mathbf{1},\mathbf{2})_{-3}$	$H^1(X,\mathcal{F}\otimes\mathcal{K}^*)$	$-3/2$	16
$(\mathbf{1},\mathbf{2})_3$	$H^1(X,\mathcal{F}^*\otimes\mathcal{K})$	$3/2$	0
$(\mathbf{1},\mathbf{3})_0$	$H^1(X,\mathcal{F}\otimes\mathcal{F}^*)$	0	7
$(\mathbf{27},\mathbf{1})_2$	$H^1(X,\mathcal{K})$	1	0
$(\mathbf{27},\mathbf{2})_{-1}$	$H^1(X,\mathcal{F})$	$-1/2$	2
$(\overline{\mathbf{27}},\mathbf{1})_{-2}$	$H^1(X,\mathcal{K}^*)$	-1	0
$(\overline{\mathbf{27}},\mathbf{2})_1$	$H^1(X,\mathcal{F}^*)$	$1/2$	0

Consider the fields of charge $(1,2)_{-3}$.

- Strictly speaking these fields are matter (they are charged under the visible U(1)).
- But they can also be thought of as bundle moduli:

$$\mathcal{V} = \mathcal{F} \oplus \mathcal{K}$$

so: $\mathcal{V} \otimes \mathcal{V}^* = \mathcal{O} \oplus \mathcal{F} \otimes \mathcal{K}^* \oplus \mathcal{F}^* \otimes \mathcal{K} \oplus \mathcal{F}^* \otimes \mathcal{F}$

thus we have:-

$$H^1(\mathcal{V} \otimes \mathcal{V}^*) = H^1(\mathcal{F} \otimes \mathcal{F}^*) \oplus H^1(\mathcal{F}^* \otimes \mathcal{K}) \oplus H^1(\mathcal{F} \otimes \mathcal{K}^*)$$

In fact they are the bundle moduli which take us away from the split locus:

$$\langle C \rangle = 0 \longrightarrow \text{split}$$

$$\langle C \rangle \neq 0 \longrightarrow \text{mixed up again}$$

Moduli Content:

Descending from higher dimensional gravitational sector

- We have all of the usual fields: $T^i, \; S, \; Z_{\hat{i}}, \; \mathfrak{z}^a, \; \text{etc.}$
- But some of them are charged under the U(1).

To lowest order we need only worry about the Kahler moduli, T^k:

$$\text{Im}[T^k] = i2\chi^k \qquad C_{11a\bar{b}} = \chi^k \omega_{ka\bar{b}}$$

and it is well known that the three-form transforms under gauge transformations...

The axion shift symmetry is gauged under our U(1):

$$\delta\chi^i = -\frac{3}{16}\epsilon_S \epsilon_R^2 c_1^i(\mathcal{F})\eta$$

The potential:

- Our 4D theory is $\mathcal{N}=1$ supersymmetric.
- The potential therefore has D-term and F-term contributions.
- F-terms turn out to be unimportant here (not true in more complicated cases).

D-terms:

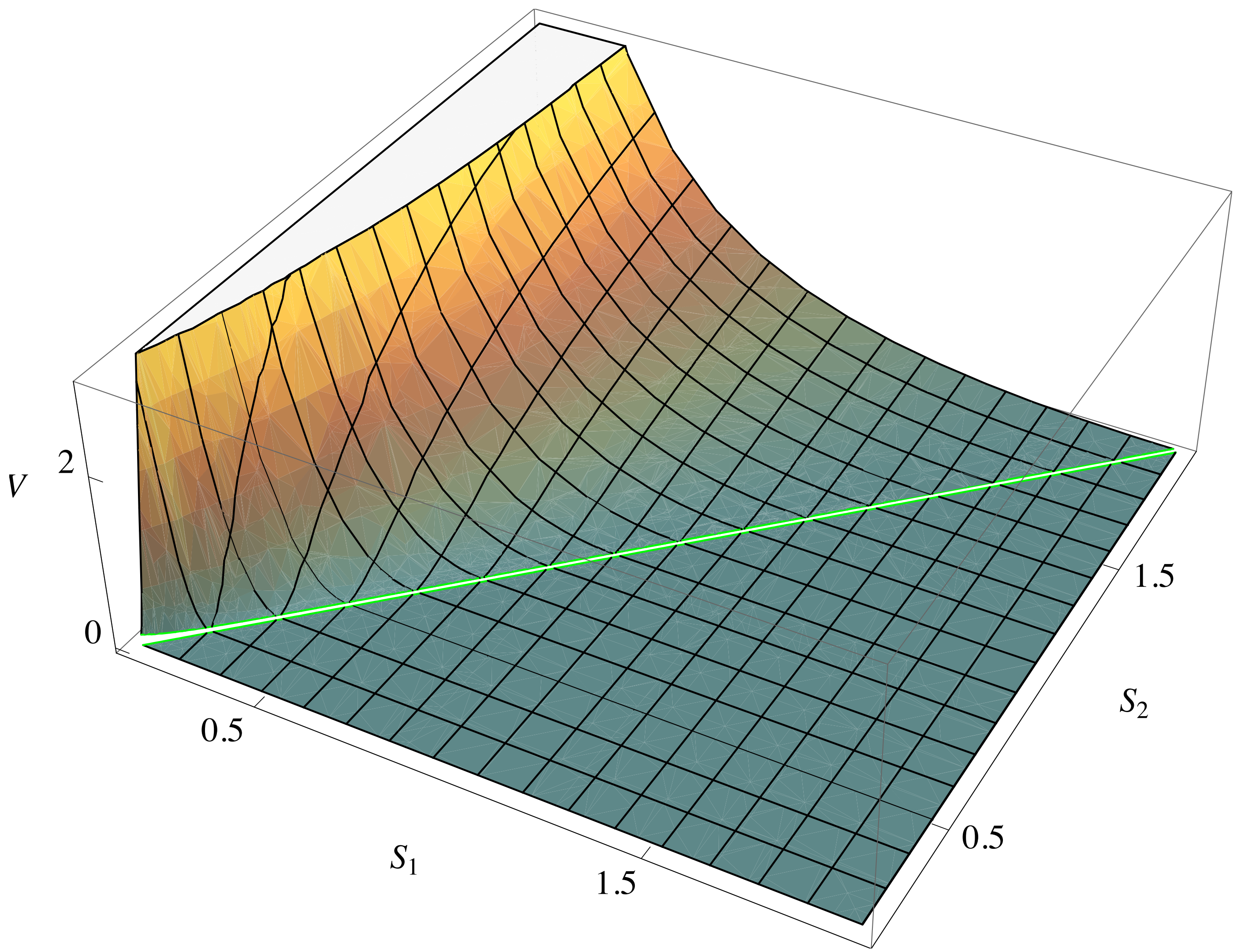
$$D^{E6} \Longrightarrow \langle 27 \rangle = 0$$

$$D^{U(1)} = \frac{3}{16}\frac{\epsilon_S \epsilon_R^2}{\kappa_4^2}\frac{\mu(\mathcal{F})}{\mathcal{V}} - \sum_{L,\bar{M}} Q^L G_{L\bar{M}} C^L \bar{C}^{\bar{M}}$$

where: $\mu(\mathcal{F}) = \frac{1}{2} d_{ijk} c_1^i(\mathcal{F}) t^j t^k$

- “FI” term negative in stable region, zero on boundary, and positive in unstable region.
- The matter states C^L are *all* negatively charged.
- D=0 possible in region where bundle is stable - the usual supersymmetric vacuum is recovered.
- D=0 not possible in region where bundle is unstable - instability of the gauge bundle corresponds to D-term supersymmetry breaking in the four dimensional theory.
- D=0 possible on the wall between the two regions but requires $\langle C \rangle = 0$. Reproduces fact that bundle has to split on the boundary between the two regions to preserve supersymmetry

Potential in Kahler cone - minimized with respect to $\langle C \rangle$:



The vevs in the susy region reproduce the usual spectrum there (higgs effect etc...).

- That there is "only one sign" of U(1) charge and "we regain the usual spectrum" etc can all be proved in complete generality (see arXiv: 0905.1748).

Higher order corrections

At next order in our expansions the dilaton and M5 position superfields also transform:

$$\delta\sigma = -\frac{3}{8}\pi\epsilon_S^2\epsilon_R^2 c_1^i(\mathcal{F})\beta_i\eta$$

From the following superfield definitions...

$$T^K = t^k + 2i\chi^k$$

$$Z^\alpha = \beta_i^\alpha\left(t^i z_\alpha + 2i\left(-n_\alpha^i\nu_\alpha + \chi^i z_\alpha\right)\right)$$

$$S = V_0 + \pi\epsilon_S\sum_{\alpha=1}^{N}\beta_i^\alpha t^i z_\alpha^2 + i\left(\sigma + 2\pi\epsilon_S\sum_{\alpha=1}^{N}\beta_i^\alpha\chi^i z_\alpha^2\right)$$

...we see that all three of these superfields transform.

The resulting D-term is:

$$D^{U(1)} = f - \sum_{L\bar{M}} Q^L G_{L\bar{M}} C^L \bar{C}^{\bar{M}}$$

$$\begin{aligned} f &= f^{(0)} + f^{(1)} \\ f^{(0)} &= \frac{3}{16} \frac{\epsilon_S \epsilon_R^2}{\kappa_4^2} \frac{\mu(\mathcal{F})}{\mathcal{V}} \\ f^{(1)} &= \frac{3\pi \epsilon_S^2 \epsilon_R^2}{8\kappa_4^2} \frac{1}{S+\bar{S}} \left[\beta_i c_1^i(\mathcal{F}) + \pi \sum_{\alpha=1}^{N} \frac{(Z^\alpha + \bar{Z}^\alpha)^2}{(\beta_i^\alpha (T^i + \bar{T}^i))^2} \beta_i^\alpha c_1^i(\mathcal{F}) \right] \end{aligned}$$

- Might think of this as “a correction to the mathematical notion of slope stability”.
- Really, this is misleading. The corrections are just due to the difference between 4d moduli and what the gauge fields actually see....

Conclusions

- We now have a 4d effective description of Heterotic ‘everywhere’ in the Kahler cone.
- An extra U(1) appears at the boundary between the supersymmetric and non-supersymmetric regions of moduli space.
- There is a potential in the non-supersymmetric region associated to the D-term of this extra U(1).
- The effective field theory describing all this can be written down explicitly.
- Corrections to the D-term are due to warping and shouldn’t be interpreted as a “correction to stability”.

Further Work

- More complicated branch structure studies - transitioning between bundles can be completely understood in a smooth manner.
- Using potential for moduli stabilization (although...).
- Susy breaking and phenomenology in the unstable region.
- Parts of bundle stability just from the 4d EFT.
- Conjectures on complex structure dependence of stability regions.

etc...