

(Warped) Moduli Stabilization in Stringy ISS models

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Based on :arXiv:0710.0001 [hep-th] with M. Yamazaki,
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To appear with P. Kumar

Introduction

■ Dynamical SUSY breaking

- will give a solution to **hierarchy problem**

- Non-renormalization

$$e^{-\frac{1}{g^2}} \ll 1$$

- Dynamical scale (dimensional transmutation)

■ Many models are known (field theory)

- 1 flavor GUT type SO(10), SU(5)

- IYIT model, ISS model...

■ How to realize in string theory?

- Many models in **non-compact** examples

- moduli fixing... may be **swampland??**

ISS model (Intriligator Seiberg Shih, hep-th/0602239)

- $SU(N_c)$ SQCD N_f flavors ($N_c < N_f < \frac{3}{2}N_c$)

$$\varphi_i, \bar{\varphi}_i$$

$$W_{el} = m\varphi\bar{\varphi} \quad m \ll \Lambda$$

- \rightarrow Seiberg dual

- $SU(N_f - N_c)$ $q_i, \bar{q}_i, M_{ij} = \varphi_i\bar{\varphi}_j$

- $W_{mag} = m\text{Tr}M + \frac{1}{\mu}qM\bar{q} + \text{nonperturbative}$

- Breaks SUSY from rank-condition

- $\partial_{M_{ij}}W = m\delta_{ij} + \frac{1}{\mu}q_i\bar{q}_j \neq 0$

- $V = N_c|m|^2|\Lambda|^2$

Moduli in ISS model

In string theory, m will become dynamical moduli
 $\rightarrow \rho$ (dynamical field)

■ effective potential: $V = N_c |\rho|^2 |\Lambda|^2$

□ $\rho \rightarrow 0$ restores SUSY

□ $\partial_{M_{ij}} W = \rho \delta_{ij} + \frac{1}{\mu} q_i \bar{q}_j = 0$

■ How to fix ρ ? (also Λ is moduli...)

We will show a first example of metastable (ISS – like) SUSY breaking models in dype IIB superstring theory.

Field theory idea to fix ISS moduli

Introduce a new $U(1)$ gauge field + F-I term ξ

■ charge:

□ $\varphi : +1, \bar{\varphi} : +1, \rho : -2$

□ $M : +2, q : -1, \bar{q} : -1$

■ The gauging is anomalous

$$\Lambda^{3N_c - N_f} \sim 2N_f$$

$$\tilde{\Lambda}^{2N_f - 3N_c} \sim -2N_f$$

□ Charges should be consistent with

$$B \sim \varphi^{N_c} \sim (-(-\mu)^{N_c - N_f} \Lambda^{3N_c - N_f})^{1/2} q^{N_f - N_c}$$

□ Superpotential should be invariant

D-term potential

We have extra **U(1) D-term potential**

$$V_D = \frac{g^2}{2} \left(\xi - |q|^2 - |\bar{q}|^2 - 2|\rho|^2 + 2\frac{|M|^2}{|\bar{\Lambda}|^2} \right)^2$$

- small $g \ll 1$ F-term dominates \rightarrow ISS vacua

$$V_D + V_F = N_c |\rho|^2 |\Lambda|^2 + \frac{g^2}{2} (\xi - 2|\rho|^2 - 2(N_f - N_c)|\mu\rho|)^2$$

$$\rightarrow |\rho| = \frac{g^2 |\mu| \xi (N_f - N_c)}{N_c |\Lambda|^2 + 2g^2 |\mu| (N_f - N_c)^2}$$

- ρ is **stabilized!** (once ξ is fixed...)

4D GS mechanism

U(1) is anomalous \rightarrow 4D GS mechanism

ξ becomes dynamical

$$T \equiv \frac{1}{g^2} + \frac{i}{8\pi^2} \phi \quad \phi \rightarrow \phi - 2N_f \alpha$$

$$\int d^4\theta K \left(T + T^\dagger - \frac{N_f}{4\pi^2} V \right)^2 \\ \sim \left(\frac{\partial K}{\partial V} \right)_{V=0} V|_{\theta^4} + \frac{1}{2} \left(\frac{\partial^2 K}{\partial V^2} \right)_{V=0} \left(\frac{\partial_\mu \phi}{2N_f} + A_\mu \right)^2$$

$$\rightarrow V_D = \frac{g^2}{2} \left(-\frac{N_f}{4\pi^2} \partial_T K + \sum_i q_i \phi_i \partial_i K \right)^2$$

- fixing of FI? (depending on $K(T)$...)
 \rightarrow Let's go to **string theory!**

Stringy ISS setup

■ Type IIB flux compactification

- Complex structure moduli

- Dilaton are fixed

$$W = \int \Omega \wedge (F - sH)$$

■ One Kahler modulus τ CY orientifold

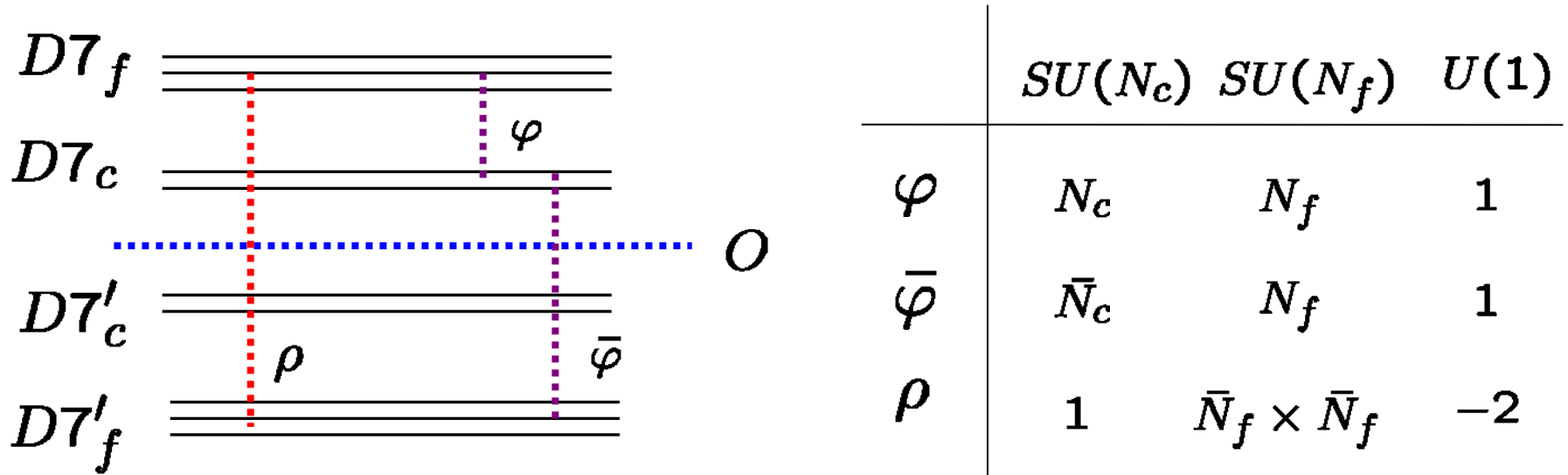
(Cremades et al: hep-th/0701154)

- D7 + O7-plane

- Flavor $SU(N_f) + U(1) \leftarrow$ magnetized (FI-term)

- Gauge $SU(N_c)$

Stringy ISS spectrum



$$W = \rho \varphi_i \bar{\varphi}^i$$

FI-term comes from (supersymmetric) **CS-term**.

$$\int_{D7} C_4 \wedge F \wedge F \rightarrow \int_{4D} B \wedge F = \int d^4x \partial_\mu \phi A^\mu$$

Seiberg duality and potential

■ Field theory Seiberg duality @ low energy

$$W = W_0 + \rho \text{Tr} M + \frac{1}{\mu} q^i M_{ij} \bar{q}^j$$

$$K = -2 \log(\tau^{3/2} + \zeta) + \frac{|\rho|^2 + |q|^2 + |\bar{q}|^2}{\tau^n} + \frac{|M|^2}{\tau^n} e^{\frac{8\pi^2\tau}{3N_c - 2N_f}}$$

n: modular weight

■ Total potential

$$V = V_F + V_D$$

$$V_F = e^K \left(K^{i\bar{j}} D_i W \bar{D}_{\bar{j}} \bar{W} - 3|W|^2 \right)$$

$$V_D = \frac{1}{2\tau} \left(\frac{3N_f}{8\pi^2\tau} (1 + \zeta\tau^{-3/2})^{-1} - \frac{2|\rho|^2 + |q|^2 + |\bar{q}|^2 - 2|M|^2 e^{\frac{8\pi^2\tau}{3N_c - 2N_f}}}{\tau^n} \right)^2 + \dots$$

Potential minimization

- $1/\tau$ expansion

- @1st order ISS vacuum is still the solution

$$V(\rho) = N_f \tau^{n-3} |\rho|^2 e^{-\frac{8\pi^2 \tau}{3N_c - 2N_f}} + \frac{1}{2\tau} \left(\frac{3N_f}{8\pi^2} \frac{2}{\tau} - \frac{|\rho|^2 + 2(N_f - N_c)|\mu\rho|}{\tau^2} \right)^2$$

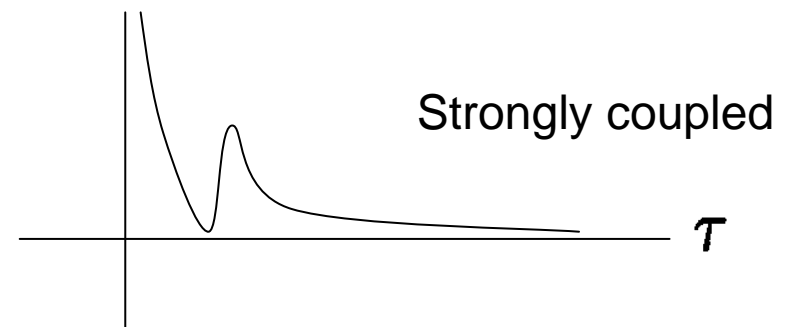
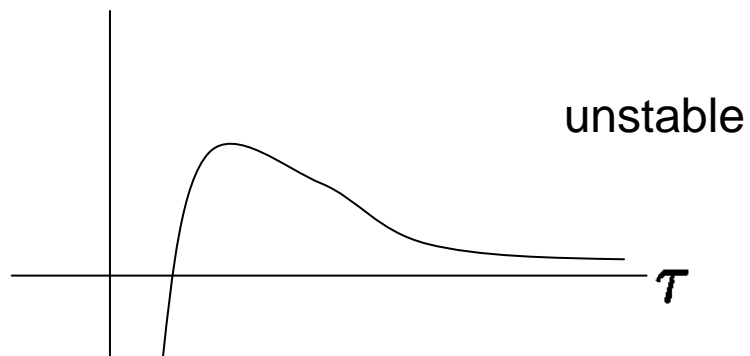
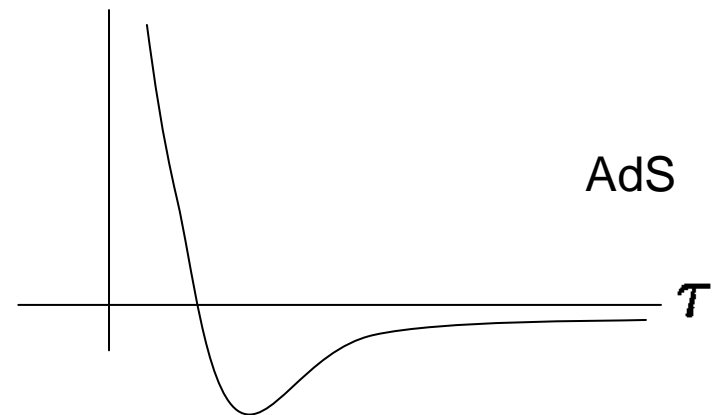
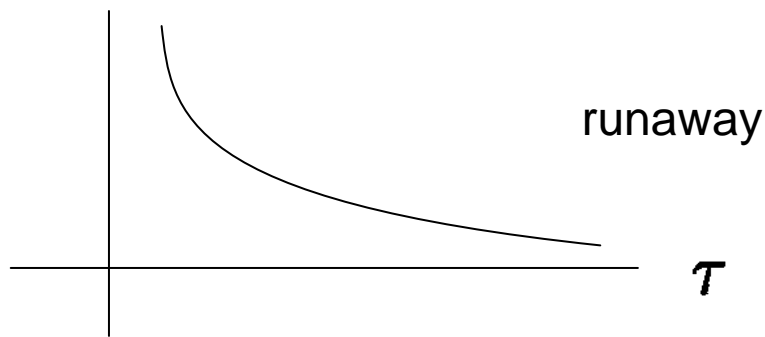
$$|\rho| = \frac{\frac{3N_f(N_f - N_c)\mu}{8\pi^2 \tau^{n+2}}}{N_c \tau^{n-3} e^{-\frac{8\pi^2 \tau}{3N_c - 2N_f}} + \frac{2|\mu|^2(N_f - N_c)^2}{\tau^{2n+1}}}$$

- To fix FI term, we need a **SUGRA contribution**

$$\begin{aligned} \delta V_{\text{SUGRA}} &= \frac{3\zeta}{2\tau^{9/2}} |W_0|^2 + (1 - n - n^2) \frac{|\rho|^2 + 2(N_f - N_c)|\rho\mu|}{\tau^{3+n}} |W_0|^2 + \dots \\ &= \frac{3\zeta}{2\tau^{9/2}} |W_0|^2 + (1 - n - n^2) \frac{2(N_f - N_c)^2 \left(\frac{3N_f}{8\pi^2}\right) \frac{|\mu|^2 |W_0|^2}{\tau^{2n+5}}}{N_c \tau^{n-3} e^{-\frac{8\pi^2 \tau}{3N_c - 2N_f}} + \frac{2|\mu|^2(N_f - N_c)^2}{\tau^{2n+1}}} + \dots \end{aligned}$$

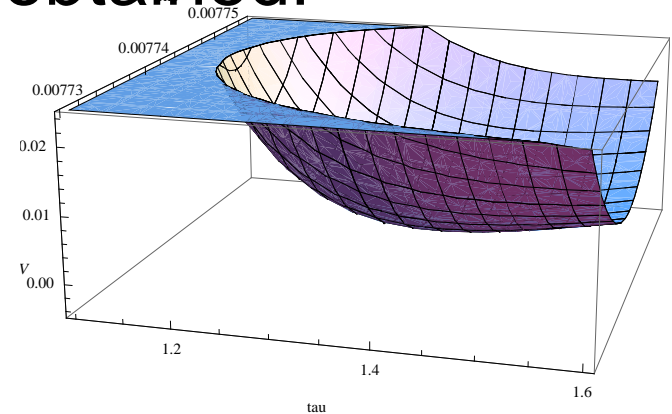
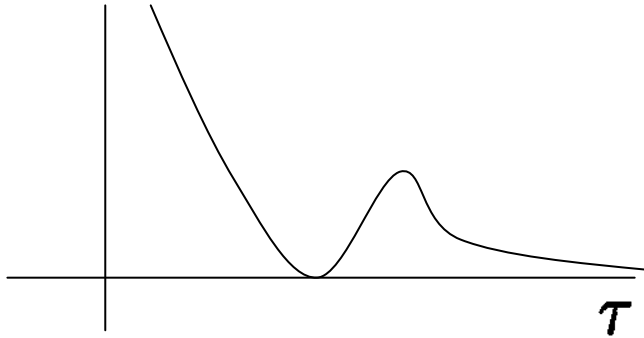
Fine tuning and cosmological constant

- We have to tune parameters so that
 - CC is small
 - Stabilized for large \mathcal{T}
 - Stable vacuum



Stabilization

- Weakly coupled de-Sitter is obtained!



$$N_c = 5000, N_f = 6000, \mu = 14.72, \zeta = 143, W_0 = 0.11$$

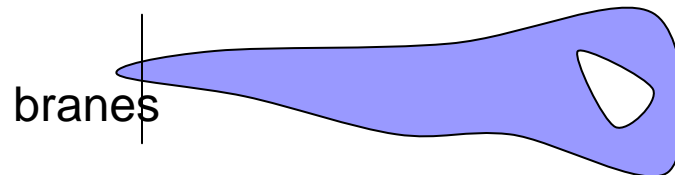
- Large gauge group necessary?
- SUSY breaking scale **large**?
 - Warped compactification might be useful

Warped Stringy ISS setup

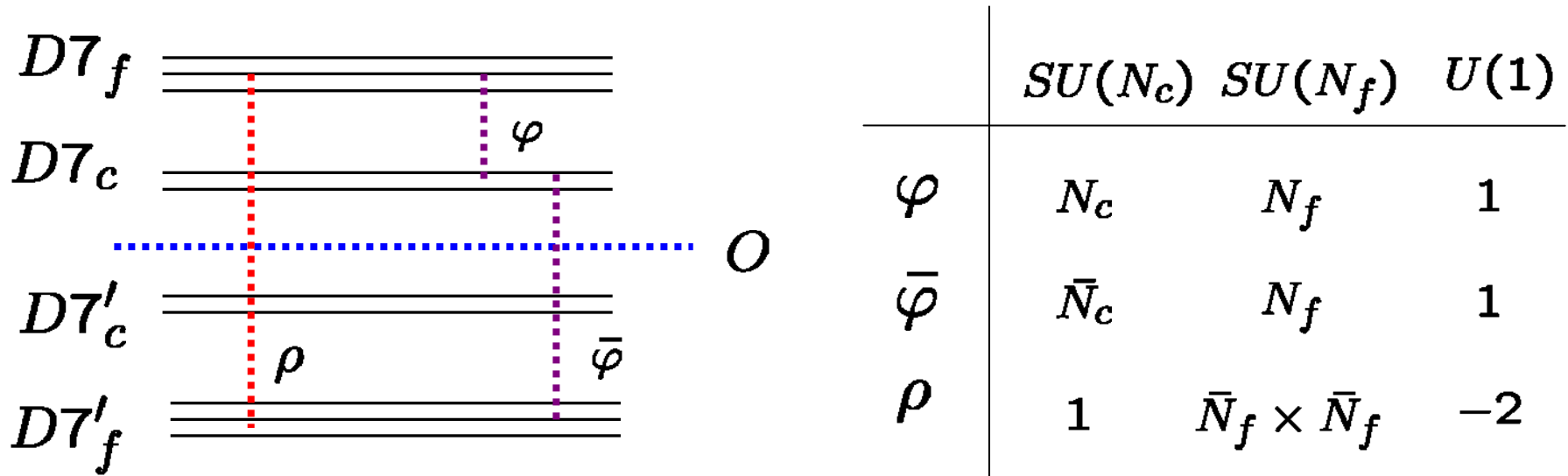
- Type IIB flux **warped** compactification

$$ds^2 = e^{-2A} g_{\mu\nu} dx^\mu dx^\nu + e^{2A} g_{mn} dy^m dy^n$$

- Complex structure moduli
- Dilaton are fixed
- **One Kahler modulus** τ **CY orientifold**
 - D7 + O7-plane
 - Flavor $SU(N_f) + U(1)$ \leftarrow magnetized (FI-term)
 - Gauge $SU(N_c)$
 - Branes are sitting at the **warped throat**



Warped Stringy ISS spectrum



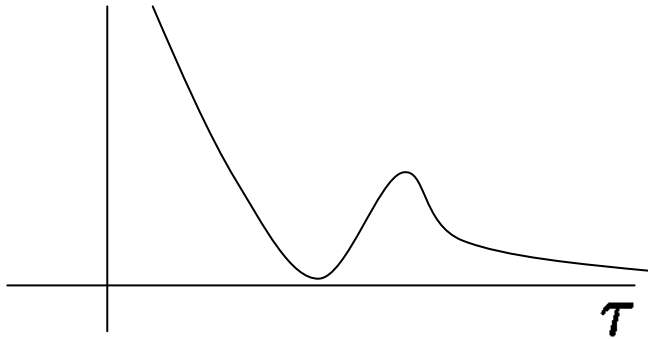
$$W = e^{-6A} \rho \varphi_i \bar{\varphi}^i$$

FI-term comes from (supersymmetric) **CS-term**.

$$\int_{D7} C_4 \wedge F \wedge F \rightarrow \int_{4D} B \wedge F = \int d^4x \partial_\mu \phi A^\mu$$

Stabilization

- Weakly coupled de-Sitter is obtained!



$$\mu = 10^4, A = 1.2, N_c = 1000, N_f = 1200, m_{3/2} = 10^5 \text{ GeV}$$

- Still Large gauge group necessary?

- Smaller gauge rank with small Yukawa

$$\mu = 10^6, A = 0.6, N_c = 100, N_f = 120, m_{3/2} = 10^5 \text{ GeV}$$

- SUSY breaking scale ?

- Can be small **compatible with gravity mediation**

Conclusion

- Moduli stabilization in Stringy ISS
 - Introduction of $U(1)$ + FI term
 - Dynamical FI-term is needed (anomaly)
 - String setup admits low-energy SUSY with small cosmological constant
- Phenomenology (gravity mediation)
 - Unlike KKLT, conventional MSUGRA is realized
 - Special sequestering cases \rightarrow anomaly mediation
- Toward gauge mediation?
 - ISS branes and SSM branes sit close in CY
 - Possible D-term gauge mediation? (see 0705.0865)