ON MODULI FIXING AND DE SITTER SPACE IN STRING THEORY

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String Problems:

* Moduli Fixing
* SUSY Breaking

A Challenge:

* De Sitter Space
    - Inflation
    - Dark Energy

Recent Progress:

. . . . . KKLT hep-th/0301240

Type IIB:

$$g_{\mu\nu}\,;\ \underbrace{\phi, C_0}_{S}\,;\ B_{\mu\nu}, C_{\mu\nu}\,,\ A_{\mu\nu\rho\sigma}$$

$$B_{\mu\nu} \to H_3 = dB \qquad C_{\mu\nu} \to F_3 = dC \qquad A_{\mu\nu\rho\sigma} \to F_5 = dA \ldots$$

$$G_3 \equiv F_3 - iS\,H_3$$

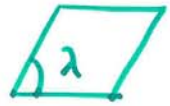
$$S = \int d^{10}x \sqrt{-g}\left\{ R - \frac{2\partial S \partial S^*}{(S+S^*)^2} - \frac{G_3 \cdot G_3^*}{6(S+S^*)} - \frac{F_5^2}{4\cdot 5!} + \cdots \right\}$$

Ingredients:

* C-Y compactification $\mathcal{N}=1$
* Fluxes of $\int_{\gamma_3} F_3$, $\int_{\gamma_3} H_3 \neq 0$
* Nonperturbative W
* Anti D3 Brane

1. Calabi-Yau/σ (orientifold).

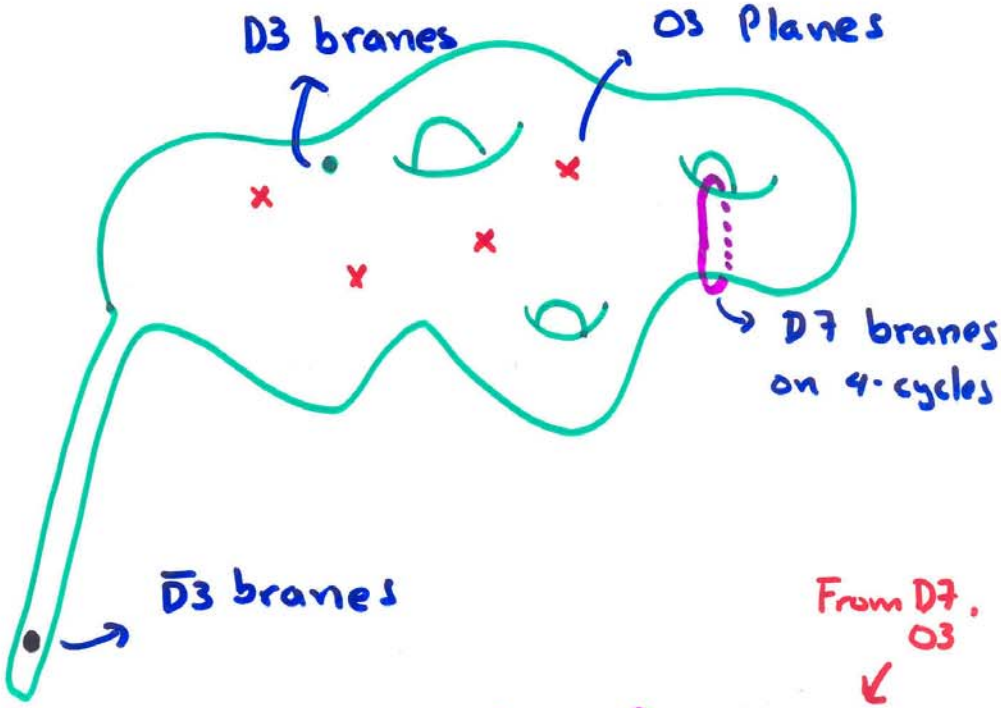
"Shape" Moduli



$z = x + \lambda y$

"Size" Moduli: (~ volume → T)

Picture:



From D7, O3

Consistency: $N_{D3} - N_{\bar{D}3} + \int H_3 \wedge F_3 = \frac{\chi}{24}$

2. Fluxes:

$$\frac{1}{4\pi^2\alpha'}\int_{\Gamma_3} F_3 = M \quad ; \quad \frac{1}{4\pi^2\alpha'}\int_{\gamma_3} H_3 = K$$

$$G_3 = G_3^+ + G_3^-$$

$$\tilde{G}_3^\pm = \pm i\, G_3^\pm$$

Scalar Potential:

$$V_F = \frac{1}{S+S^*}\int_{M_6} G_3^- \wedge \tilde{G}^-$$

↳ Depend on S, λ
NOT on T !

Superpotential:

$$W = \int_{M_6} G_3 \wedge \Omega$$

Kähler Potential:

$$K = -3\log(T+T^*) + K_{rest}$$

⇒ No scale.

$$\boxed{V_F = e^K K^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} \geq 0}$$

Minimum $D_i W = 0$; $D_T W \neq 0$.
⇒ Fix S, λ not T !

3. Nonperturbative W :

D7 Gauge theory

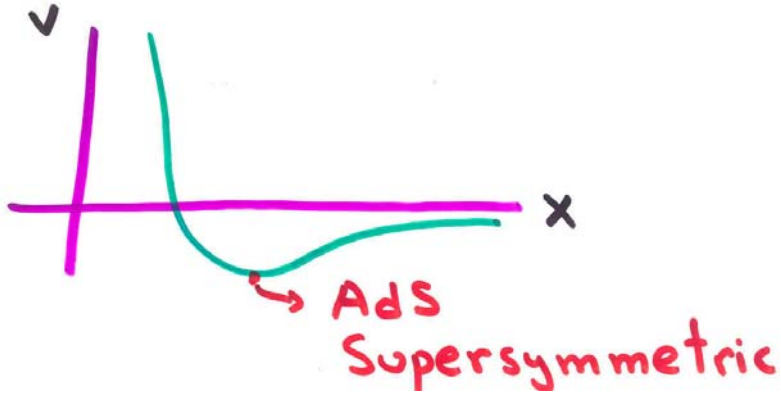
$$(\text{gauge coupling})^{-2} = T = X + iY$$

$$\Rightarrow W_{np} \sim e^{-aT}$$

$$W = W_0 + A e^{-aT}$$

W_0 → from fluxes.

$$V_F = \frac{1}{8X^3}\left\{\frac{1}{3}|2XW' - 3W|^2 - 3|W|^2\right\}$$



4. Anti D3 Brane

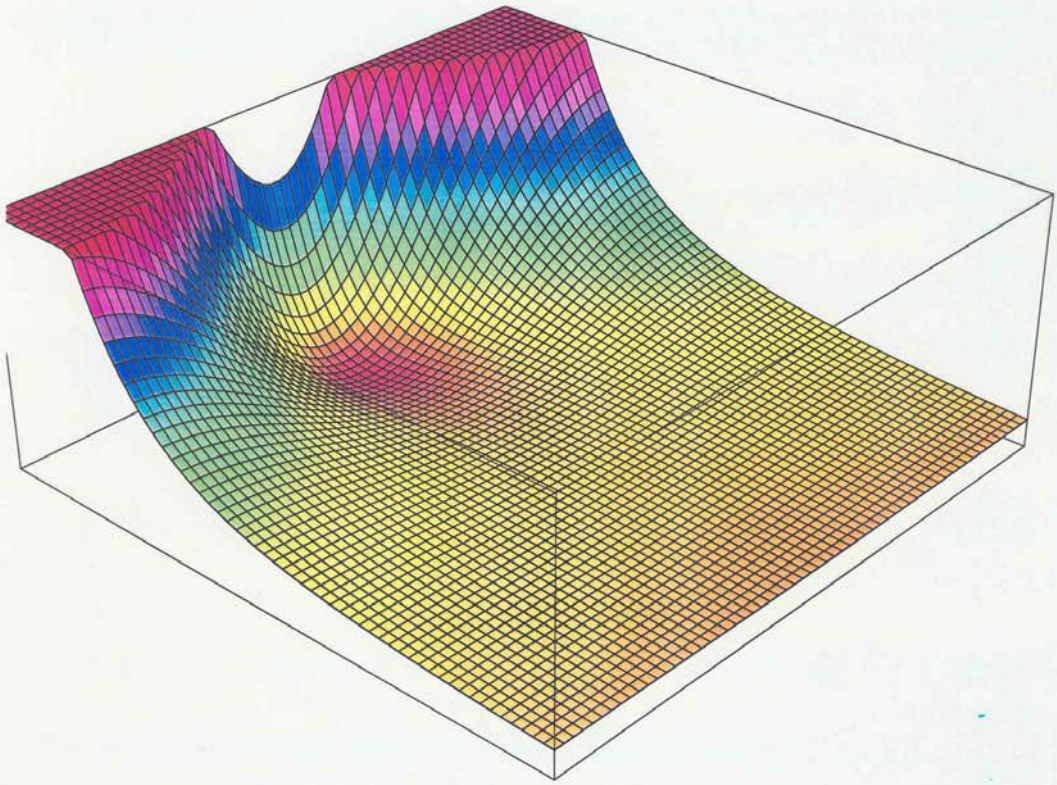
* Break SUSY
* Add term to V_F
  (From its tension)

$$V = V_F + \frac{K}{X^2}$$

($\frac{K}{X^3}$ originally).

$$\Downarrow$$

De Sitter !



Variant Scenarios

(i) Modify 3

$$W_{np} = \sum_{i=1}^{P} A_i e^{-a_i T}$$

P : finite $\Rightarrow$ Racetrack

Infinite ~ Full instanton sum

e.g. $\mathcal{N} = 1^*$

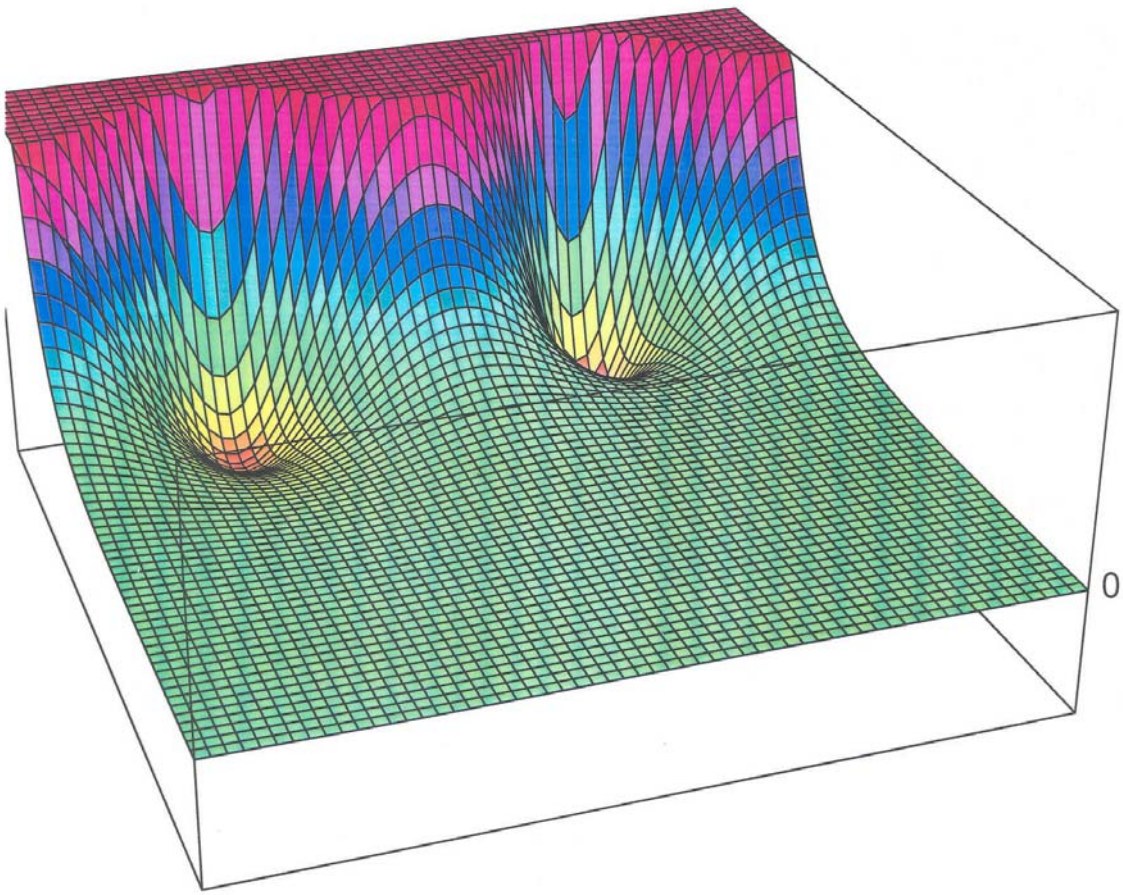
$$W_{np} = E_2(T) - \frac{1}{N} E_2(T/N)$$

Eisenstein

$E_2 = 1 - 24 \sum \sigma_1(n) e^{-2\pi n T}$

$\Downarrow$

Many de Sitter minima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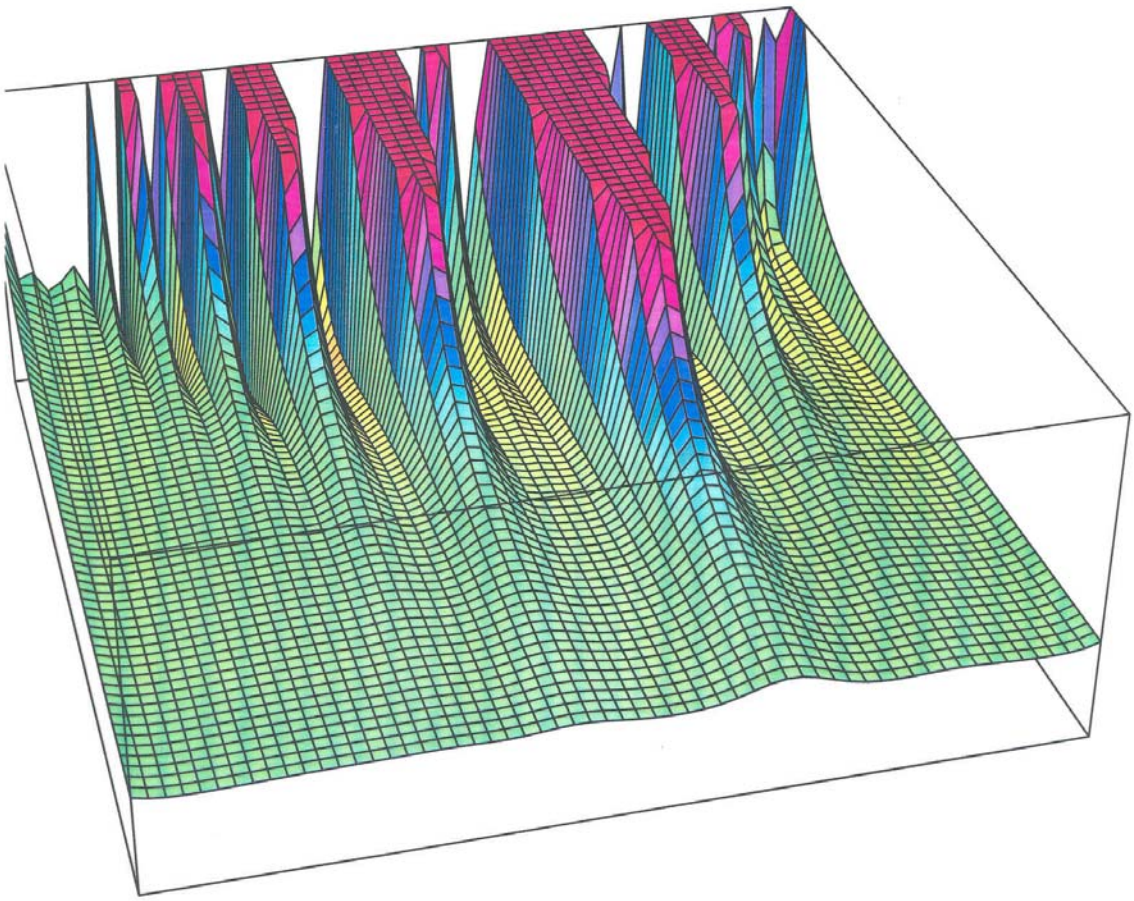

(ii) Modify 4.

No $\overline{D3}$ but flux of gauge fields from D7:

$$\int_{\Gamma} d^4y \sqrt{g_8}\, F^{mn} F_{mn} = \frac{2\pi E^2}{X^3} = V_D \; !$$

$\Rightarrow$ FI term.

Since Chern-Simons:

$$\int_{M_8} (C \wedge \mathrm{Tr}\, e^{iF/2\pi})$$

$$\Rightarrow \underbrace{C_{\mu\nu mn}}_{B_{\mu\nu}} F_{\rho\sigma} F_{pq} \epsilon^{\mu \ldots q}$$

$\Rightarrow B \wedge F$

$\Downarrow$

$A_m \partial^m Y$ susy

$\Rightarrow$ FI. !

General D-term:

$$V_D = \frac{2\pi}{X}\left(\frac{E}{X} + q_i |Q_i|^2\right)^2$$

Matter fields.

$Q_i = 0 \Rightarrow$ similar results to KKLT, EGQ.

Advantages:

* Supersymmetric (SUSY broken spontaneously).
* Generalizable (Any Anomalous $U(1)$)

  e.g. Heterotic

$$V_D = \frac{1}{S+S^*}\left(\frac{\mathrm{Tr}\, q}{4\pi^2(S+S^*)} + \sum q_i |Q_i|^2\right)^2$$

Disadvantages:

* Consider $\langle Q_i \rangle$
* E less flexible

Implications:

* String Landscape
  (varying K, M ⇒ huge # vacua & S, ...)

* de Sitter minima: metastable
  (τ_{decay} >> Age of Universe)

* Inflation
  - D-Brane inflation (KKLMMT)
    (1% fine tuning, open).
  - D-Term inflation?
  - T-inflation