LARGE EXTRA DIMENSIONS AND SOFT SUSY BREAKING FROM FLUX COMPACTIFICATIONS

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J. Conlon, FQ, K. Suruliz hep-th/0505076 JHEP.

II B Flux Compactifications

Calabi-Yau orientifold.

$$\frac{1}{(2\pi)^2\alpha'}\int_a F_3 = n_a \in \mathbb{Z} \qquad \frac{1}{(2\pi)^2\alpha'}\int_b H_3 = m_b \in \mathbb{Z}$$

$$W = \int G_3 \wedge \Omega \qquad G_3 \equiv F_3 - \tau H_3$$

$$K = -2\log \mathcal{V} + K_{cs}$$

$$\mathcal{V} = \int_M J^3 = \frac{1}{6} t^i t^j \underbrace{t^k}_{\text{Kähler}} \alpha_{ijk} \rightarrow \text{Volume}$$

$$G^{i\bar{j}} K_i K_{\bar{j}} = 3 \Rightarrow \text{no-scale}$$

$$\Rightarrow V = e^K G^{a\bar{b}} D_a W \bar{D}_{\bar{b}} \underbrace{\bar{W}}_{\rightarrow cs + \tau}$$

$\boxed{D_a W = 0}$ fix $cs + \tau$

t^i flat directions

GKP

KKLT :

$$W = \underbrace{W_0}_{\text{fluxes}} + \sum A_n e^{i a_n \rho_n} \rightarrow \text{non perturbative}$$

(cs + τ integrated out).

$$V_F = e^K \left[G^{ij} \, D_i W \, D_j \overline{W} - 3|W|^2 \right]$$

$$\Rightarrow \quad D_{\rho_i} W = 0 \quad \Rightarrow \quad \text{Fix } \rho_i$$

SUSY AdS

* Need $|W_0| \ll 1$

$(\rho \sim \frac{1}{a_1} \log W_0)$

* Lift to dS by adding

$$\Delta V \sim \frac{\epsilon}{\mathcal{V}^x}$$

KKLT
BKQ
SS

* Often tachyonic directions

DD ...

Importance of Corrections to K

In general:

$$K_T = K_0 + K_p + K_{np} \approx K_0 + J$$

$$W_T = W_0 + W_{np} \approx W_0 + \Omega$$

$$\Rightarrow \quad V = V_0 + V_J + V_\Omega + \mathcal{O}(J^2, J\Omega)$$

* Usually V_0 determines structure of V

  $(V_J, V_\Omega \ll V_0)$

* Except: Flat directions $\left(\frac{\partial V_0}{\partial X_m} \equiv 0\right)$

  Relevant $V_J > V_\Omega \neq 0$

  Example: No-scale !

* Can neglect V_J only if

  $W_0 = 0$

  or

  $W_0 \ll 1 \quad (W_0 \sim \Omega)$

α' Corrections to K

Becker Haack Louis

$$K = K_{cs} - 2\log\left[\mathcal{V} + \tfrac{\xi}{2} g_s^{3/2}\right] \cong \underbrace{K_{cs} - 2\log\mathcal{V}}_{K_0} - \underbrace{\xi/\mathcal{V} g_s^{3/2}}_{J}$$

$\xi \propto -\chi(M)$

$$W = W_0 + \overbrace{\sum_n A_n e^{i a_n \rho_n}}^{\Omega}$$

F-term potential:

$$V_F \cong e^K \Big[\overbrace{G^{j\bar{k}} \Big(A_j \bar{A}_k a_j a_k e^{i(a_j\rho_j - a_k\bar{\rho}_k)}}^{V_\Omega} + A_j a_j e^{i a_j \rho_j} \bar{W}_0 K_{\bar{k}} - \bar{A}_k a_k e^{-i a_k \bar{\rho}_k} W_0 K_j \Big) \Big]$$

$$+ \overbrace{\frac{3 e^K |W_0|^2 \xi}{\mathcal{V} g_s^{3/2}}}^{V_J}$$

$V_\Omega > V_J$?

$n = 1, \quad g_s = 1/10, \quad a = 2\pi, \quad \xi = 0.48$

$V_\Omega > V_J \implies W_0 \sim 10^{-75}$!

$\Rightarrow$ Cannot neglect V_J.

$\mathbb{P}^4_{[1,1,1,6,9]}$ Example

Candelas, Font, Katz, Morrison

Denef, Douglas, Florea

* $h^{1,1} = 2 \; ; \; h^{2,1} = 272$

$\xi > 0$

* $\mathcal{V} = \frac{1}{9\sqrt{2}} \left(\tau_5^{3/2} - \tau_4^{3/2} \right)$

$\tau_i \equiv \mathrm{Im}\, \rho_i$

$$W = W_0 + A_4 e^{i a_4 \rho_4} + A_5 e^{i a_5 \rho_5}$$

$$K = K_{cs} - 2 \log\left(\mathcal{V} + \tfrac{\xi}{2} g_s^{3/2}\right)$$

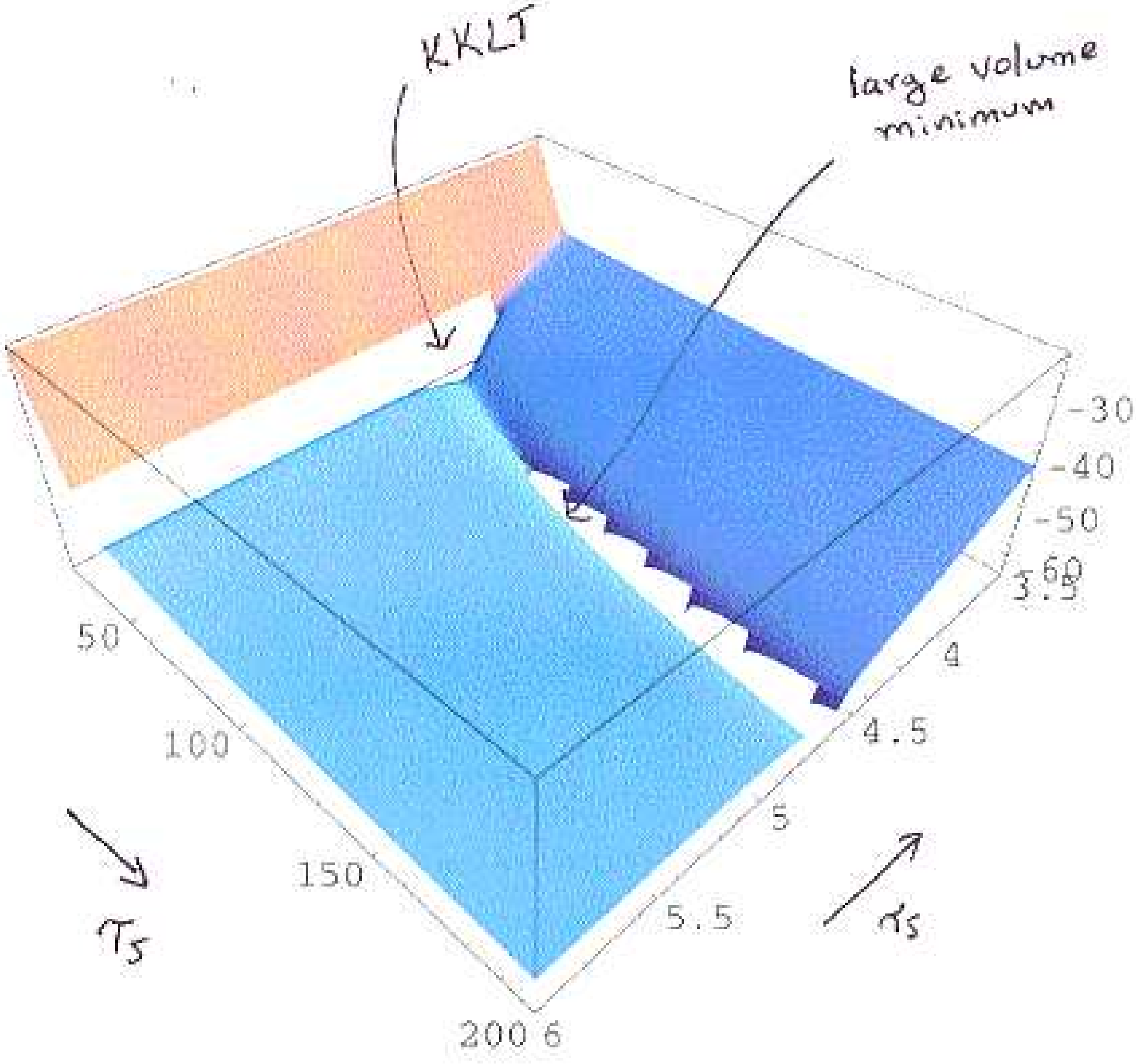
F-term Potential:

$$V_F \cong \frac{\lambda \sqrt{\tau_4}\,(a_4 A_4)^2 e^{-2 a_4 \tau_4}}{\mathcal{V}} - \frac{\mu \tau_4 W_0 (a_4 A_4) e^{-a_4 \tau_4}}{\mathcal{V}^2} + \frac{\xi W_0^2}{\mathcal{V}^3}$$

Minimum:

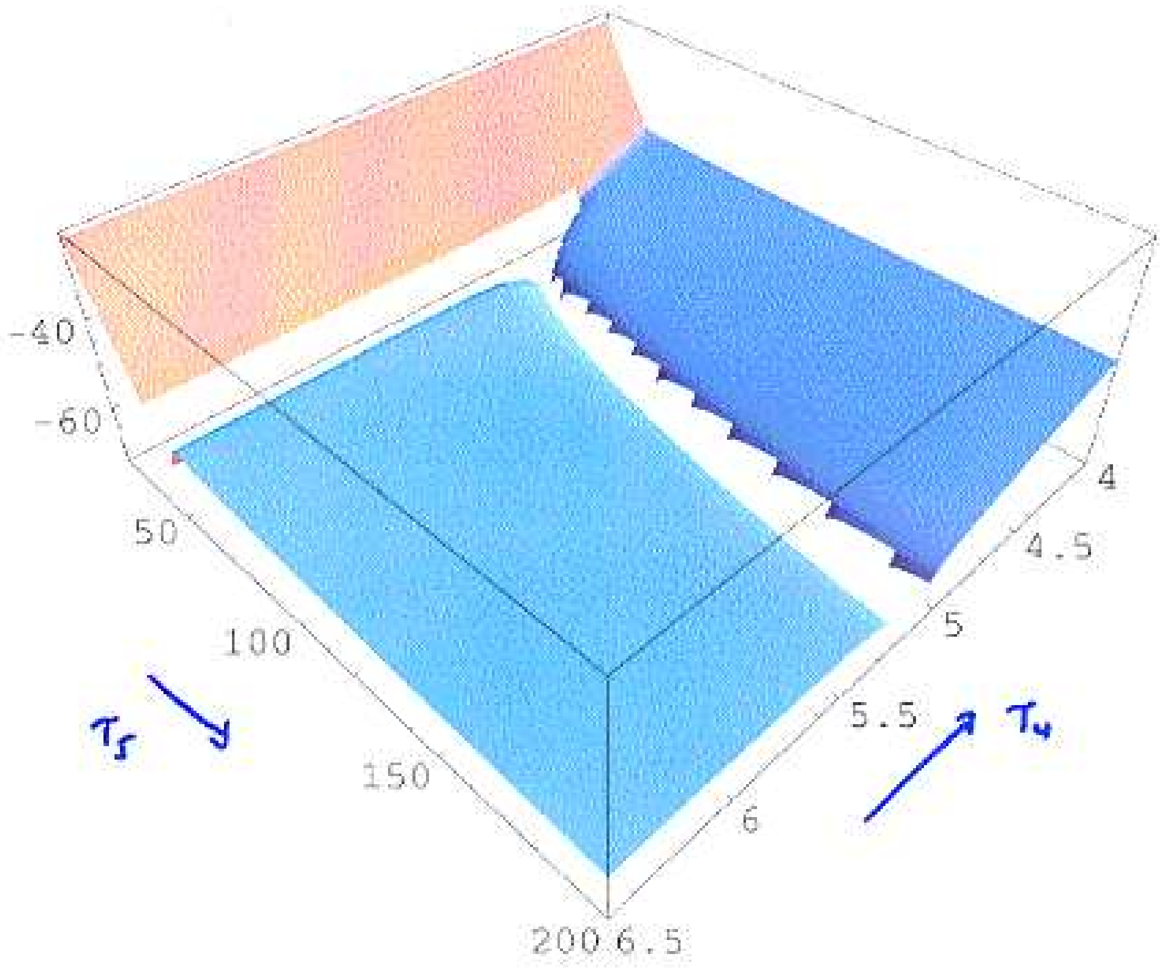
$$\tau_4 \sim \frac{(4\xi)^{2/3}}{g_s} > 1$$

$$\mathcal{V} \propto W_0 \, e^{a_4 \tau_4} \quad !$$



$W_0 \sim 1\text{-}10$ only large volume minimum

$W_0 \sim 10^{-10}$ large volume reduces and approaches KKLT.



$W_0 < 10^{-11}$
Two minima merge.

$\Rightarrow$ Large Extra Dimensions!

$$a_4 = {}^{2\pi}/_N$$
$$\mathcal{V} \sim e^{2\pi/g_s N}$$

String scale : $M_s \sim {}^{M_P}/_{\sqrt{\mathcal{V}}}$

e.g.: $g_s \sim 0.1$, $W_0 \sim 10$, $A_4 \sim 1$

N	Volume	String Scale
22	4600	10^{15} GeV
9	4.6×10^{9}	10^{12} GeV
3	4.6×10^{27}	TeV

Table 3: Moduli spectra for GUT, intermediate and TeV string scales

Scale	Mass	GUT	Intermediate	TeV
M_P	M_P	2.4×10^{18} GeV	2.4×10^{18} GeV	2.4×10^{18} GeV
m_s	$\frac{g_s}{\sqrt{4\pi\mathcal{V}_s^0}} M_P$	1.0×10^{15} GeV	1.0×10^{12} GeV	1.0×10^{3} GeV
m_S	$2\pi m_s = \frac{g_s\sqrt{\pi}}{\sqrt{\mathcal{V}_s^0}} M_P$	6×10^{15} GeV	6×10^{12} GeV	6×10^{3} GeV
m_{KK}	$\frac{2\pi m_s}{(\mathcal{V}_s^0)^{\frac{1}{6}}} = \frac{g_s\sqrt{\pi}}{(\mathcal{V}_s^0)^{\frac{2}{3}}} M_P$	1.5×10^{15} GeV	1.5×10^{11} GeV	0.15 GeV
$m_{3/2}$	$\frac{g_s^2 W_0}{\sqrt{4\pi\mathcal{V}_s^0}} M_P$	1.5×10^{12} GeV	1.5×10^{6} GeV	1.5×10^{-12} GeV
m_τ	$\frac{g_s N m_s}{\sqrt{\mathcal{V}_s^0}} = \frac{g_s^2 N}{\sqrt{4\pi\mathcal{V}_s^0}} M_P$	1.5×10^{12} GeV	1.5×10^{6} GeV	1.5×10^{-12} GeV
m_{cs}	$\frac{g_s N m_s}{\sqrt{\mathcal{V}_s^0}} = \frac{g_s^2 N}{\sqrt{4\pi\mathcal{V}_s^0}} M_P$	1.5×10^{12} GeV	1.5×10^{6} GeV	1.5×10^{-12} GeV
m_{τ_4}, m_{b_4}	$\frac{a_4 g_s W_0}{\sqrt{4\pi\mathcal{V}_s^0}} M_P$	1.5×10^{11} GeV	1.5×10^{5} GeV	1.5×10^{-11} GeV
m_{τ_5}	$\frac{g_s^2 W_0}{\sqrt{4\pi}(\mathcal{V}_s^0)^{\frac{3}{2}}} M_P$	2.2×10^{10} GeV	22 GeV	2.2×10^{-26} GeV
m_{b_5}	$\exp(-a_5\tau_5) M_P \sim 0$	$\sim 10^{-300}$ GeV	$\exp(-10^{6})$ GeV	$\exp(-10^{18})$ GeV

Properties of Minimum

* $\cancel{\text{SUSY}}$ AdS

$$V \sim \mathcal{O}(1/\mathcal{V}^3)$$

$$m_{3/2}^2 = e^K |W|^2 \sim \mathcal{O}(1/\mathcal{V}^2) \Rightarrow D_{\tau_s} W \neq 0$$

* Tachyon Free !

$$V_F = \underbrace{\frac{G^{a\bar{b}} D_a W D_{\bar{b}} \bar{W}}{\mathcal{V}^2}}_{V_{cs}} - \underbrace{\mathcal{O}(1/\mathcal{V}^3)}_{V_{Kahler}}$$

$\mathcal{V} \gg 1 \Rightarrow D_a W = 0$ minimum

unlike KKLT !

* $m_{3/2}$ "Flux Independent"

$$\mathcal{V} \sim W_0 \qquad e^K \sim 1/\mathcal{V}^2$$

$$\Rightarrow m_{3/2}^2 \sim e^K |W|^2 \text{ indep of } W_0$$

" fixed g_s

unlike KKLT !

* Can uplift to dS

(as KKLT).

Further Corrections to K?

$$S = S_{b_0} + S_{\ell_0} + S_{b_3} + S_{\ell_3} + \cdots$$

* $$S_{b_3} \sim \int d^{10}x \sqrt{-g} \Big[\underset{v^{-4/3}}{R^4} + R^3 \big(\underset{v^{-3}}{G_3^2} + \underset{v^{-11/3}}{F_5^2} + \partial\tau^2 \big) + R^2 \big(\underset{v^{-14/3}}{G_3^4} + \cdots \big) + R \big(\underset{v^{-19/3}}{G_3^6} + \cdots \big) + \big(\underset{v^{-8}}{G_3^8} + \cdots \big) \Big]$$

* Bulk loop corrections suppressed by α'

* Local (D3, D7, ...) loop corrections model dependent.

Berg, Haack, Kors

General Case:

The structure generalizes to <u>all</u> Calabi-Yau's with:

$$h^{2,1} > h^{1,1} > 1$$

$$\begin{array}{lll} 1 & \tau_b \ggg 1 & \\ h^{1,1}-1 & \tau_{s,i} > 1 & \mathcal{O}(1) \end{array}$$

$$V \sim \frac{\sqrt{\log \mathcal{V}} - \log \mathcal{V} + \xi}{\mathcal{V}^3}$$

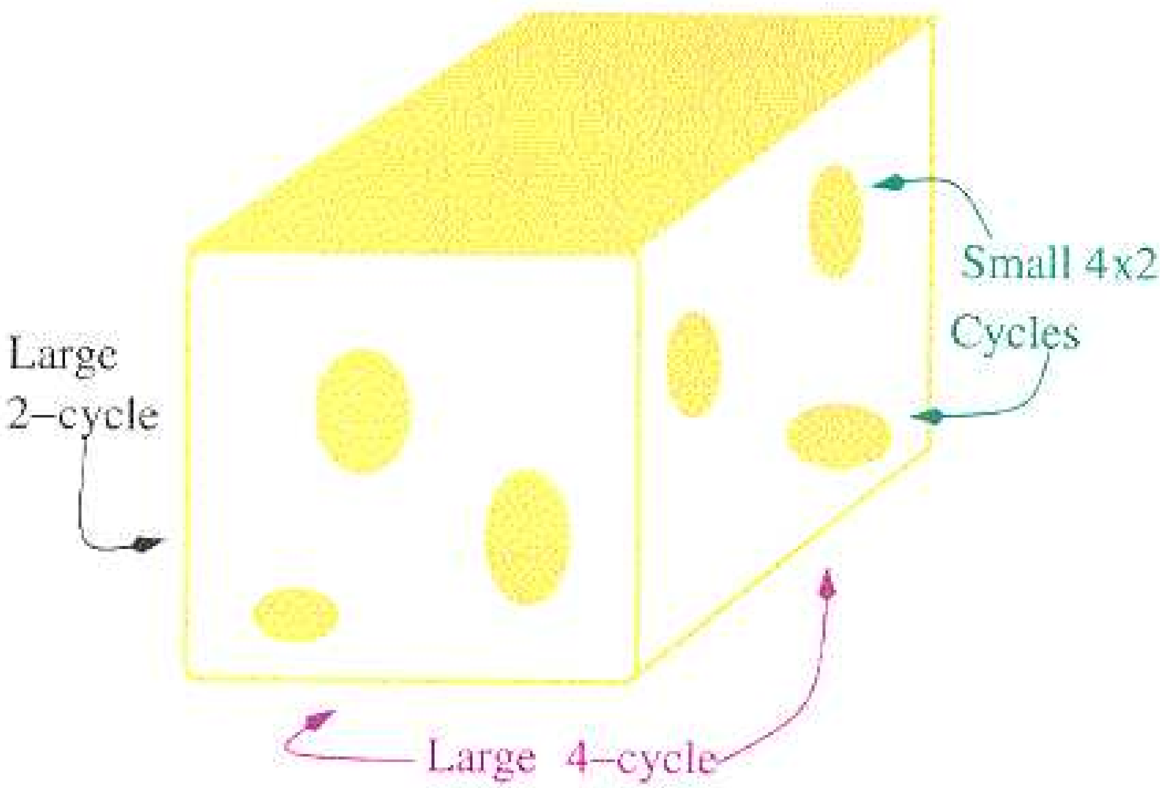
$V \to 0_- \qquad \mathcal{V} \to \infty$

$\Rightarrow$ AdS minimum.

Swiss Cheese Picture ?

$$\mathcal{V} = \tau_5^{3/2} - \tau_4^{3/2}$$

Also $\frac{\partial^2 \mathcal{V}}{\partial t_i \partial t_j}$ signature $(\underbrace{+}_{1}, \underbrace{-, - \cdots -}_{h^{11}-1})$ Candelas de la Ossa



Or throat-like ?

K3 fibrations : $\mathcal{V} = t_1 t_2^2 + \cdots$

$$\tau_1 = t_2^2 \qquad \tau_2 = 2 t_1 t_2 + \cdots$$

Soft SUSY Breaking.

KKLT:

AdS minimum SUSY

$\Rightarrow$ $\cancel{\text{SUSY}}$ from lifting (D-term)

$$D = \epsilon / \mathcal{V}^{\alpha}$$

$$\Rightarrow F_{cs}, F_{K}, F_{\tau} \longrightarrow 0 \,, \quad \epsilon \to 0$$

No explicit model calculation!?

Here:

AdS minimum $\cancel{\text{SUSY}}$

$$F^{s} \sim 1/\mathcal{V}^{1/3}$$
$$F^{4} \sim 1/\mathcal{V}$$
$$F^{\tau} \sim 1/\mathcal{V}^{2}$$
$$F_{cs} = 0$$
$$D \sim 1/\mathcal{V}^{4/3}$$

$\Rightarrow$ hierarchy $F^{s} \gg F^{4} \gg F^{\tau} \gg D$

$F_{cs} = 0$

Computed Explicitly!

Table 1: Soft terms for D3 branes (AMSB contributions not included)

Scale	Mass	GUT	Intermediate	TeV
Scalars m_i	$\frac{g_s^2}{(\mathcal{V}_s^0)^{7/6}} W_0 M_P$	3.6×10^{11} GeV	3.6×10^{4} GeV	3.6×10^{-17} GeV
Gauginos M_{D3}	$\frac{g_s^2}{(\mathcal{V}_s^0)^{2}} W_0 M_P$	3.6×10^{9} GeV	3.6×10^{-3} GeV	3.6×10^{-39} GeV
A-term A	$\frac{g_s^2}{(\mathcal{V}_s^0)^{4/3}} W_0 M_P$	3.2×10^{11} GeV	3.2×10^{3} GeV	3.2×10^{-21} GeV
μ-term $\hat{\mu}$	$\frac{g_s^2}{(\mathcal{V}_s^0)^{4/3}} W_0 M_P$	3.2×10^{11} GeV	3.2×10^{3} GeV	3.2×10^{-21} GeV
B term $\hat{\mu}B$	$\frac{g_s^2}{(\mathcal{V}_s^0)^{7/6}} W_0 M_P$	3.6×10^{11} GeV	3.6×10^{4} GeV	3.6×10^{-17} GeV

* $m_s \sim 10^{13}$ GeV $M_{3/2} \sim 10^{2}$ GeV, $m_0 \sim 10^{7}$ GeV
  * $m_s \gtrsim 10^{13}$ GeV no 5th force nor CMP
* $m_s \sim M_{GUT}$ "viable" if warping
* $m_s \sim$ TeV "viable" if $\overline{D3}$.

Table 2: Soft terms for D7 branes (AMSB not included)

Scale	Mass	GUT	Intermediate	TeV
Scalars m_ζ	$m_{3/2}$	1.5×10^{12} GeV	1.5×10^{6} GeV	1.5×10^{-12} GeV
Gauginos M_4, M_5	$m_{3/2}$	1.5×10^{12} GeV	1.5×10^{6} GeV	1.5×10^{-12} GeV
A-term A	$m_{3/2}$	1.5×10^{12} GeV	1.5×10^{6} GeV	1.5×10^{-12} GeV
μ-term $\hat{\mu}$	$m_{3/2}$	1.5×10^{12} GeV	1.5×10^{6} GeV	1.5×10^{-12} GeV
B term $\hat{\mu}B$	$m_{3/2}$	1.5×10^{12} GeV	1.5×10^{6} GeV	1.5×10^{-12} GeV

(Madrid, Hamburg, Berlin)

Conclusions:

* Concrete + Model independent analysis.

  Minimum:

  - AdS, $\cancel{s}$usy, large volume
  - Lift to dS
  - No tachyons
  - $m_{3/2}$ "flux independent"

* Perturbative Corrections to K important.

* Soft $\cancel{s}$usy

Open:

* Effects: warping, loops, ...

* Phenomenology + Cosmology

⋮