7/24/2013

Comments on Racetrack Kahler Uplift

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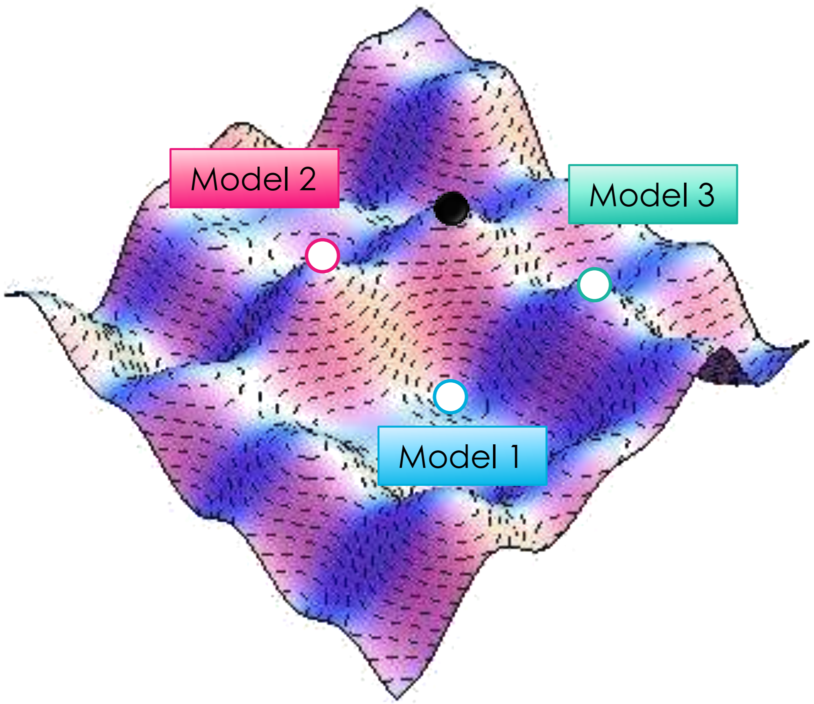
- ❖ Sumitomo, Tye
  - arXiv:1204.5177, JCAP 1208 (2012) 032
  - arXiv:1209.5086, JCAP 1302 (2013) 006
  - arXiv:1211.6856, PLB 723 (2013) 406-410
- ❖ Sumitomo, Tye, Wong
  - arXiv:1305.0753, JHEP 07 (2013) 052

Just moved! (June 17)




Landscape

Metastable vacua in moduli space



- Inflation

  rolling down
  (& tunneling)

- dS vacua

Low energy

Initial conditions?

On which directions (models), can we achieve the tiny cosmological constant?

$$\Lambda \sim 10^{-123} M_P^4$$

Stringy Landscape

There are many types of vacua in string theory, as a result of a variety of (Calabi-Yau) compactification.

$$ds_{10}^2 = ds_4^2 + ds_6^2$$

A class of Calabi-Yau gives Swiss-cheese type of volume.

$$\mathcal{V}_6 = \gamma_1 (T_1 + \bar{T}_1)^{3/2} - \sum_{i=2} \gamma_i (T_i + \bar{T}_i)^{3/2} ,$$

Examples: [Denef, Douglas, Florea, 04]

- $\mathbb{P}^4_{[1,1,1,6,9]}$: $h^{1,1} = 2,\ h^{2,1} = 272$
- $\mathcal{F}_{11}$: $h^{1,1} = 3,\ h^{2,1} = 111$
- $\mathcal{F}_{18}$: $h^{1,1} = 5,\ h^{2,1} = 89$

All can be stabilized *(a la KKLT)*, with a variety of fluxes.

($h^{1,1}$: # of Kahler, $h^{2,1}$: # of c.s. moduli)

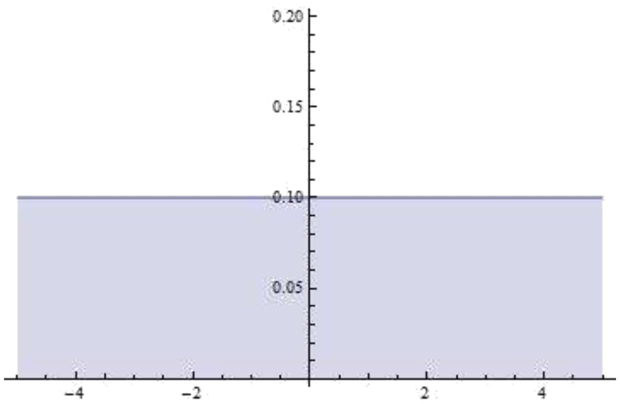
More recently, for $2 \leq h^{1,1} \leq 4$, 418 manifolds

Rich vacuum structures! [Gray, He, Jejjala, Jurke, Nelson, Simon, 12]

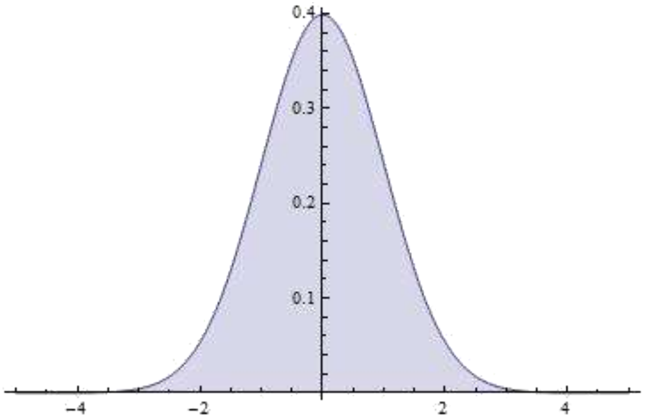
Distribution

What distribution do you imagine for physical quantities?

Uniform (equally probable)?



Gaussian (normal)?



Yes, if the system is quite simple enough.

However, complicated system + moduli stabilization

→ somewhat non-trivial distributions

Statistical Approach in Stringy Models

Kahler Uplift

[Balasubramanian, Berglund, 04], [Westphal, 06], [Rummel, Westphal, 11], [de Alwis, Givens, 11]

Similar setup as that of Large Volume Scenario

α' correction

$$K = -2\ln\left(\mathcal{V}_6 + \frac{\xi}{2}\right) + \cdots, \qquad \mathcal{V}_6 = \gamma_1 (T_1 + \bar{T}_1)^{3/2} - \sum_{i=2} \gamma_i (T_i + \bar{T}_i)^{3/2},$$

Swiss-cheese

$$W = W_0 + \underline{A_1 e^{-a_1 T_1}} + \sum_{i=2} A_i e^{-a_i T_i}$$

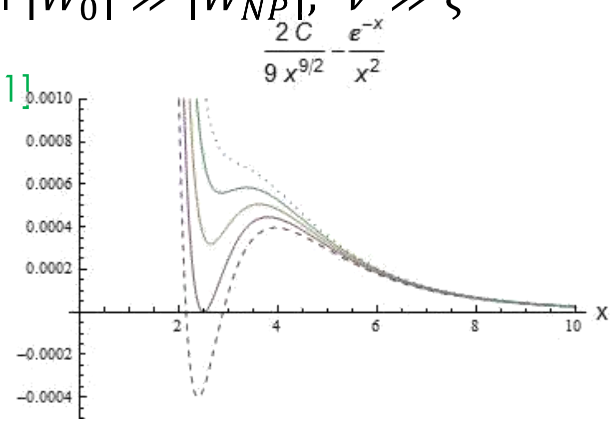
This term plays a roll. (cf. negligible in LVS)

→ less large volume than LVS, but still $|W_0| \gg |W_{NP}|$, $\mathcal{V} \gg \xi$

E.g. single modulus [Rummel, Westphal, 11]

$$\Lambda \equiv V\Big|_{\min} \sim \frac{1}{9}\left(\frac{2}{5}\right)^{\frac{9}{2}} \frac{-W_0 a_1^3 A_1}{\gamma_1^2}(C - 3.65)$$

$$C = \frac{-27 W_0 \xi a_1^{\frac{3}{2}}}{64\sqrt{2}\gamma_1^2 A_1}$$



Distribution of Kahler Uplift

Starting with the simplified potential: [YS, Tye, 12 (Apr)]

$$\Lambda \propto -W_0 A_1 (c - c_0), \qquad c_0 \leq c = \frac{-W_0}{A_1} < c_1$$

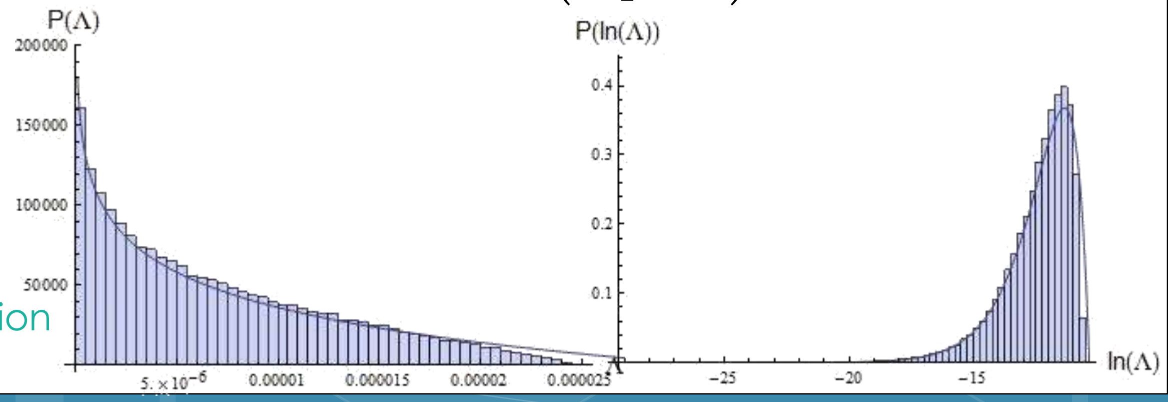
Many ways to fix W_0, A_1 due to varieties of fluxes, and that each c.s. moduli (with $h^{2,1}$) stabilization gives different values.

⇨ $W_0,\ A_1 \in [-1, 1]$, uniform distribution (for simplicity)

Probability distribution function

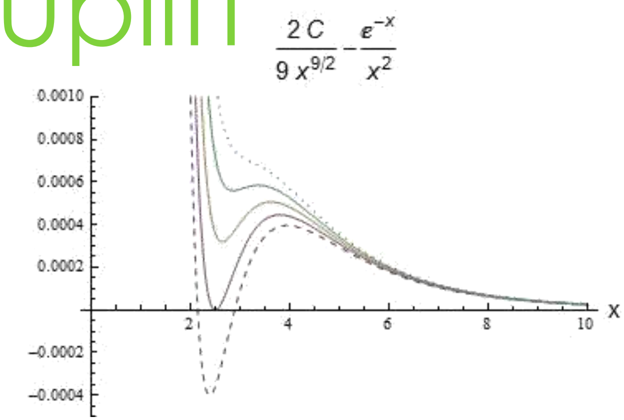
$$P(\Lambda) = N_0^{-1} \int dc \int dW_0 dA_1\ \delta(w_1 w_2 (c - c_0) - \Lambda)\ \delta\left(\frac{-W_0}{A_1} - c\right)$$

$$= \frac{c_1}{c_1 - c_0} \ln \frac{c_1 - c_0}{c_1 \Lambda}$$



Good agreement
at smaller Λ
owing to product distribution

Racetrack Kahler Uplift



Kahler Uplift has a potential problem:

$$x_1 = a_1\, Re\, T_1 \lesssim 3.11$$

Volume moduli is restricted from above.

$a_1 = \frac{2\pi}{N}$ (for SU(N)) would be bounded below by tadpole condition.

[Cicoli, Mayrhofer, Valandro, 11]
[Louis, Rummel, Valandro, Westphal, 12]

⇒ concerns about α'-corrections e.g. [Pedro, Rummel, Westphal, 13]

⇓

Let's introduce racetrack superpotential:

$$W = W_0 + A_1 e^{-a_1 T_1} + B_1 e^{-b_1 T_1}$$

⇒ There opens up a new region of solutions. [YS, Tye, Wong, 13]

(See also [Westphal, 05], [de Alwis, Givens, 11])

Solutions in Racetrack Kahler Uplift

dS vacua at large x_1 (> 3.11): [YS, Tye, Wong, 13]

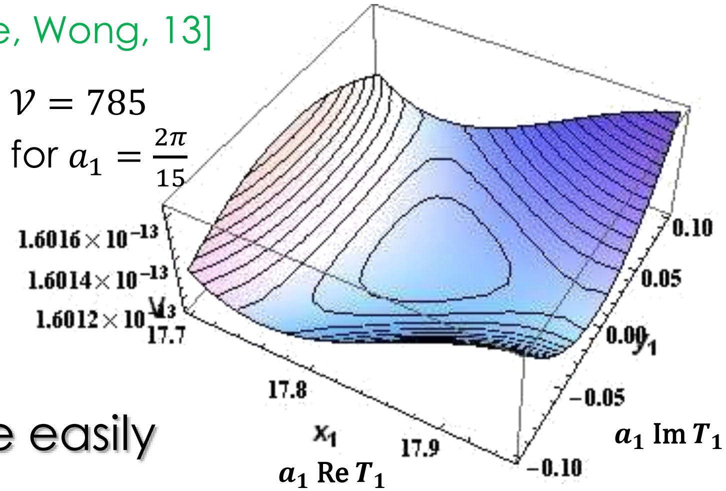
$$x_1 = a_1 \,\mathrm{Re}\, T_1 \sim \frac{1}{\beta - 1} \ln\left[\frac{\beta^3}{-z}\right]$$

when $\beta = b_1/a_1 \approx 1$, $|z| = |A_1/B_1| \ll 1$

No upper bound ➡ Larger volume easily

$\mathcal{V} = 785$

for $a_1 = \frac{2\pi}{15}$

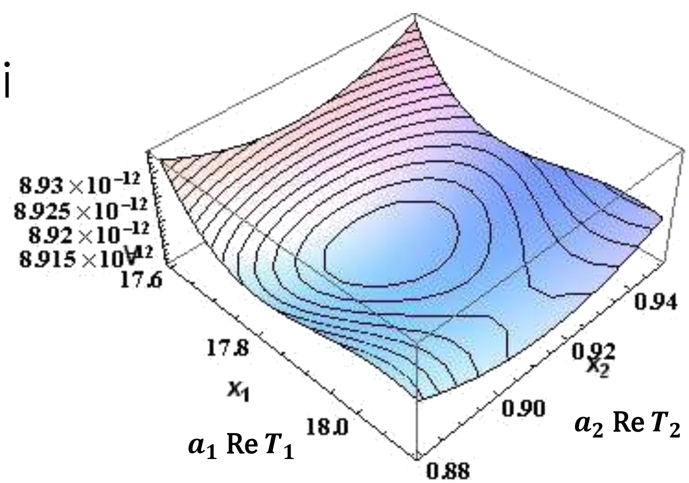


Applicable even for multi Kahler moduli

$$\mathcal{V}_6 = \gamma_1 (T_1 + \bar{T}_1)^{3/2} - \sum_{i=2} \gamma_i (T_i + \bar{T}_i)^{3/2}$$

$$W = W_0 + A_1 e^{-a_1 T_1} + B_1 e^{-b_1 T_1} + \sum_{i=2} A_i e^{-a_i T_i}$$

Large volume holds.



Distributions of Racetrack Kahler Uplift

Cosmological constant $W = W_0 + A_1 e^{-a_1 T_1} + B_1 e^{-b_1 T_1}$

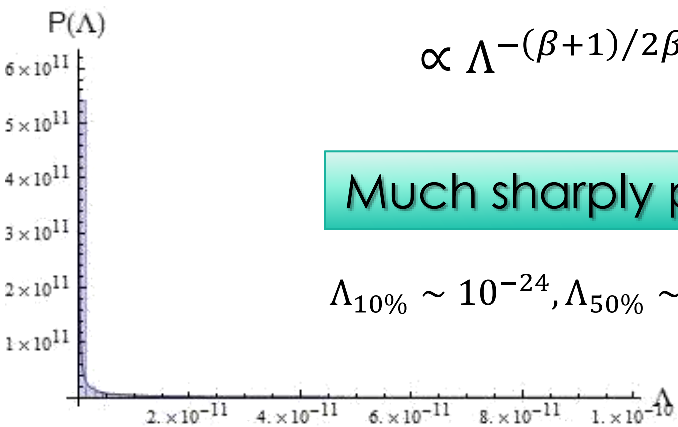
$$\Lambda \propto \kappa^{2\beta/(\beta-1)}(-\ln\kappa)^{5/2}, \qquad \kappa = \frac{-z}{\beta^3} \qquad \beta = b_1/a_1 \approx 1, \quad |z| = |A_1/B_1| < 1$$

As $\beta \approx 1$, exponentially suppressed CC is realized.

Introduce uniformly distributed $-1 \leq z = A_1/B_1 \leq 0$.

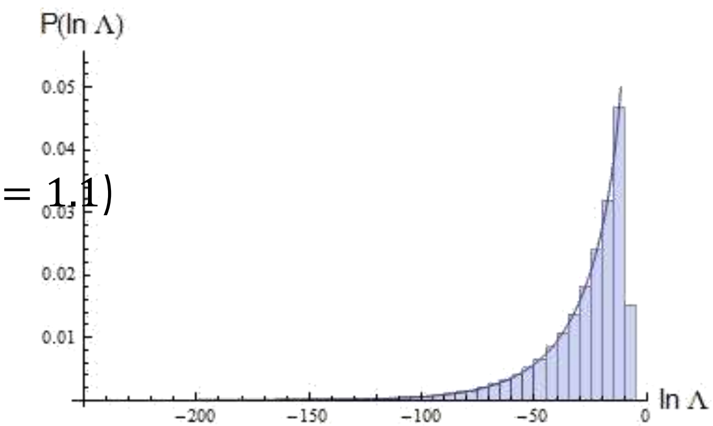
$$P(\Lambda) = \int dz\, P(z)\, \delta\left(\Lambda - \text{const.}\, \kappa^{2\beta/(\beta-1)}(-\ln\kappa)^{5/2}\right)$$

$$\propto \Lambda^{-(\beta+1)/2\beta}(-\ln\Lambda)^{-5/2}$$



Much sharply peaked $(\beta = 1.1)$

$\Lambda_{10\%} \sim 10^{-24}, \Lambda_{50\%} \sim 10^{-9}, \langle\Lambda\rangle \sim 10^{-5}$



Summary & Discussion

Random mini-Landscape in String Theory

We may expect that stringy motivated models have the following properties:

- Non-trivial function (Racetrack Kahler Uplift, SUSY KKLT) [YS, Tye, 12 (Nov)]
- Product of parameters (Kahler Uplift)
- Correlation of each term via dynamics (multi-moduli) [YS, Tye, 12 (Sep)]

⇒ All seem to work for diverging peaked distributions that prefer smaller physical quantities.

Complex sector stabilization may make W_0 smaller.
Smallness of W_0 is good for the hierarchical structure.

⇒ Kahler stabilization with NP-effect is more reliable in the presence of large $h^{2,1}$. [YS, Tye, 12 (Nov)]

(Probability of positive mass matrix increases as $h^{2,1}$ increases)

Detail of Racetrack Kahler Uplift

$$\frac{1}{z} \equiv \frac{B_1}{A_1} \sim -\frac{1}{\beta^3} e^{(\beta-1)x_1}, \qquad \hat{C} \equiv -\frac{3{a_1}^{3/2} W_0 \xi}{32\sqrt{2} A_1} \sim \frac{2(\beta-1)}{9\beta} e^{-x_1} {x_1}^{7/2}$$

or

$$x_1 \sim \frac{1}{\beta-1} \ln\left(\frac{\beta^3}{-z}\right), \qquad \hat{C} \sim \frac{2}{9\beta(\beta-1)^{5/2}} \left(\frac{\beta^3}{-z}\right)^{-1/(\beta-1)} \left(\ln\frac{\beta^3}{-z}\right)^{7/2}$$

Solution:

$$W_0 = -0.223, A_1 = 1.65, B_1 = -4.77, a_1 = \frac{2\pi}{15}, b_1 = \frac{2\pi}{14}, \xi = 3.41 \times 10^{-3}$$

or

$$z = -0.346, \hat{C} = 8.28 \times 10^{-6}, \beta = 1.07, \mathcal{V} = 785$$