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A Stringy Mechanism for A Small Cosmological Constant

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- Y. Sumitomo, S.-H. H. Tye, arXiv:1204.5177
- and some more

Stringy Landscape

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

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

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

E.g. workable models: [Denef, Douglas, Florea, 04]

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

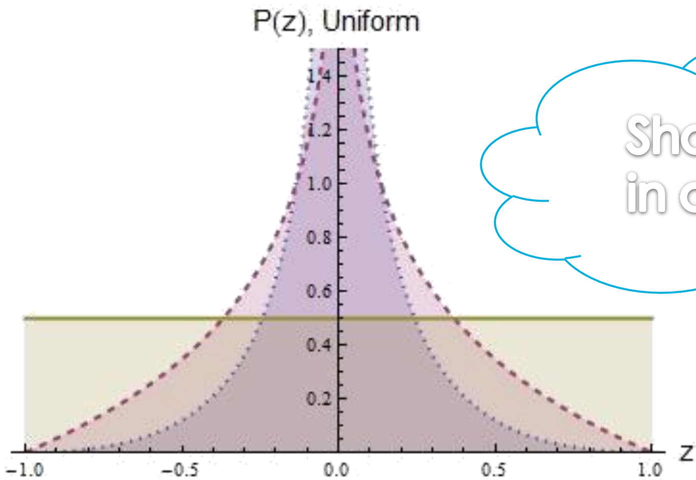
All can be stabilized *(a la KKLT)*, but in various way.

Is there any implication of multiple vacua?

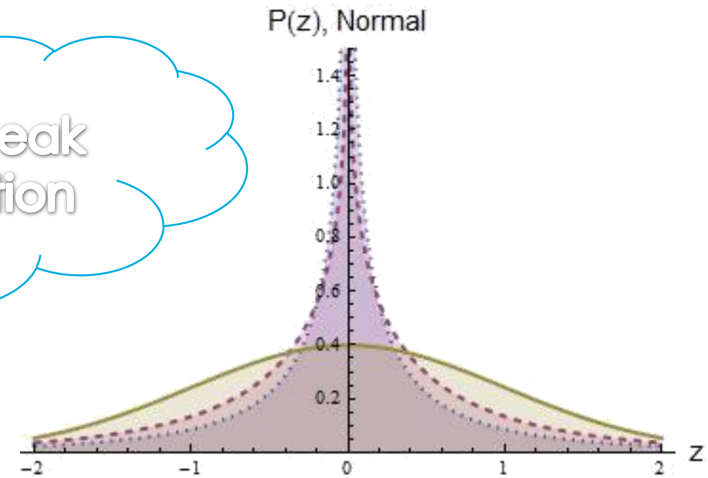
Key of this talk

Product distribution

Assuming products of random variables: $z = y_1 y_2 y_3 \cdots$



Sharper peak in distribution



Many terms? → correlate each other through stabilization

→ $z = y_1 y_2 y_3 \cdots f(y_1, y_2, y_3, \cdots)$ still peaked

We apply this mechanism for cosmological constant (CC)

→ suppression is still mild for current CC

A working model in type IIB

Hierarchical structure of mass matrix/potential helps to stabilize moduli at positive cosmological constant.

Gary's talk, [X. Chen, Shiu, YS, Tye, 12]

No scale structure → Hierarchy between Kahler and Complex

Moduli stabilization with positive cosmological constant

- Fluxes → Complex structure & dilaton
- Non-perturbative effect, α'-correction, localized branes

→ Kahler [KKLT, 03], [Balasubramanian, Berglund, Conlon, Quevedo, 05], [Balasubramanian, Berglund, 04]

$$V = V_{\text{Flux}} \quad + \quad \underline{V_{\text{NP}} + V_{\alpha'} + \cdots}$$

V_{Flux} → Complex; $V_{\text{NP}} + V_{\alpha'} + \cdots$ → Kahler

A class of models of interest, assuming stabilized complex moduli:

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

$$K = -2M_P^2 \ln\left(\mathcal{V} + \frac{\xi}{2}\right),$$

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

: Swiss-cheese type

$$W = M_P^3\left(W_0 + \sum A_i e^{-a_i T_i}\right).$$

Treat α' and NP-terms as perturbations

$$\frac{V}{M_P^4} \propto \mathcal{O}\left(\frac{A_i e^{-a_i T_i}}{W_0}\right) + \mathcal{O}\left(\frac{\xi}{\mathcal{V}}\right) + \cdots$$

If we focus on smaller cosmological constant (CC), this is a good approximation.

Focusing on real part of single modulus model, (imaginary part is trivial)

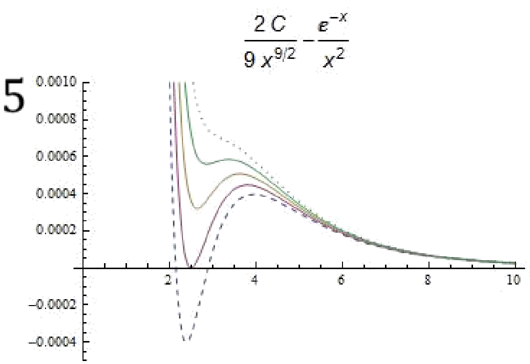
$$\frac{V}{M_P^4} = -\frac{W_0 a_1^3 A_1}{2\,\gamma_1}\left(\frac{C}{9{x_1}^{9/2}} - \frac{e^{-x_1}}{x_1^2}\right), \qquad \mathrm{C} = \frac{-27 W_0 \xi {a_1}^{\frac{3}{2}}}{64\sqrt{2}\gamma_1^2 A_1}, \qquad x_1 = a_1 t_1$$

Markus's talk, [Rummel, Westphal, 11]

The stability constraint with positive CC at stationery points:

$$V \geq 0 \longrightarrow 3.65 \leq C < 3.89 \longleftarrow \partial_x^2 V > 0$$

Further focusing on smaller CC region: $C \sim 3.65$



$$\frac{V}{M_P^4} \sim \frac{1}{9}\left(\frac{2}{5}\right)^{\frac{9}{2}} \frac{-W_0 a_1^3 A_1}{\gamma_1^2}(C - 3.65)$$

Neglecting the parameters a_1, γ_1, ξ, the model is simplified to be

$$\Lambda = w_1 w_2 (c - c_0), \qquad c_0 \leq c = \frac{w_1}{w_2} < c_1 \qquad (w_1 = -W_0, w_2 = A_1, c \propto C)$$

Stringy Random Landscape

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

$$\Lambda = w_1 w_2 (c - c_0), \qquad c_0 \le c = \frac{w_1}{w_2} < c_1$$

Since W_0, A_1 are given model by model (various ways of stabilizing complex moduli), here we impose reasonable randomness on parameters.

$w_1, w_2 \in [0,1]$, uniform distribution (for simplicity)

Probability distribution function

$$P(\Lambda) = N_0 \int dc \int dw_1 dw_2 \;\; \delta(w_1 w_2 (c - c_0) - \Lambda)\, \delta\left(\frac{w_1}{w_2} - c\right)$$

N_0: normalization constant

Divergence in product distribution

When $z = w_1 w_2$,

$$P(z) = \int dw_1 dw_2\, \delta(w_1 w_2 - z) = \frac{1}{2} \ln \frac{1}{z}$$

log divergence at $z = 0$

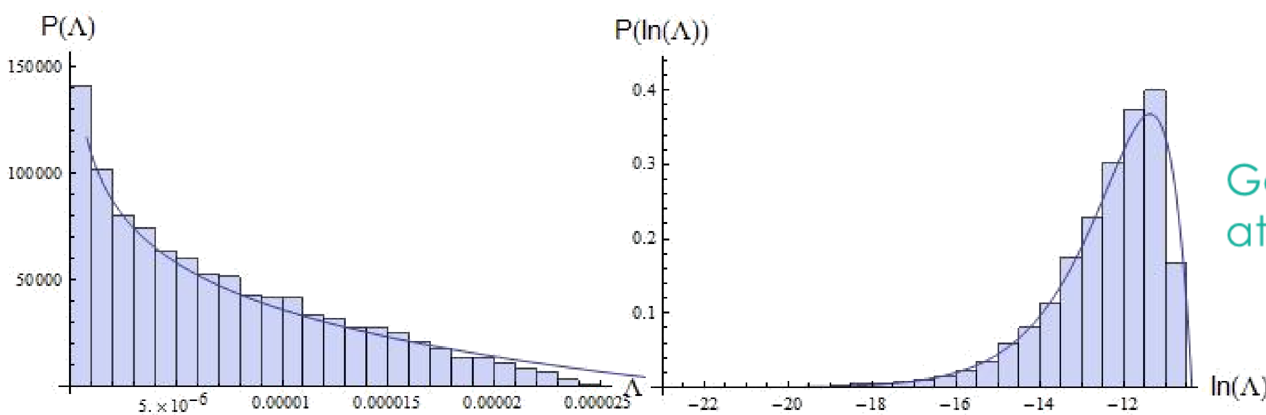
With constraint? $\Lambda = w_1 w_2 (c - c_0)$, $c_0 \leq c = \frac{w_1}{w_2} < c_1$

positivity (for $c_0 \leq c$), stability (for $c < c_1$)

$$\Rightarrow \quad P(\Lambda) = \frac{c_1}{c_1 - c_0} \ln \frac{c_1 - c_0}{c_1 \Lambda}$$

still diverging!!

Comparison to the full-potential (randomizing W_0, A_1 without approx.)



Good agreement at smaller Λ

Zero-ness of parameters

We assumed the parameters W_0, A_1 passing through zero value, but is it true?

- E.g. T^6 model: $W_0 = -\left(c_1 + \sum d_i U_i\right) - \left(c_2 + \sum e_i U_i\right) S$

  SUSY condition ⇒ $W_0 = 2\, du(1-s)$ $\quad u = \mathrm{Re}(U), s = \mathrm{Re}(S)$

  easy to be zero

  e.g. [Rummel, Westphal, 12]

- Brane position dependence of A_1 [Baumann, Dymarsky, Klebanov, Maldacena, McAllister, Murugan, 06]

$$A_1 = \hat{A}_1(U_i)\big(f(X_i)\big)^{1/n}, \qquad f(X_i) = \prod X_i^{p_i} - \mu^q$$

$f(X_i) = 0$ when D3-brane hits D7-brane (divisor, at μ)

known as *Ganor zero*

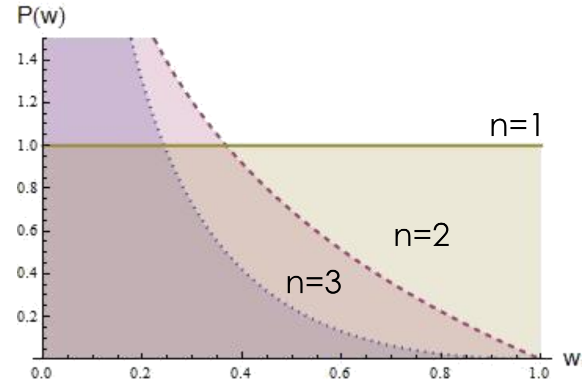
Toward multi moduli

If w_1, w_2 consist from a product of random variables

$$w = y_1 y_2 \cdots y_n,\ \ y_i \in [0,1] \text{ uniform}$$

⇒ $$P(w) = \frac{1}{(n-1)!}\left(\ln\frac{1}{z}\right)^{n-1}$$

$\langle w \rangle = e^{-(\ln 2)\, n}$: exponentially suppressed



W_0, A_1 are complicated functions of complex structure moduli.

⇒ W_0, A_1 may have sharper peak by themselves

↓ coefficients in front

$$\Lambda = \overbrace{w_1 w_2}\underbrace{(c - c_0)}$$

What happens in this part as increasing N_K?

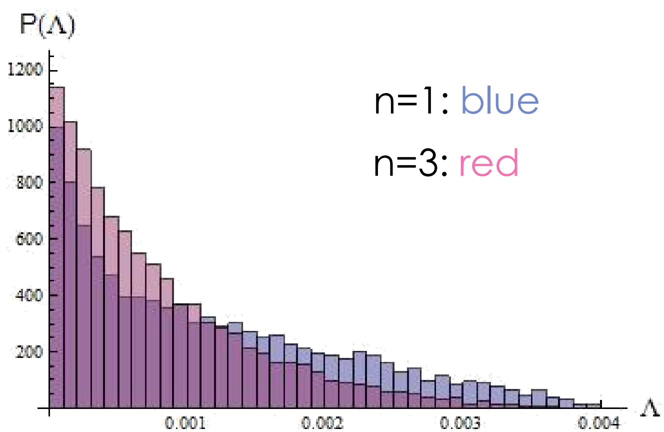
[In preparation]

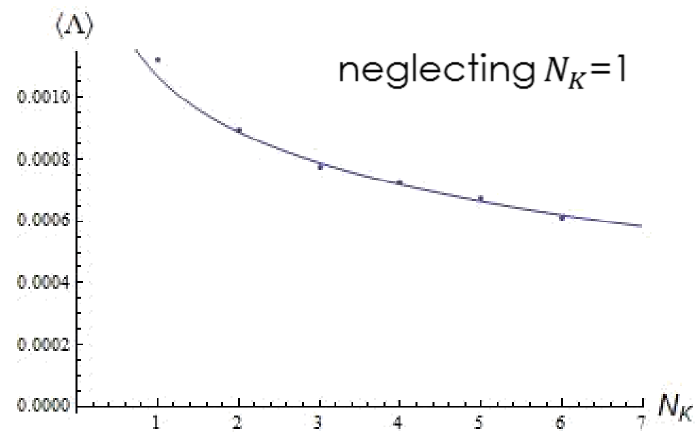
Again, limit ourselves in perturbed regime up to $\mathcal{O}\left(\frac{Ae^{-x}}{W_0}\right), \mathcal{O}\left(\frac{\xi}{\mathcal{V}}\right)$

$$\frac{V}{M_P^4} = -\frac{A_1 W_0 a_1^3}{2\,\gamma_1}\left(\frac{2C}{9\mathcal{V}^3} - \frac{x_1 e^{-x_1}}{\mathcal{V}^2} - \sum_{i=2}\frac{B_i x_i e^{-x_i}}{\mathcal{V}^2}\right), \qquad x_i = a_i t_i, B_i = \frac{A_i}{A_1}$$

same coefficient

Randomizing W_0, A_i, (keeping other parameters fixed)





More moduli bring shaper peak.
(though mild suppression)

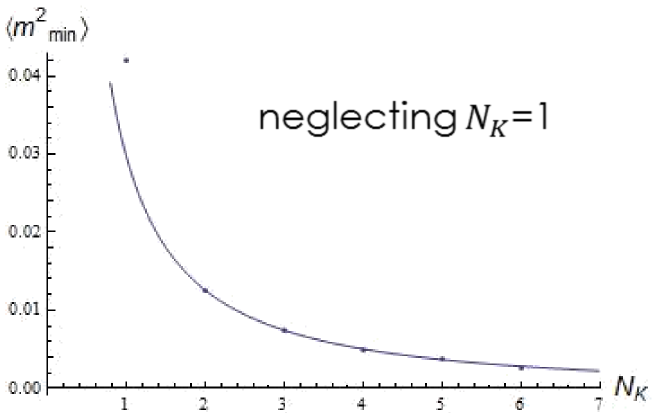
$$\langle\Lambda\rangle \sim 1.1\times 10^{-3} N_K^{0.23} e^{-0.028\,N_K} M_P^4$$

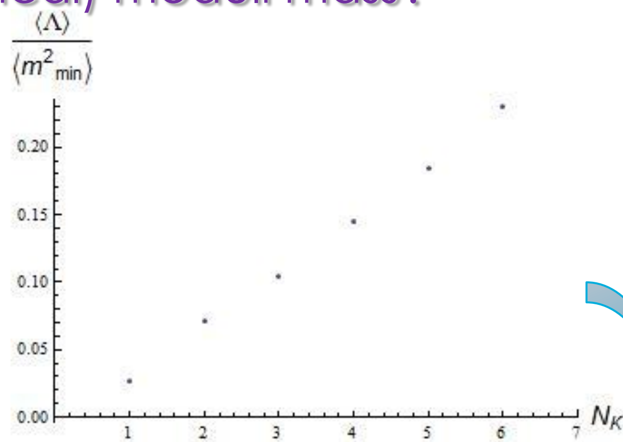
Cosmological moduli problem

Reheating for BBN: $T_r \geq \mathcal{O}(10)$ MeV $\qquad T_r \sim \sqrt{M_P \Gamma_\phi},\ \ \Gamma_\phi \sim \frac{m_\phi^3}{M_P}$

→ $m_\phi \geq \mathcal{O}(10)\ \text{TeV} \sim 10^{-15}\, M_P$

What happens in lightest (physical) moduli mass?





$\langle m^2_{\min} \rangle = 0.031\, N_K^{1.0} e^{-0.10\, N_K} M_P^2$: also suppressed

Suppression of mass is relatively faster than Λ.

→ $\langle m^2_{\min} \rangle \sim 10^{-30} M_P^2$ is likely met earlier than $\langle \Lambda \rangle \sim 10^{-122} M_P^4$

Summary

1. Stringy Random Landscape helps making CC small.

- Product distribution
- Correlation by dynamics (among terms)

→ Both works for smaller CC.

A number of moduli and their stabilization cause
a mild suppression in general.

2. But a potential problem exists.

Lightest moduli mass is suppressed simultaneously.

→ cosmological moduli problem
before reaching $\Lambda \sim 10^{-122} M_P^4$.

Thermal inflation, coupling suppression to SM,
or some other mechanism and etc. may help.