Moduli stabilization, SUSY breaking and the fine-tuning problem

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based on

Abe, Higaki, T.K., hep-th/0511160, 0512232

Choi, Jeong, T.K., Okumura, hep-ph/0508029, ...

1. Introduction

Superstring theory as well as extra dimensional theory has several moduli fields including the dilaton.

Moduli correspond to the size and shape of compact space.

VEVs of moduli fields
→ couplings in low-energy effective theory,
e.g. gauge and Yukawa couplings

Thus, it is important to stabilize moduli VEVs at realistic values from the viewpoint of particle physics as well as cosmology

Actually, lots of works have been done so far.

KKLT scenario

Kachru, Kallosh, Linde, Trivedi, '03

They have proposed a new scenario

leading to de Sitter (or Minkowski) vacua in type IIB.

This scenario consists of three steps.

1) Flux compactification

Giddings, Kachru, Polchinski, '01

The dilaton S and complex structure moduli U are assumed to be stabilized by the flux-induced superpotential

$$W_{flux}(S,U)$$

while the Kaher moduli remain unstabilized.
(It is stabilized in the next step.)

2) Non-perturbative effect

We add T-dependent superpotential induced by

e.g. gaugino condensation.

$$W = \left\langle W_{flux}(S,U) \right\rangle + Ae^{-aT}, \qquad A = O(1)$$

$$K = -3\ln(T + \overline{T})$$

Scalar potential

$$V_F = e^K [D_T W (\overline{D_{\overline{T}} W}) K^{T\overline{T}} - 3|W|^2]$$

$$D_T W = K_T W - W_T$$

T is stabilized at $D_T W = 0$

→ SUSY Anti de Sitter vacuum V < 0

$$V_F = -3m_{3/2}^2$$

Moduli mass $$m_T = a(T + \overline{T})m_{3/2}$$

3) Uplifting

We add uplifting potential generated by

e.g. anti-D3 brane at the tip of warp throat

$$V_L = D/(T+\bar{T})^{n_p}$$

The value of D can be suppressed by the warp factor.

We fine-tune D such that

$V_F + V_L = 0$ (or slightly positive)

→ SUSY breaking de Sitter/Minkowski vacuum

T is shifted slightly from the point $D_T W = 0$

$$F^T \neq 0$$

$$\frac{F^T}{(T+\bar{T})} \cong \frac{m_{3/2}}{a \operatorname{Re} T}, \qquad a \operatorname{Re} T >> 1$$

Soft SUSY breaking terms

Choi, Falkowski, Nilles, Olechowski, Pokorski '04, CFNO '05

Modulus med. and anomaly med. are comparable.

It is useful to define the ratio, AM/modulus med.

$$\alpha \equiv \frac{m_{3/2}(T+\bar{T})}{F^T \ln(M_P / m_{3/2})}$$

An interesting aspect is the mirage scale, where anomaly med. at the cut-off scale and RG effects between the cut-off scale and the mirage scale cancel each other.

$$M_{mirage} = M_X (m_{3/2} / M_P)^{\alpha/2}$$

Original KKLT → $\alpha = 1$

$\alpha = 2$ → a solution of the little SUSY hierarchy problem

Choi, Jeong, T.K., Okumura, '05

2. Moduli mixing in gauge coupling

In several string models, gauge kinetic function f is obtained as a linear combination of two or more fields.

Weakly coupled hetero. /heterotic M

$$f = S + \beta T$$

Similarly,

IIA intersecting D-branes/IIB magnetized D-branes

$$f = mS + wT$$ Lust, et. al. '04

Gaugino condensation → exp[-a f]

Moduli mixing superpotential

3. KKLT type models with moduli mixing superpotentail

We consider moduli-mixing superpotential

However, we assume that one of moduli is stabilized already at the string scale.

Remark

This assumption is realized in certain models.

(We are preparing a paper, Abe, Higaki, T.K.)

Alternatively, two moduli may remain light.

Abe, Higaki, T.K. '05

Our models

$$K = -n_T \ln(T + \overline{T})$$

$$W = W_a + W_b$$

$$W_a = e^{-8\pi^2 S/N_a}, \qquad \text{or} \qquad e^{-8\pi^2 (m_a S + w_a T)/N_a}$$

$$W_b = e^{-8\pi^2 (m_a S \pm w_a T)/N_a}$$

S is replace by its VEV.

We also add the same uplifting potential.

Model 1

$$W = e^{-8\pi^2 S/N_a} + e^{-8\pi^2 (m_b S + w_b T)/N_b}$$

Analysis is very similar to the original KKLT.

We may not need fine-tune the flux to lead to low energy SUSY.

$$\alpha = \frac{2 n_T}{3 n_p (1 + m_b \mathrm{Re}\, S / w_b \mathrm{Re}\, T)}$$

In the original KKLT

$$n_T = 3, n_p = 2 \quad \Rightarrow \quad 0 < \alpha < 1$$

Model 2

$$W = e^{-8\pi^2 (m_a S + w_a T)/N_a} + e^{-8\pi^2 (m_b S + w_b T)/N_b}$$

Racetrack type

$$\alpha = \frac{32\pi^2 w_b \,\mathrm{Re}\, T / N_b}{3 n_p (1 + m_a \,\mathrm{Re}\, S / w_a \,\mathrm{Re}\, T)}$$

Naturally, anomaly mediation is dominant, but in special models. We may have α = O(1).

Cf. Choi, et. al. ‘05

Model 3

$$W = e^{-8\pi^2 S/N_a} + e^{-8\pi^2 (m_b S - w_b T)/N_b}$$

The sign of exponent is different.

$$\alpha = \frac{2 n_T}{3 n_p (1 - m_b \operatorname{Re} S / w_b \operatorname{Re} T)}$$

α is negative

$$|\alpha| = O(1)$$

Model 4

$$W = e^{-8\pi^2 (m_a S + w_a T)/N_a} + e^{-8\pi^2 (m_b S - w_b T)/N_b}$$

α is negative

$$|\alpha| = O(4\pi^2)$$

5. SUSY phenomenology and cosmology

SUSY phenomenology

Our models have a rich structure on soft SUSY breaking terms, i.e. various values of α.

Gauge kinetic function in the visible sector

$$f_v = m_v S + w_v T$$

Effective α for the visible gaugino mass

$$\alpha_{eff} = \alpha (1 + m_b \mathrm{Re}\, S / w_b \mathrm{Re}\, T)$$

Spectrum

Orders of mass scales are similar to the original.

MSSM s-particle masses = O(100) GeV – O(1)TeV

gravitino mass = O(10) TeV

moduli mass = O(100) TeV for α =O(1)

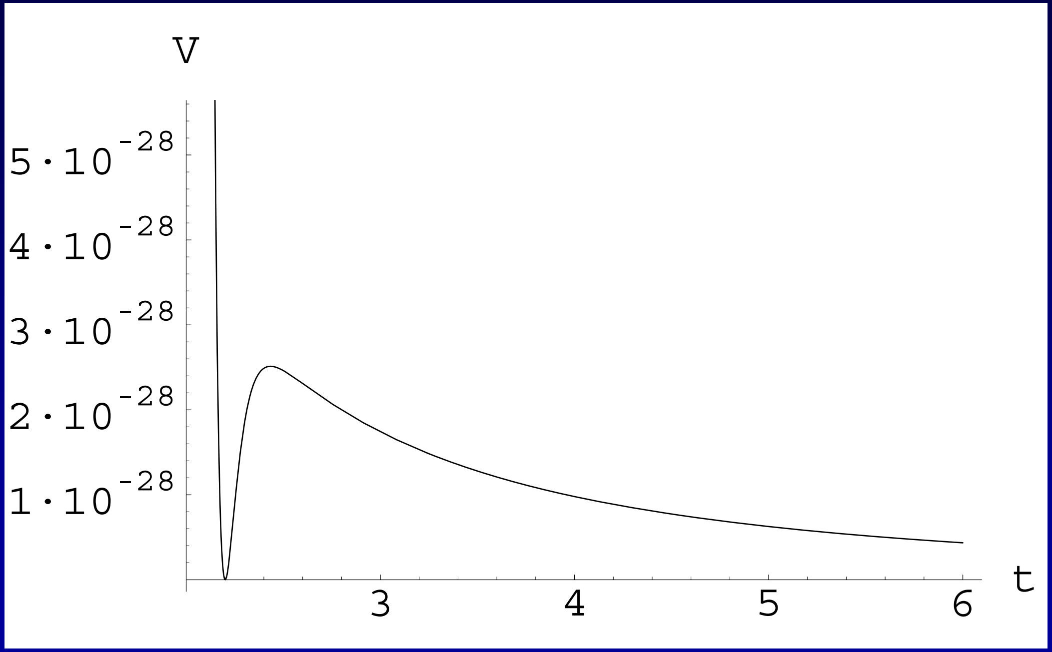
Details of s-spectrum depends on models,

e.g. a value of α .

Further phenomenological study would be interesting.

Cosmology

Model 1



Height of bump is determined by gravitino mass

Overshooting problem Brustein, Steinhardt, '93

Inflation ?

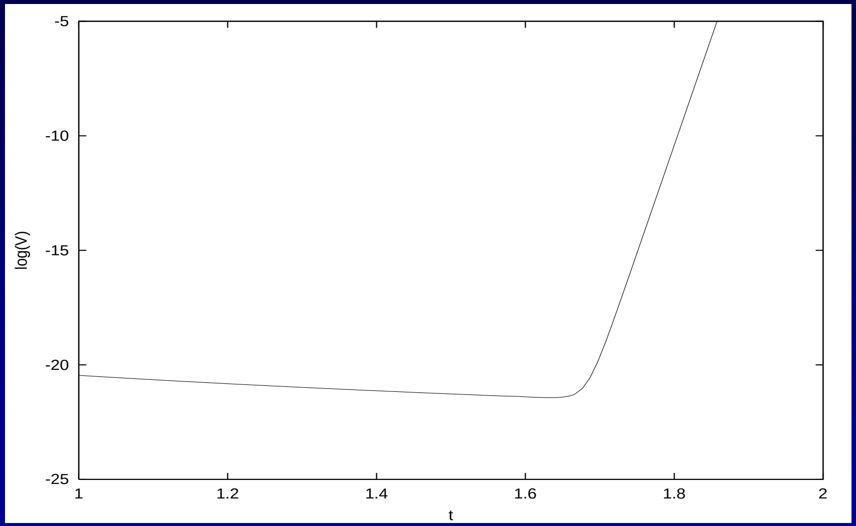
destabilization due to finite temperature effects

$\Delta V = (\alpha_0 + \alpha_2 g^2)\hat{T}^4$ Buchmuler, et. al. '04

$\Delta V = [\alpha_0 + \alpha_2/(mS + wT)]\hat{T}^4$

Model 3, 4

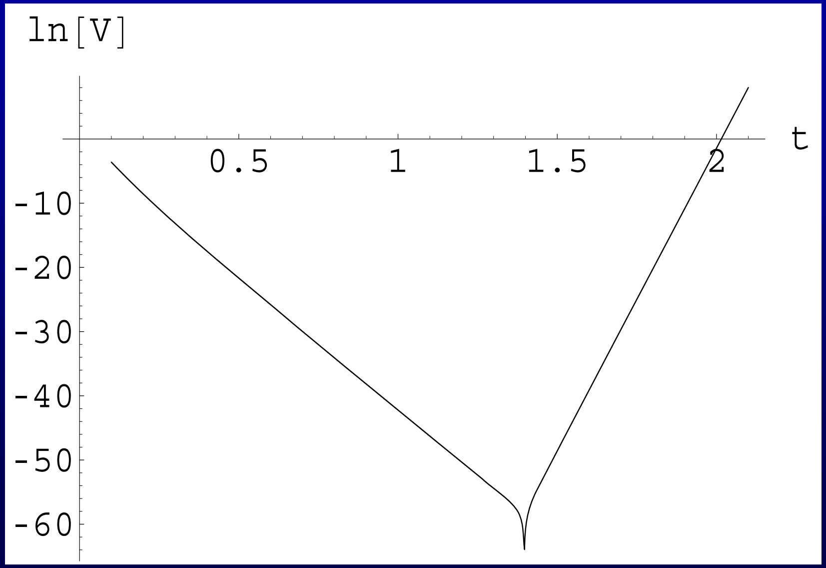
Model 3



$$W = C + e^{-8\pi^2 (m_b S - w_b T)/N_b}$$

$$\Delta V = [\alpha_0 + \alpha_2 /(mS - wT)] T\hat{\ } 4$$

Model 4



The above problems may be avoided.

Little SUSY hierarchy

Less fine-tuning, higgs mass > 114 GeV

⇒ the little hierarchy

$$m_{stop}^2, |A_t|^2 >> |m_h^2|$$

The usual model ⇒ $m_{stop}^2 \approx |m_h^2|$

Mirage mediation with $M_{mirage} = M_X (m_{3/2} / M_P)^{\alpha/2}$

α =2 → a solution of

the little SUSY hierarchy problem

Choi, Jeong, T.K., Okumura, '05

Mirage mediation

Mirage mediation

= (modulus med.) + (Anomaly med.)

S-spectrum = (modulus med.)

+(Anomaly med.) + (RG effect)

If the following condition is satisfied,

$$A_{ijk} = -M, \qquad Y_{ijk} \neq 0$$

$$m_i^2 + m_j^2 + m_k^2 = M^2$$

AM and RG effects cancel each other at

the mirage scale $M_{mirage} = M_X (m_{3/2} / M_P)^{\alpha/2}$

TeV-scale mirage mediation

$\alpha = 2 \quad \Rightarrow$ Mirage scale = TeV scale

If the modulus mediation leads to

$$m_{stop}^2 = M^2/2, \qquad m_h^2 = 0$$

the little hierarchy between the stop mass and the Higgs soft mass is naturally realized at TeV scale. Choi, Jeong, T.K. Okumura, '05

In this model, A-term at the weak scale is large.

That is important to increase the Higgs mass in the full analysis. Kitano, Nomura, '05

Summary

We have studied KKLT type models with moduli-mixing superpotential.

Soft SUSY breaking terms have a rich structure.

→ further study

important e.g. for the fine-tuning problem

Certain models have important characters from the cosmological viewpoint.