Bounds on the reheating temperature from Dilaton Destabilization

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Outline :

(1) gauge couplings at high T

(2) dilaton stabilization

(3) dilaton potential at high T

(4) implications

Gauge Couplings at high T.

Free energy in SUSY $SU(N_c)$ theory:

$$F(g,T) = -\frac{\pi^2 T^4}{24}\left\{\alpha_0 + \alpha_2 g^2 + \mathcal{O}(g^3)\right\},$$

g = coupling
N_f = # of flavors

$$\begin{cases} \alpha_0 = N_c^2 + 2N_c N_f - 1 & \leftarrow \text{blackbody} \\ \alpha_2 = -\frac{3}{8\pi^2}(N_c^2-1)(N_c+3N_f) & \leftarrow \text{interactions} \end{cases}$$

Important:

$$\boxed{\alpha_2 < 0}$$

$\Rightarrow$ interactions INCREASE the free energy!

(at weak coupling)

$\Rightarrow$ gauge interactions increase the free energy even for $\lesssim 1$ coupling.

$$\Downarrow$$

if $g = \langle \varphi \rangle$,
gauge interactions in plasma push φ such that g decreases.

Strings:

$$g^2 = \frac{1}{\mathrm{Re}\, S} \quad \Rightarrow \quad S \to \infty .$$

Dilaton Stabilization.

Consider, for example, weakly coupled het. string.

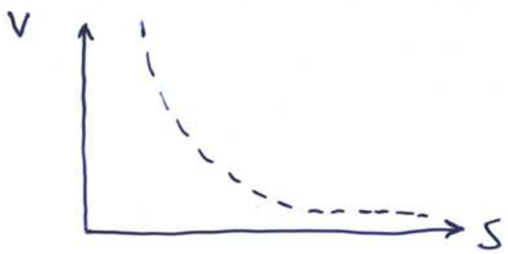
Gaugino condensation:

$$W(S,T) = \eta(T)^{-6}\,\Omega(S)$$

$$\Omega(S) = d_1\, e^{-3S/2\beta_1} + \dots$$

$$K = \kappa(S+\bar{S}) - 3\ln(T+\bar{T})$$

Dilaton runaway problem:



(one condensate)

Popular solutions:

(1) multiple condensates

(2) nonperturbative Kähler potential

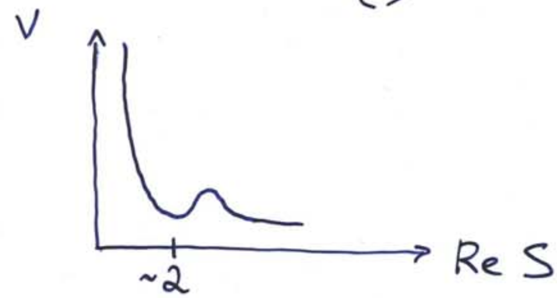
(1) multiple condensates ("racetrack")

$$K(S+\bar{S}) = -\ln(S+\bar{S})$$

$$W = \eta(T)^{-6}\left\{ d_1 e^{-3S/2\beta_1} + d_2 e^{-3S/2\beta_2} \right\}$$

$SU(N_1)$ + matter $SU(N_2)$ + matter

$$\beta_1 \sim \beta_2 \quad \Rightarrow \begin{cases} \mathrm{Re}\, S_{min} \sim 2 \\ \cancel{\mathrm{SUSY}} \sim 10^2 - 10^4\ \mathrm{GeV} \end{cases}$$



(2) Kähler Stabilization.

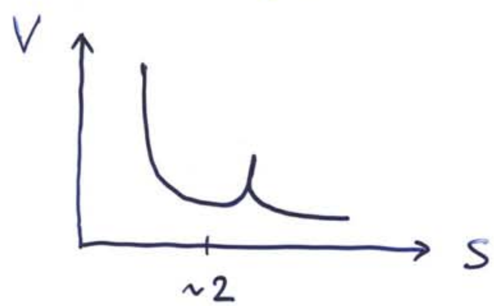
$$\tilde{K}(S+\bar{S}) = \ln\left(e^{K_0} + e^{K_{np}}\right),$$

$$\begin{cases} K_0 = -\ln(S+\bar{S}) \\ K_{np} = c\,(\mathrm{Re}\,S)^{p/2}\, e^{-q\sqrt{\mathrm{Re}\,S}} \end{cases}$$

$$W = \eta^{-6}(T)\cdot d\, e^{-3S/2\beta}$$

By tuning c, p, q one achieves $K'' \ll 1$

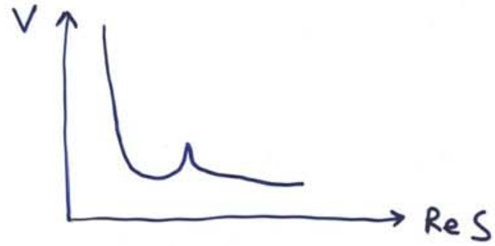
and $\begin{cases} \mathrm{Re}\,S_{min} \sim 2 \\ \cancel{\text{SUSY}} \sim 10^2 - 10^4\ \text{GeV} \end{cases}$



Dilaton Potential at High T.

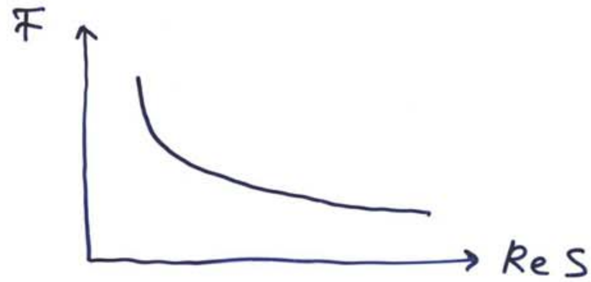
$$V = V_{SUGRA} + \mathcal{F}(T)$$

$V_{SUGRA} \sim$

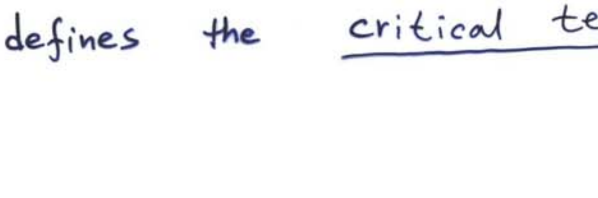


$$\mathcal{F}(T) \sim T^4 \left(\text{const} + \frac{1}{\text{Re}\,S} + \dots \right)$$

$\sim$



At high T, the minimum at $\text{Re}\,S \sim 2$ disappears :



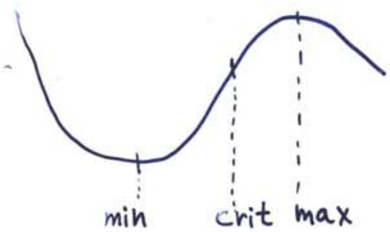
This defines the <u>critical temperature</u>.

Calculational procedure:

$$\mathcal{F}(\mathrm{Re}S, T) = A T^4 - \delta \mathrm{Re}S \cdot \underbrace{B T^4}_{>0} + \mathcal{O}(\delta \mathrm{Re}S^2)$$

expand around $\mathrm{Re}S_{min}$;

$\delta \mathrm{Re}S \equiv \mathrm{Re}S - \mathrm{Re}S_{min}$



$$\begin{cases} V''(\mathrm{Re}\,S_{crit}) = 0 \\ T_{crit} = \left(\frac{1}{B} V' \Big|_{\mathrm{Re}\,S_{crit}} \right)^{1/4} \end{cases}$$

$$\Downarrow$$

$$T_{crit} \sim \sqrt{m_{3/2}} \left(\frac{3}{\beta} \right)^{3/4} \left(\frac{1}{B \cdot K''} \right)^{1/4}$$

Here $\begin{cases} \beta = \beta\text{-function of the condensing gauge group}, \\ B = \text{coefficient } (N_c, N_f) \\ K'' = \text{curvature of the Kähler potential} \end{cases}$

For $m_{3/2} \sim 100$ GeV, $\beta \sim 0.1$, $K'' \sim 10^{-4} \ldots 1$,

$T_{crit} \sim 10^{11} \ldots 10^{12}$ GeV.

Implications.

T_{crit} = maximal allowed temperature in the radiation dominated epoch

$$T < T_{crit}$$

(1) In particular,

$$\underline{T_{reheat.} < T_{crit} \sim 10^{11} - 10^{12} \text{ GeV}}$$

(2) Stronger constraints may apply in inflation models (depending on inflaton-dilaton coupling)

$$T_{max} = (T_{reheat.}^{2} M_{Pl} H_{inf})^{1/4}$$

$$T_{max} < T_{crit}$$

In practice, $\underline{T_{reheat.} < 10^{6} - 10^{10} \text{ GeV.}}$

(doesn't apply if inflaton **STABILIZES** the dilaton during <u>preheating</u>)

(3) Additional constraints (mod. dependent) from the S-modulus problem.

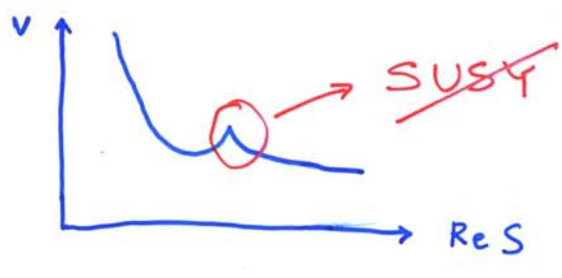
$$m_S \sim \left(\frac{3}{\beta}\right)^2 \frac{1}{K''} m_{3/2} \sim 100 \text{ TeV}$$

Most importantly, T_{crit} gives a model-independent upper bound on T_{reheat}.

In contrast, a similar bound due to the "gravitino problem", $T_{reheat.} < 10^6 \ldots$ GeV can be circumvented by

- additional entropy production
- gravitino dark matter w/ $g(T)$
- ...

$T < T_{crit}$ bound applies much more generally, whenever



$$T_{crit} \sim \sqrt{m_{3/2} M_{Pl}} \ll \langle \tilde{g} \tilde{g} \rangle^{1/3}$$

Further, this bound is based on well unnderstood thermodynamics of the OBSERVABLE SECTOR.

Conclusions.

- dilaton in a thermal bath is destabilized at

$$T_{crit} \sim 10^{11} - 10^{12}\ \text{GeV}$$

- this constrains $T_{reheat.}$ in a model-independent way

- imposes more model-dependent constraints on inflation, leptogenesis, ... models