Effects of Reheating on Moduli Stabilization

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Talk based on K. Alam, K. Dutta,JCAP **10** 085 (2022) [arXiv:2208.00427 [hep-ph]]

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Outline

Cosmological moduli problem

Decay width of the moduli: $\Gamma_\phi \sim \frac{m_\phi^3}{M_P^2}$

Decay at today's time :$m_\phi \sim (H_0 M_{pl}^2)^{1/3} \sim 20 MeV$

Case: (I)No decay by the today's time: $m_\phi \lesssim 20\ MeV$

Mass range :$10^{-26} eV \lesssim m_\phi \lesssim 20 MeV \rightarrow$ Overclose the universe

Case: (II) Decay before today's time $m_\phi \gtrsim 20 MeV$

$20 MeV \lesssim m_\sigma \lesssim 30 TeV \rightarrow$ Problem on BBN-theory

Way out of the above mass range: Abundance at BBN time

$$\frac{\rho_\phi}{s} \lesssim 10^{-14}\ \mathrm{GeV} \implies \phi_{\mathrm{init}} \lesssim 10^{-10} M_P$$

Comment: No cosmological moduli problem for superheavy or superlight moduli field.

Stabilization of moduli

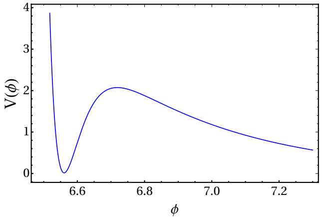

Figure: Plot of moduli potential.

Comment: we have to fix the vev of the moduli potentail to fix the several observal quantity(like gauge coupling, interval volume.)

hep-th/9212049(Brustein and Steinhart)
hep-th/0411011(Kallosh and Linde)

Temperature correction to moduli potential

Temperature correction of moduli potential:

$$V_{\text{total}} = V_{\text{KKLT}}(\sigma) + V_T(\sigma), \quad \text{where, } V_T = T^4\left(a_0 + \frac{a_2}{\sigma}\right)$$

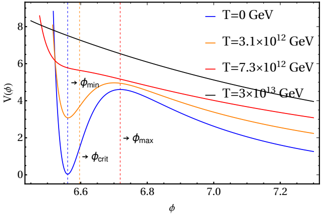

Figure: KKLT potential at different temperature where $\phi = \sqrt{3/2}\ln(\sigma)$

$$T_{crit} \sim 8 \times 10^{12}\text{GeV}$$

hep-th/0411109(Buchmüller and Hamaguchi, Lebedev)
hep-th/0404168(Buchmüller, Hamaguchi, Lebeev and Ratz)

Analytic calculation of critical temperature

The critical temperature is defined by the appearance of a saddle point at some value σ_{crit},

$$V'_{\mathrm{total}}(\sigma_{crit}, T_{crit}) = 0, \tag{1}$$
$$V''_{\mathrm{total}}(\sigma_{crit}, T_{crit}) = 0,$$

From above two equations, we get

$$V'_{\mathrm{KKLT}}(\sigma_{crit}) = \frac{a_2}{\sigma_{crit}^2} T_{crit}^4 \tag{2}$$
$$V''_{\mathrm{KKLT}}(\sigma_{crit}) = -\frac{2a_2}{\sigma_{crit}^3} T_{crit}^4$$

After dividing above two equations,

$$\frac{V'_{\mathrm{KKLT}}(\sigma_{crit})}{V''_{\mathrm{KKLT}}(\sigma_{crit})} = -\frac{\sigma_{crit}}{2} \tag{3}$$

hep-th/0411109(Buchm$\ddot{u}$ller and Hamaguchi, Lebedev)

Consider, $y = V'_{\rm KKLT}(\sigma)$ and $y = -\frac{1}{2}\sigma V''_{\rm KKLT}(\sigma)$

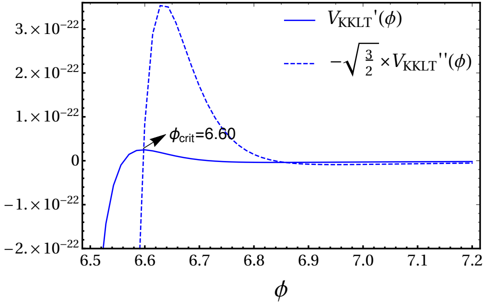

Figure: Plot to find $\phi_{\rm crit}$ for KKLT potential where $\phi = \sqrt{3/2}\,\ln(\sigma)$.

Using Eqs. (2)

$$T_{\rm crit}^{\rm KKLT} \sim 2 \times 10^{13}{\rm GeV}$$

Effect of background radiation & moduli dynamics

Assumation: Thermal bath is already there at initial time

Dynamics of moduli field

$$\ddot{\sigma} + 3H\dot{\sigma} - \frac{\dot{\sigma}^2}{\sigma} + \frac{2\sigma^2}{3} V'_{\rm total}(\sigma, \rho_r) = 0$$
$$\dot{\rho}_r + 4H\rho_r = 0,$$
$$3M_p^2 H^2 = \frac{3}{4}\left(\frac{\dot{\sigma}}{\sigma}\right)^2 + \rho_r + V(\sigma),$$

where, $\rho_r = -3a_0(1 + rg^2)T^4$, $r = \frac{a_2}{a_0}$, and $g^2 = 1/\sigma$. 3rd term is coming due to the present of non-canonical kenetic term into the Lagrangian.

hep-ph/0506045 & 0712.2394(Barreiro, Carlos, Copeland and Nunes)

Dynamics of the moduli field for background radiation

Consider: $T_{\rm init} > T_{\rm crit} \rightarrow$ Minimum of KKLT potential disappears.

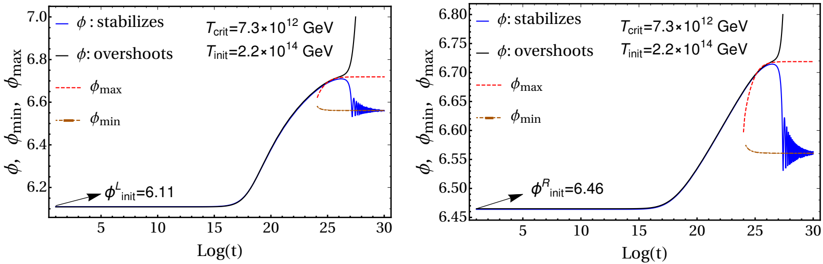

Figure: Time evolution of moduli field($\phi = \sqrt{\frac{3}{2}}\,\ln(\sigma)$)

Field does not 'overshoot' due to (a)hubble damping (b) expansion of the universe within the range 6.11 $\leq \phi_{\rm init} \leq$6.46.

Initial field range vs initial temperature

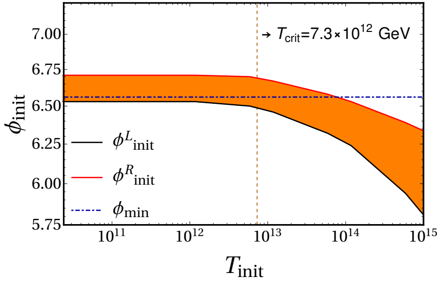

Figure: Plot of the initial field range vs initial temperature.

Comment: Stabilization of the moduli field alway depend on the inital field values for any temperature and for $T_{\text{init}} > T_{\text{crit}}$, sitution does not going to worse.

Effects of reheating & moduli dynamics

Assumption: inflaton perturbatively dacay into radiation $\rightarrow$ instantaneously thermalize
Inflaton and radiation energy density is governed by the equations,

$$\ddot{\sigma} + 3H\dot{\sigma} - \frac{\dot{\sigma}^2}{\sigma} + \frac{2\sigma^2}{3} V'_{\mathrm{total}}(\sigma, \rho_r) = 0$$
$$\dot{\rho_\varphi} + 3(1+\omega_\varphi)H\rho_\varphi + \Gamma_\varphi(1+\omega_\varphi)\rho_\varphi = 0$$
$$\dot{\rho_r} + 4H\rho_r - (1+\omega_\varphi)\Gamma_\varphi\rho_\varphi = 0$$
$$3M_p^2H^2 = \frac{3}{4}\left(\frac{\dot{\sigma}}{\sigma}\right)^2 + \rho_\varphi + \rho_r + V_{\mathrm{KKLT}}(\sigma)$$

where Γ_φ is the decay width of the inflaton field. and ω_φ is the equation of states.

Dynamics of moduli field in the presence of continuous reheating

Consider: $T_{max} > T_{crit}$, where $T_{max} \propto (H_{inf}\Gamma_\Phi M_p^2)^{\frac{1}{4}}$

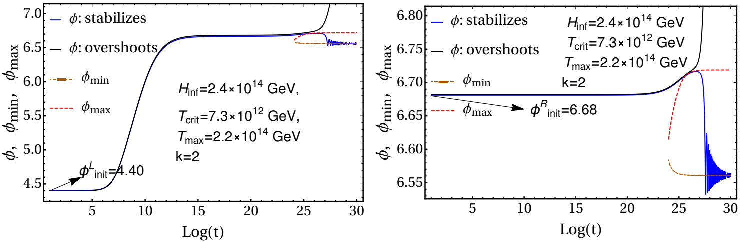

Figure: Time evolution of moduli field($\phi = \sqrt{\frac{3}{2}}\ln(\sigma)$)

No overshoot because: (a) hubble damping (b) expansion of the universe and (c) contineous reheating effects

Comment: field does not overshoot for the initial field range $4.40M_p \leq \phi_{\text{init}} \leq 6.68M_p$(Range for previous case: $6.11 \leq \phi_{\text{init}} \leq 6.46$)

Range of the initial field value vs inflation scale

Upper bound of the tensor-to-scalar ratio,

$$r \lesssim 0.035 \implies H_{inf} \lesssim 2.4 \times 10^{14}\, Gev$$

$$T_{max} \propto (H_{inf} \Gamma_{\Phi} M_p^2)^{\frac{1}{4}}$$

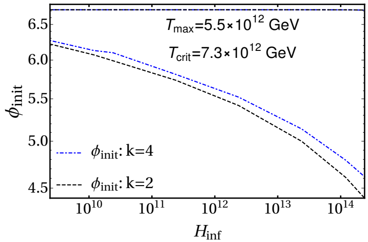

Figure: Initial field range vs inflation scale with fix maximum temperature.

Commend: Initial field range increases as H_{inf} because temperature takes large time to reach the maximum temperature.

Conclusion

- Moduli field will be destabilised when $T_{\rm crit} \lesssim T^{\rm reh}_{\rm max}$ in non-dynamical process. But, in the dynamical process, the upper bound of the reheating temperature relaxes.
- The initial field range of the moduli field relaxes further due to the reheating effect.
- For more details, see the paper (K. Alam, K. Dutta,JCAP **10** 085 (2022) [arXiv:2208.00427 [hep-ph]]).

Thanks for your attention!