Matter Inflation in Heterotic String Theory

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Abstract

Inflation is a very appealing paradigm solving e.g. the flatness and horizon problems of standard big bang cosmology [1]. However, its connection to particle physics remains unknown, which makes scenarios of matter inflation attractive.

Unfortunately, inflation generically suffers from the η-problem and thus an appropriate symmetry is required to protect the potential. In the case of matter inflation, this is achieved using the so-called Heisenberg symmetry [2, 3, 4]. It combines the inflaton with a modulus and hence one has to address the issue of moduli stabilization. For this purpose, we employ a generlization of the model of [4], where inflation ends via the (supersymmetric) hybrid mechanism [5]. This class of models is capable of realizing matter inflation, i.e. inflation with a gauge non-singlet field, as has been shown recently in [6].

We outline how such a scenario with an extended 'tribrid' structure might be realized in orbifold compactifications of the heterotic string. The inflaton is a D-flat direction in the untwisted sector of the orbifold and hence enjoys the Heisenberg symmetry. During inflation, moduli stabilization can be achieved using the F-term providing the vacuum energy, while moduli stabilization after inflation requires a different mechanism.

General Model

We consider a class of models which is a generalization of the 'tribrid' models [4], suitable to realize matter inflation along the lines of [6]:

$$\begin{aligned} W &= a(T_i)X\left(b(T_i,T_3)H^+H^- - \langle\Sigma\rangle^2\right) + c(T_i,T_3)H^+H^-\Phi^2 + \dots\,, \\ K &= -\log(T_1+\bar T_1) - \log(T_2+\bar T_2) - \log x_3 + k(T_i+\bar T_i, x_3)\,|X|^2 \\ &\quad + \tilde k(T_i+\bar T_i,x_3)\,|H^+|^2 + \tilde k(T_i+\bar T_i,x_3)\,|H^-|^2 + \dots\,, \end{aligned}$$

with Φ^2 a shorthand for a D-flat direction, e.g. $\Phi^+\Phi^-$, $x_3 \equiv T_3 + \bar T_3 - |\Phi^+|^2 - |\Phi^-|^2$ etc., and

$$k(T_i+\bar T_i,x_3) = \frac{1+d(x_3)}{(T_1+\bar T_1)^{q_1}(T_2+\bar T_2)^{q_2}}\,,\quad \tilde k(T_i+\bar T_i,x_3) = \frac{1}{(T_1+\bar T_1)^{p_1}(T_2+\bar T_2)^{p_2}x_3^{p_3}}\,,$$

where the $q_i, p_i \geq 0$ are rational numbers and $i = 1, 2$.

Inflation takes place along the D-flat trajectory

$$\langle H^+\rangle = \langle H^-\rangle = \langle X\rangle = 0 \quad \text{and e.g. } |\langle\Phi^+\rangle| = |\langle\Phi^-\rangle| \text{ for } \Phi^2 = \Phi^+\Phi^-\,.$$

Important advantages of this scenario:

- During inflation: W, $W_\Phi \simeq 0$, $W_X \neq 0$ and W_X set dynamically by $\langle\Sigma\rangle$, e.g. via cancelling a Fayet-Illiopoulos term.
- Tree-level: inflaton potential flat and of 'hybrid' form.
- One-loop: $H^\pm$ induces a slope for Φ via Coleman-Weinberg effective potential.

Moduli Stabilization

The moduli can be stabilized by $W_X \neq 0$, for example

- if $d(x_3) = \gamma + \beta x_3$ and $a(T_1,T_2) = e^{a_1T_1+a_2T_2}$ with $a_i > 0$, $q_i < 1$, $|\gamma| \ll 1$ and $\beta < 0$
- at $\langle \mathrm{Re}\,T_i\rangle \sim \mathcal{O}(1)$, $\langle x_3\rangle \sim 1/\beta$ and with masses $m^2 \sim V$.

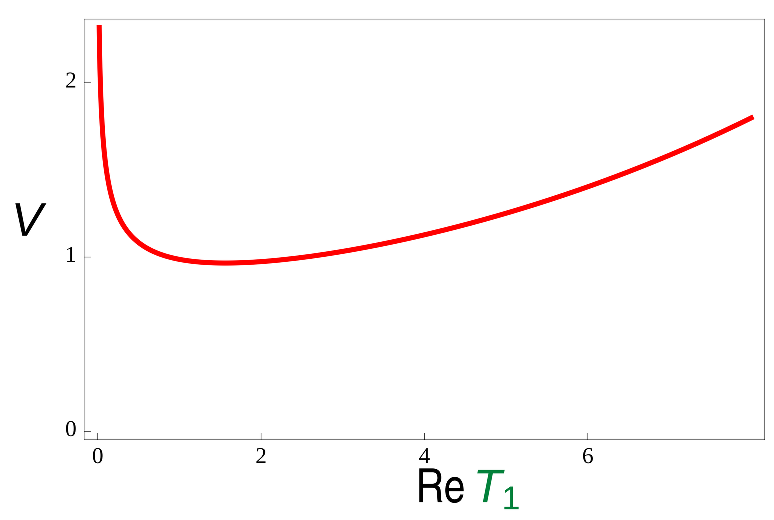

Fig. 1: Re T_1-dependence of the potential.

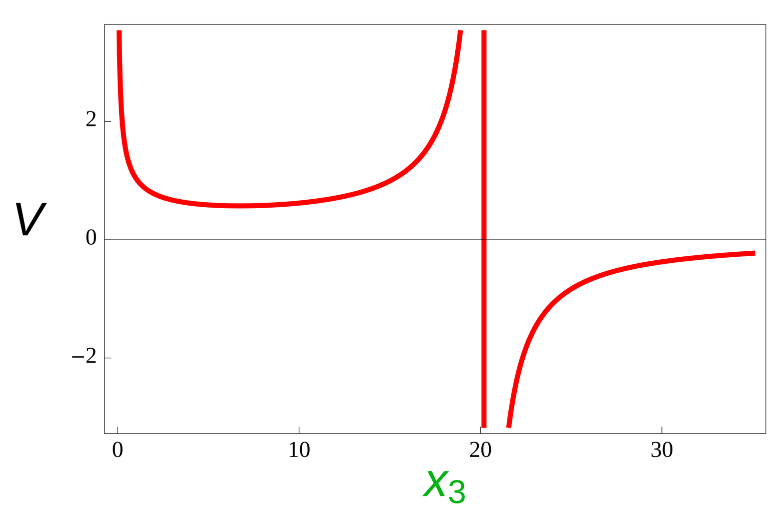

Fig. 2: x_3-dependence of the potential.

Realization in Heterotic Orbifolds

The above class of models might be realized in the context of heterotic orbifolds:

- $T_i \leftrightarrow$ Kähler moduli, i.e. radii of the three tori,
- $\Phi \leftrightarrow$ D-flat direction of untwisted matter fields, associated to e.g. T_3 $\Rightarrow$ Heisenberg symmetry and $V_D = 0$ during inflation,
- $X \leftrightarrow$ twisted matter field in $\mathcal{N} = 2$ subsector,
- $H^\pm \leftrightarrow$ a priori twisted or untwisted matter fields,
- $\Sigma \leftrightarrow$ string theory superpotential starts at cubic order $\Rightarrow$ provides $W_X \neq 0$;
- Modular invariance $\Rightarrow a(T_1,T_2) = \eta(T_1)^{b_1}\eta(T_2)^{b_2} \approx e^{a_1T_1+a_2T_2}$, with rational numbers b_i and $a_i = -\frac{\pi}{12}b_i$.
- For large radius, Re $T \gtrsim 1$, and without background matter fields, string-loop corrections to K have a moduli-dependence of the form [7]

$$\log|\eta(T)|^4(T+\bar T) \approx \log(T+\bar T) - \frac{\pi}{6}(T+\bar T) + \mathcal{O}(e^{-2\pi T} + c.c.)\,.$$

We assume that this also holds approximately including background matter fields, i.e.

$$d(x_3) \approx \gamma + \beta\ell\,(\log x_3 - \frac{\pi}{6}x_3 + \lambda|\Phi|^2)\,,$$

where $|\Phi|^2 = |\Phi^+|^2 + |\Phi^-|^2$ etc. and $\ell \sim 1/(S+\bar S)$ denotes the dilaton.

Dilaton Stabilization

The presence of the dilaton ℓ makes the situation more complicated, but it can be stabilized via non-perturbative corrections to the Kähler potential [3]. The ℓ and x_3 dependence of the potential in our case is of the form

$$V \propto \frac{x_3{}^q\,\ell^d\,e^{g(\ell)}}{1+\gamma\ell+\beta\ell\,(\log x_3 - \frac{\pi}{6}x_3 + \lambda|\Phi|^2)}\,,$$

where d is an integer, q is some rational number and $g(\ell)$ parametrizes $K_{\text{non-pert.}}$.

- Moduli fixed at $\langle\ell\rangle \sim \mathcal{O}(1)$, $\langle x_3\rangle \sim 1/\beta\langle\ell\rangle$ and with masses $m^2 \sim V$.
- $\langle x_3\rangle$ fixed at 'large radius' for $\beta\langle\ell\rangle$ sufficiently small.

The typical shape of V with respect to ℓ and x_3 is

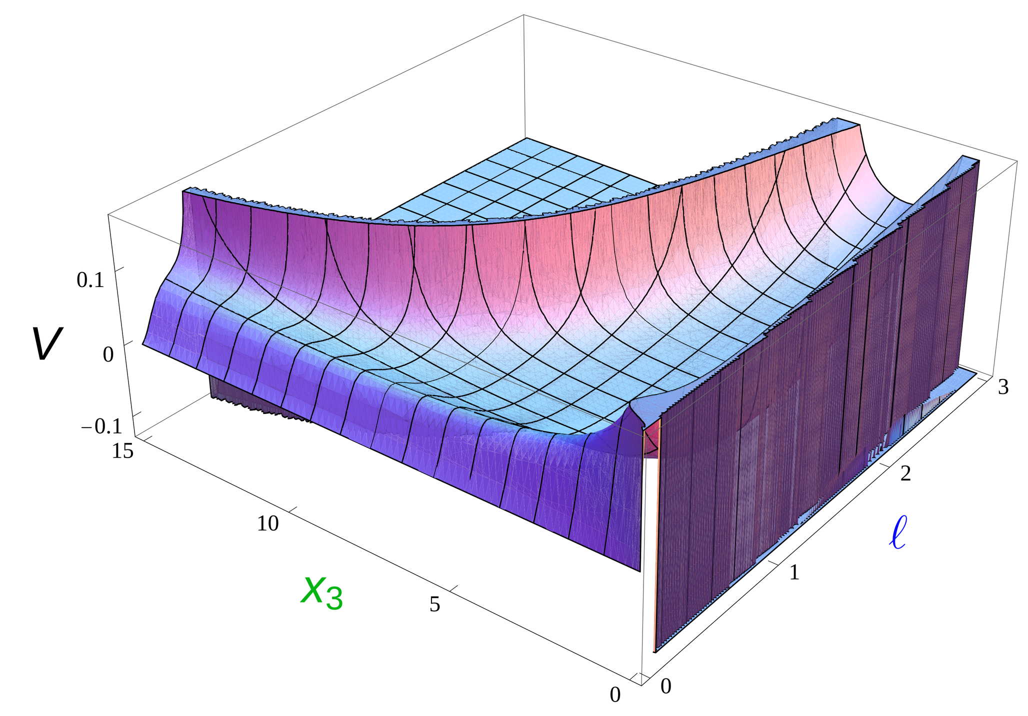

Fig. 3: Dependence of the potential on the dilaton ℓ and the 'radius' x_3.

Inflaton Slope

At tree-level: inflaton slope induced by $\lambda|\Phi|^2$ term. Around $\Phi \simeq 0$, the slow-roll η-parameter is simply $\eta \sim \lambda$. If λ is exponentially suppressed for 'large radius', i.e. $\sim e^{-2\pi T_3}$, $\eta \ll 1$ is easily achieved. However, λ has to be determined by a direct string computation.

Alternatively, the dominant slope could be induced by other sources, for example

- neglected terms in W with e.g. $\langle W\rangle \neq 0$ but small compared to W_X,
- one-loop Coleman-Weinberg effective potential via $H^\pm$.

Conclusions and Outlook

We have described a general class of models suitable for hybrid inflation in the matter sector. By extending the 'tribrid' models of [4] to a case with three moduli, we arrived at models which could possibly be realized in heterotic orbifolds. The untwisted matter fields in heterotic orbifolds enjoy a Heisenberg symmetry in their Kähler potential, which is required to solve the η-problem.

- Several problems of a gauge non-singlet inflaton can be solved in this class of models [6].
- Different mechanisms to stabilize moduli during and after inflation $\Rightarrow$ relaxes tension between low-scale supersymmetry breaking and high-scale inflation present in a large class of string inflation models [8].
- Heterotic orbifolds are promising candidates for realizing MSSM-like spectra in string theory, see e.g. [9] $\Rightarrow$ establish connection to particle physics.
- Open issues:
  - construct an explicit model,
  - compute λ directly from string theory.

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