Racetrack inflation and F-term uplifting

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in collaboration with Marek Olechowski

Outline

1. Racetrack inflation
2. Constraints for the Kähler potential
3. F-term uplifted racetrack inflation

KKLT Moduli Stabilization

F-term potential in 4D SUGRA

$$V = e^K \left(K^{I\bar{J}} D_I W \overline{D_J W} - 3 |W|^2 \right)$$

Kähler potential for the volume modulus

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

For fixed dilaton and CSM fluxes contribute a constant term to the superpotential

$$W = A$$

Introducing non-perturbative correction (e.g. gaugino condensation) to the superpotential

$$W = A + Ce^{-cT}$$

volume modulus can be stabilized at AdS SUSY minimum.

We live in dS space $\Rightarrow$ $\overline{D3}$-branes introduced to uplift minimum to dS space:

$$\Delta V = \frac{E}{(T + \bar{T})^2}$$

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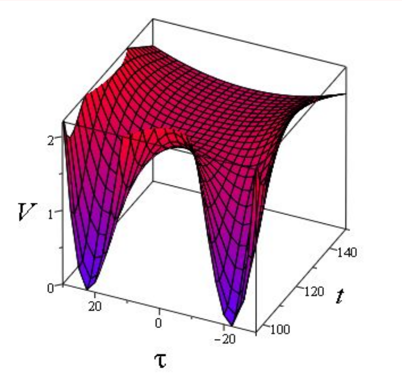
Racetrack Inflation

- Moduli stabilization allow for constructing inflationary models inspired by string theory.
- Moduli fields can be considered as candidates for the inflaton (moduli inflation).
- KKLT potential is too steep ($|\eta| > 1$) and does not fulfil the slow-roll conditions $\Rightarrow$ inflation cannot be realized.
- Inflation can be realized with the racetrack superpotential:

$$W = A + Ce^{-cT} + De^{-dT}$$

Racetrack Inflation - Saddle Point Model



Blanco-Pillado et al. '04

Inflation in the vicinity of a saddle point

Axion τ is the inflaton

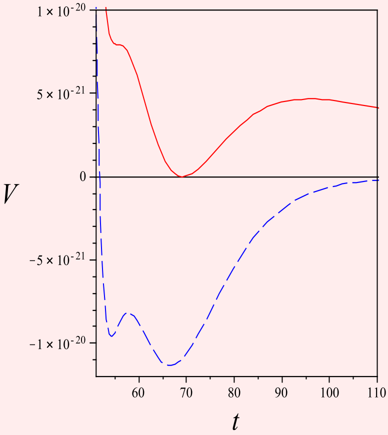
Fine-tuning

Flux parameter A fine-tuned at the level of 10^{-4}

CMB signatures

- $n_s \lesssim 0.95$
- $r \ll 1$

Racetrack Inflation - Inflection Point Model



Linde, Westphal '07

Inflation in the vicinity of an inflection point

t is the inflaton

Fine-tuning

Fine-tuning of parameters related to the height of the barrier

MB,Olechowski '08

Avoiding overshooting problem requires fine-tuning at the level of 10^{-8}

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Uplifting in Racetrack Inflation

In both racetrack inflation models SUSY is broken explicitly by $\overline{D3}$-branes
Most of the existing uplifting mechanisms have not been applied to inflationary models

Goal

Construct racetrack inflation models in a fully supersymmetric framework with the hidden sector matter field as a source of uplifting and SUSY breaking

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Constraints for the Kähler Potential

The maximal value of η is related to the curvature of the Kähler manifold spanned by the scalar fields appearing in the theory.
MB, Olechowski '08; Covi et al. '08

The necessary condition for $|\eta| \ll 1$:

$$R(f^i) < \frac{2}{\widehat{G}^2} < \frac{2}{3}$$

where $G = K + \log|W|^2$ and $\widehat{G}^2 \equiv \sqrt{G^i G_i} = 3 + e^{-G} V$

$R(f^i) \equiv R_{i\bar{j}p\bar{q}} f^i f^{\bar{j}} f^p f^{\bar{q}}$ is the sectional curvature along the direction of the SUSY breaking ($f_i \equiv G_i / \widehat{G}^2$ is the unit vector defining that direction).

Note: $\widehat{G}^2 = 3$ for Minkowski, $\widehat{G}^2 > 3$ for de Sitter.

The above condition can be used to eliminate some models even without specifying the superpotential!

In the one field case the necessary condition simplifies:

$$R_T < \frac{2}{\widehat{G}^2} < \frac{2}{3}$$

Kähler potential for the volume modulus:

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

The curvature scalar for the volume modulus takes the form:

$$R_T = \frac{2}{3}$$

The trace of the η-matrix is constant and negative: *MB,Olechowski '08*

$$\mathrm{Tr}(\hat{\eta}) = -\frac{4}{3}$$

$\eta \leqslant -2/3 \Rightarrow$ slow-roll conditions violated!

How is it possible that racetrack inflation works?

Uplifting from $\overline{D3}$-branes is non-supersymmetric and gives additional, positive contribution to $\mathrm{Tr}(\hat{\eta})$

One Field Case - the Role of $\overline{D3}$-brane Uplifting

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Volume Modulus and Matter Field - No-scale Kähler Potential

For the no-scale Kähler potential

$$K = -3\ln(T + \overline{T} - |\Phi|^2)$$

the Kähler manifold is a maximally symmetric coset space with a constant curvature $R(f^i) = 2/3$
Gomez-Reino, Scrucca '06

$\Downarrow$

Necessary condition for slow-roll inflation violated $\Rightarrow$ Racetrack inflation cannot be uplifted for any kind of coupling between the volume modulus and the matter field in the superpotential

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Separable Kähler Potentials

For the separable Kähler potential:

$$K = K^{(T)}(T,\overline{T}) + K^{(\Phi)}(\Phi,\overline{\Phi})$$

the necessary condition for slow-roll inflation reduces to:

$$R_T\Theta_T^4 + R_\Phi\Theta_\Phi^4 < \frac{2}{\widehat{G}^2}$$

R_i are the scalar curvatures of the one dimensional submanifolds associated with each of the fields

$\Theta_i^2 \equiv G_{i\bar{i}}f^i f^{\bar{i}}$ parameterize SUSY breaking and satisfy $\sum_i \Theta_i^2 = 1$

Polonyi Uplifting

Volume modulus coupled to canonically normalized matter field:

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

$R_\Phi = 0$ so the necessary condition for slow-roll inflation is:

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If the matter field dominates SUSY breaking during inflation ($\Theta_T^2 \ll 1$) then F-term uplifted racetrack inflation is possible

Superpotential

$$W = A + Ce^{-cT} + De^{-dT} - \mu^2\Phi$$

is sufficient to uplift both racetrack inflation models!

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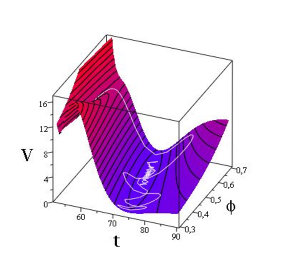
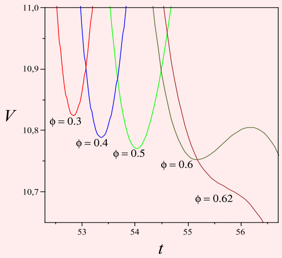
Polonyi Uplifting of Inflection Point Inflation





$\Theta_\Phi^2 \gg \Theta_T^2 \Rightarrow \Phi$ dominates SUSY breaking (during and after inflation)

ϕ is the main component of the inflaton

Fine-tuning

Fine-tuning is not strictly related to the height of the barrier

Fine-tuning at the level of $10^{-3} \Rightarrow$
5 orders of magnitude weaker than in the original model!

CMB signatures

$n_s \gtrsim 0.93$ not altered by F-term uplifting but for some sets of parameters isocurvature perturbations may be produced

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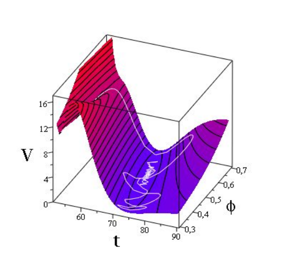

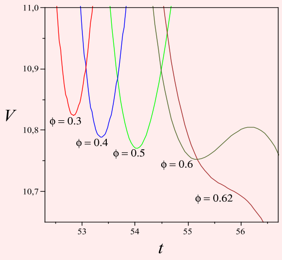

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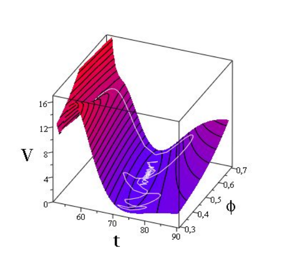

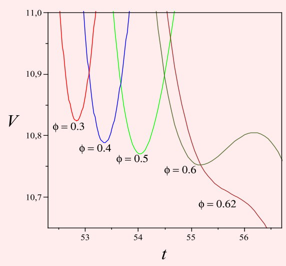

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All 4 fields are involved in the inflationary dynamics

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Summary of Polonyi uplifting

Volume modulus no longer the inflaton but fine-tuning reduced

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O'uplifting

The volume modulus coupled to quantum corrected O'Raifeartaigh model:

Modified Kähler potential

$$K = -3\ln(T+\overline{T}) + \Phi\overline{\Phi} - \frac{(\Phi\overline{\Phi})^2}{\Lambda^2}, \qquad \Lambda \ll 1$$

Kallosh, Linde '06

$$R_\Phi = \frac{-4}{\Lambda^2(1-4|\Phi|^2/\Lambda^2)^3} < 0$$

Superpotential

$$W = A + Ce^{-cT} + De^{-dT} - \mu^2\Phi$$

SUSY breaking minimum occurs at $|\Phi| \sim \Lambda^2 \ll 1$

The mass matrix at $\tau=\theta=0$ in the limit $\phi \ll \Lambda \ll 1$:

$$\begin{pmatrix} m^2_{tt} & m^2_{t\tau} & m^2_{t\phi} & m^2_{t\theta} \\ m^2_{t\tau} & m^2_{\tau\tau} & m^2_{\tau\phi} & m^2_{\tau\theta} \\ m^2_{t\phi} & m^2_{\tau\phi} & m^2_{\phi\phi} & m^2_{\phi\theta} \\ m^2_{t\theta} & m^2_{\tau\theta} & m^2_{\phi\theta} & m^2_{\theta\theta} \end{pmatrix} \sim \begin{pmatrix} \Lambda^0 & 0 & \phi m^2_{\phi\phi} & 0 \\ 0 & \Lambda^0 & 0 & \Lambda^0 \\ \phi m^2_{\phi\phi} & 0 & \Lambda^{-2} & 0 \\ 0 & \Lambda^0 & 0 & \Lambda^{-2} \end{pmatrix}$$

- the matter field is heavier than the volume modulus
- the mixing between the matter field and the volume modulus is strongly suppressed

The matter field is decoupled from the inflationary dynamics

O'uplifting - Decoupling of the Matter Field

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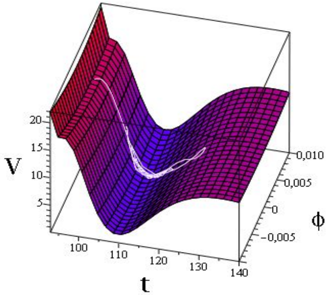
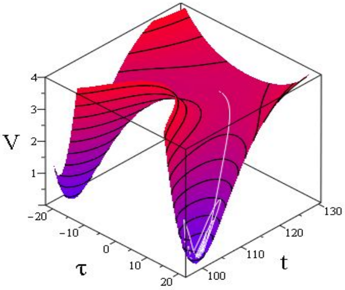
O'uplifting of Racetrack Inflation Models

- Φ is almost constant during inflation
- SUSY breaking dominated by the matter field ($\Theta_\Phi > \Theta_T$)
- matter field F-term provides effective uplifting term $|F_\Phi|^2 \sim 1/t^3$
- O'uplifted racetrack models resemble the original ones
- Volume modulus is the inflaton but SUSY is broken spontaneously by the matter field





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- Racetrack inflation can be realized in a fully supersymmetric framework with the matter field F-term as a source of SUSY breaking and uplifting
- Details of the inflationary scenario depend on the choice of the matter field sector
    - Polonyi uplifting - the volume modulus is no longer the inflaton but fine-tuning significantly reduced
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