Multi-field α-attractor in fundamental theory

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work with

R. Kallosh, A. Linde, D. Roest, A. Westphal, T. Wrase

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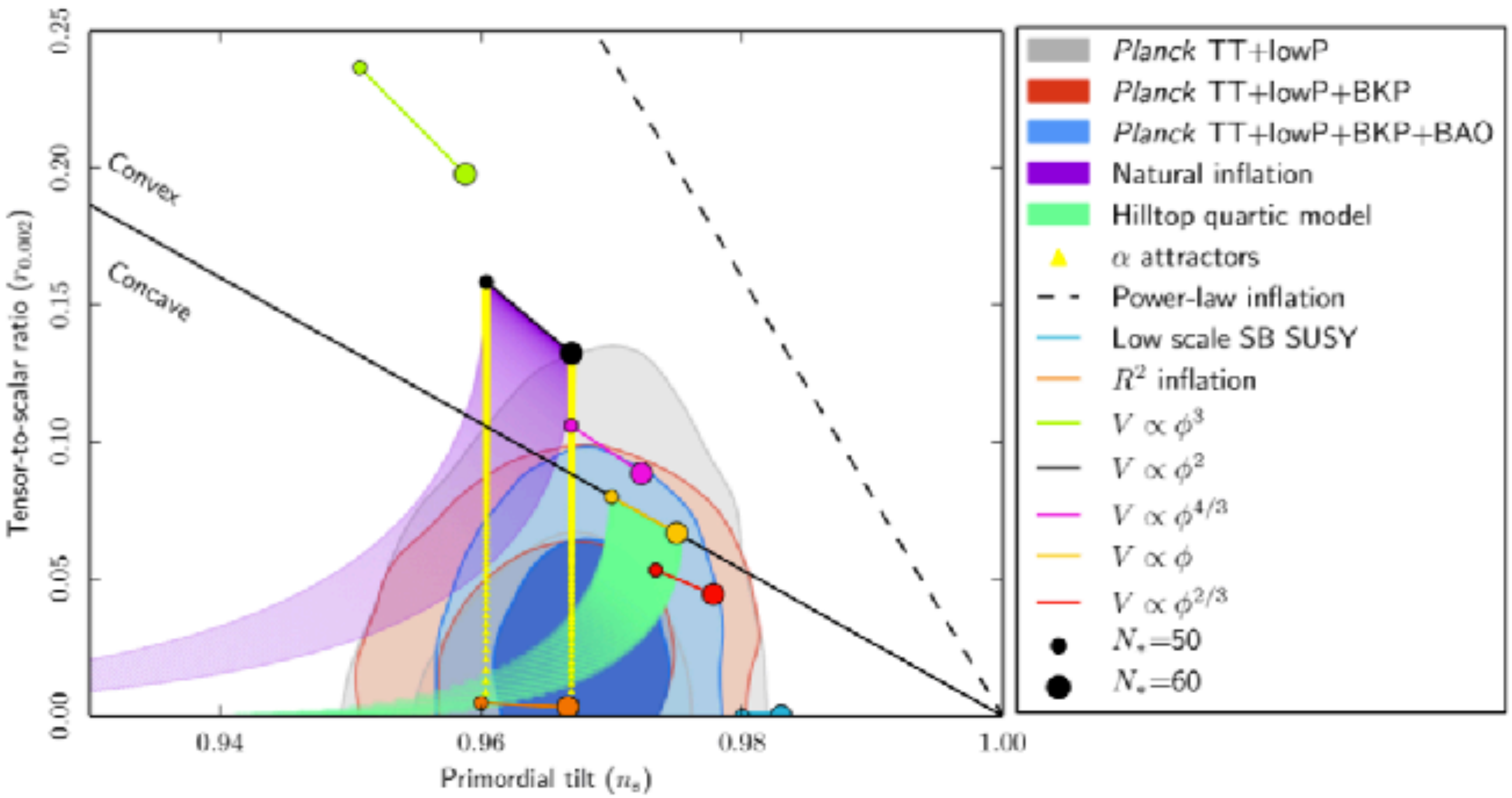
Introduction



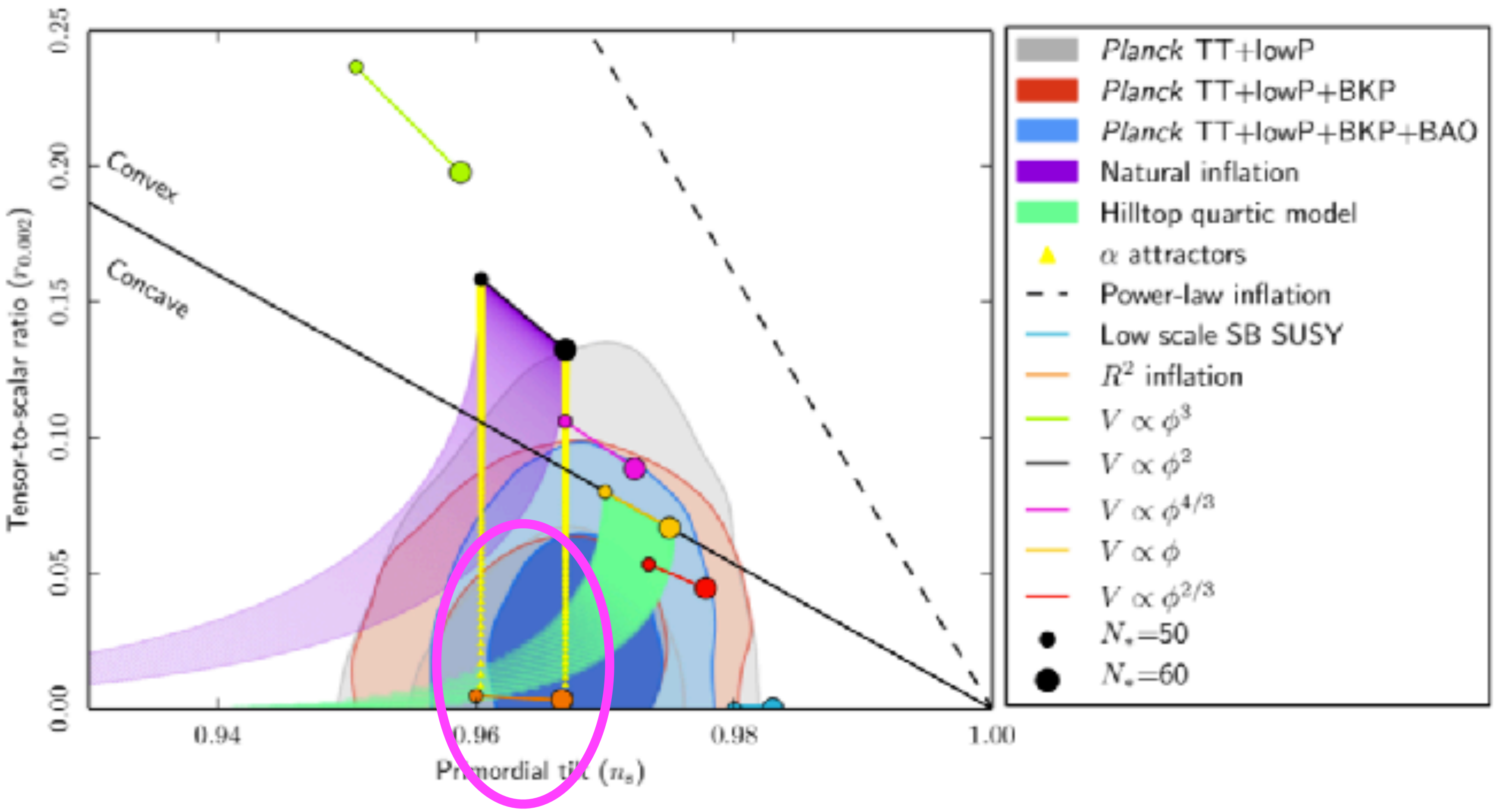
Still models with r<0.1 can explain the data.

But, naively, from the center value of the spectral tilt,

the most favored potential seems

$$V(\phi) = 1 - ce^{-a\phi} + \cdots$$

Introduction



$$V(\phi) = 1 - ce^{-a\phi} + \cdots$$

$$n_s = 1 - \frac{2}{N} \sim 0.964 \quad (\text{for } N = 55)$$

$$r = \frac{8}{a^2 N^2}$$

Introduction

$$V(\phi) = 1 - ce^{-a\phi} + \cdots$$

Is there any hidden structure?

Introduction

Kallosh, Linde, Roest (2013)
Galante, Kallosh, Linde, Roest (2014)
Broy, Galante, Roest, Westphal (2015)

$$V(\phi) = 1 - ce^{-a\phi} + \cdots$$

Is there any hidden structure?

$$\mathcal{L} = -\frac{3\alpha(\partial\tau)^2}{4\tau^2} - V(\tau)$$

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Is there any hidden structure?

$$\mathcal{L} = -\frac{3\alpha(\partial\tau)^2}{4\tau^2} - V(\tau)$$

introduce canonical field ϕ

$$\tau = e^{-\sqrt{\frac{2}{3\alpha}}\phi}$$

$$V(\tau) = V(e^{-\sqrt{\frac{2}{3\alpha}}\phi}) = V(0)(1 - Ce^{-\sqrt{\frac{2}{3\alpha}}\phi} + \cdots)$$

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Is there any hidden structure?

$$\mathcal{L} = -\frac{3\alpha(\partial\tau)^2}{4\tau^2} - V(\tau) \qquad \tau = e^{-\sqrt{\frac{2}{3\alpha}}\phi}$$

$$V(\tau) = V(e^{-\sqrt{\frac{2}{3\alpha}}\phi}) = V(0)(1 - Ce^{-\sqrt{\frac{2}{3\alpha}}\phi} + \cdots)$$

attracted to the “favored” potential

α-attractor

α-attractor in supergravity

Kallosh, Linde, Roest (2013)
Cecotti, Kallosh (2014)

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

$$\mathcal{L} = -K_{T\overline{T}} \partial T \partial \overline{T} = -\frac{3\alpha(\partial\tau)^2}{4\tau^2} - \frac{3\alpha(\partial\chi)^2}{4\tau^2}$$

$$V(\tau) = V(e^{-\sqrt{\frac{2}{3\alpha}}\phi}) = V(0)(1 - Ce^{-\sqrt{\frac{2}{3\alpha}}\phi} + \cdots)$$

$$n_s = 1 - \frac{2}{N} \sim 0.964 \quad (\text{for } N = 55)$$

$$r = \frac{12\alpha}{N^2}$$

α^{-1} : curvature of the Kahler geometry

α-attractor in fundamental theories

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

$$r = \frac{12\alpha}{N^2}$$

The value of α determines the tensor-to-scalar ratio “r”

Phenomenologically, **α is arbitrary**

But, how about the UV completion?

e.g. superstring, M-theory, extended supergravity

α-attractor in fundamental theories

Ferrara, Kallosh (2016)

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

string theory compactified on

$T_2 \times T_2 \times T_2$ $\quad K = -\log(S + \overline{S}) - \sum_{i=1}^{3} \log(T_i + \overline{T}_i) - \sum_{i=1}^{3} \log(U_i + \overline{U}_i)$

T_6 (volume modulus) $K = -3\log(T + \overline{T})$

N=8 → N=1 supergravity

$E_{7(7)} \to [SL(2,R)]^7$ $\quad K = -\sum_{i=1}^{7} \log(T_i + \overline{T}_i)$

Interestingly, multiple α-attractor scalar fields appear in extended supergravity / string/ M theory

α-attractor in fundamental theories

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But in most cases, $\alpha \leq 1$ ➡ $r < 0.004 \left(\frac{55}{N}\right)^2$?

It seems difficult to observe primordial GW in these cases

α-attractor in fundamental theories

Ferrara, Kallosh (2016)

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

But in most cases, $\alpha \leq 1$ → $r < 0.004 \left(\frac{55}{N}\right)^2$?

Is it impossible to realize "r" observable in near future?

No, by using **multiple** α attractor fields, large α can be realized effectively.

Larger α from merger

a simple way to realize larger α

let us consider two-disk model

$$\alpha_i = \frac{1}{3} \qquad\qquad -\frac{(\partial t_1)^2}{4t_1^2} - \frac{(\partial t_2)^2}{4t_2^2}$$

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$$\alpha_i = \frac{1}{3} \qquad -\frac{(\partial t_1)^2}{4t_1^2} - \frac{(\partial t_2)^2}{4t_2^2}$$

if $\quad t_1 = t_2 = t$: merger of two directions

$$-\frac{2(\partial t)^2}{4t^2} \qquad \alpha_{\text{eff}} = \frac{2}{3}$$

If we realize the condition dynamically, "r" can be larger

ex. multi-disk model

Kallosh, Linde, Wrase, YY (2017)
Kallosh, Linde, Roest, YY (2017)

$$K = \sum_{i=1}^{7} -\log\left(\frac{T_i + \overline{T}_i}{2|T_i|}\right) + S\overline{S} \qquad W = W_{\rm stab} + W_{\rm inf}$$

n-disk merger
(others are stabilized at constant value)

$$W_{\rm stab} = \sum_{1\leq i<j\leq n} M^2 (T_i - T_j)^2 + \sum_{k=n+1}^{7} M^2 (T_k - c)^2$$

$$\Rightarrow \quad T_1 = \cdots = T_n = T \qquad T_{n+1} = \cdots = T_7 = c$$

If M is sufficiently large, the desired trajectory is realized during inflation

On the trajectory, we only have one modulus direction “T”=inflaton

ex. multi-disk model

Kallosh, Linde, Wrase, YY (2017)
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$$W_{\text{stab}} = \sum_{1\le i<j\le n} M^2 (T_i - T_j)^2 + \sum_{k=n+1}^{7} M^2 (T_k - c)^2$$

$$T_1 = \cdots = T_n = T \qquad T_{n+1} = \cdots = T_7 = c$$

$$W_{\text{inf}} = f\left(T_1 + \cdots + T_n\right) S \sim f(nT) S$$

$$V_{\text{inf}} = |f(nT)|^2 = V\left(e^{-\sqrt{\frac{2}{n}}\phi}\right) \qquad \alpha_{\text{eff}} = \frac{n}{3}$$

ex. multi-disk model

Kallosh, Linde, Wrase, YY (2017)
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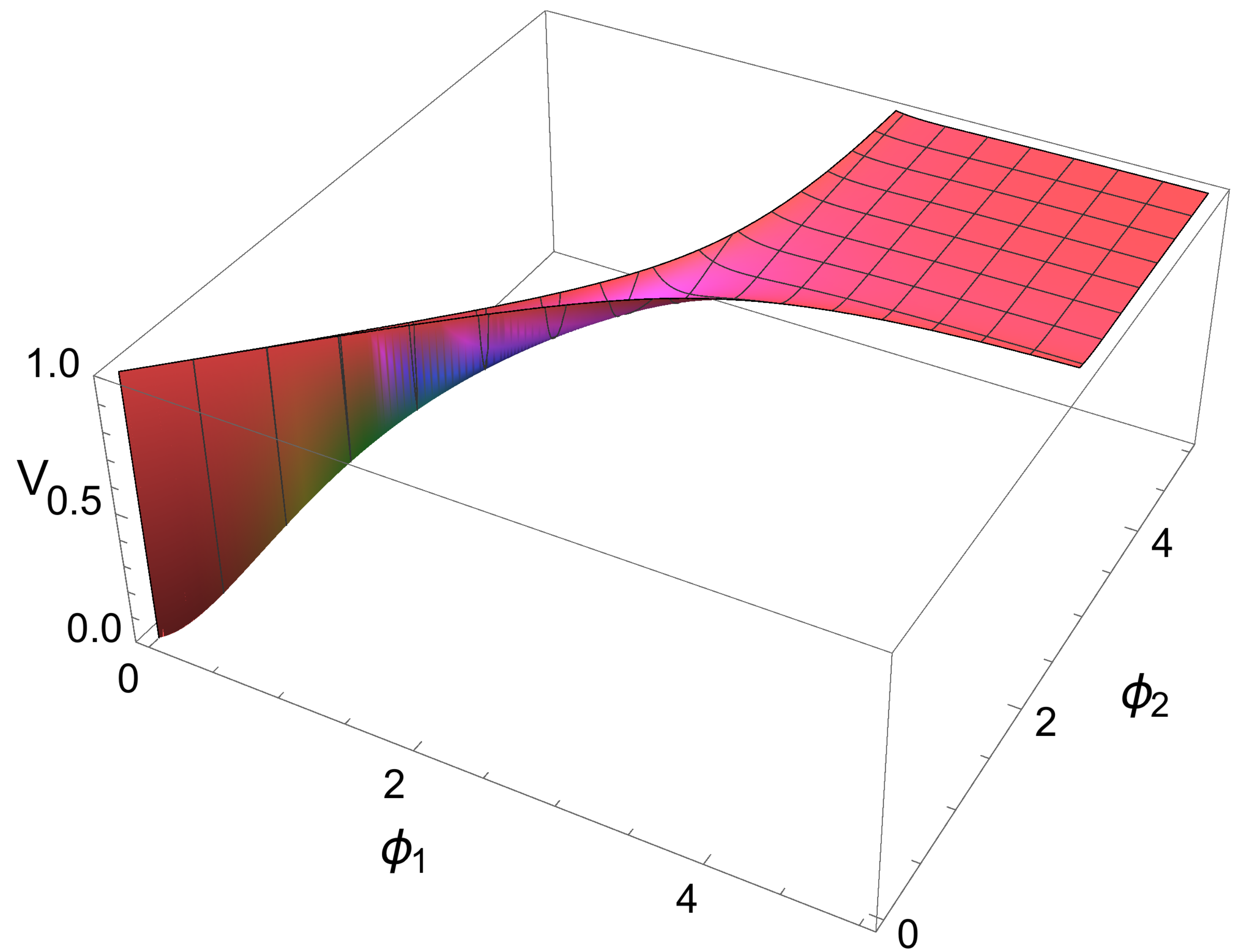
two-disk merger case

ex. M=10m

$$W = m\left(1 - \frac{T_1 + T_2}{2}\right) S + W_{\rm stab}$$



For sufficiently strong stabilization, the condition is effectively realized for last 50 - 60 e-foldings

imaginary parts (axions) are stabilized at origin

Larger α from merger

We can consider more general situation: $-\frac{3\alpha_1(\partial t_1)^2}{4t_1^2} - \frac{3\alpha_2(\partial t_2)^2}{4t_2^2}$

$$t_1 = t^p,\ t_2 = t \quad \Rightarrow \quad -\frac{3\alpha_{\rm eff}(\partial t)^2}{4t^2} \qquad \alpha_{\rm eff} = \alpha_1 p^2 + \alpha_2$$

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This generalized "merger" condition is naturally realized in moduli stabilization models

e.g. Fibre inflation Cicoli, Burgess, Quevedo (2008)

$$K = -2\log(\mathcal{V} + \xi) + \cdots \qquad W = W_0 + Ae^{-aT_3}$$

$$\mathcal{V} = t_1^{\frac{1}{2}} t_2 - \gamma t_3^{\frac{3}{2}}$$

$$t_1^{\frac{1}{2}} t_2 \gg 1 \quad \Rightarrow \quad K \sim -\log(T_1 + \overline{T}_1) - 2\log(T_2 + \overline{T}_2) + \cdots$$

$$\mathcal{V} \sim t_1^{\frac{1}{2}} t_2$$

Larger α from merger

We can consider more general situation: $-\frac{3\alpha_1(\partial t_1)^2}{4t_1^2} - \frac{3\alpha_2(\partial t_2)^2}{4t_2^2}$

$$t_1 = t^p, \ t_2 = t \quad \rightarrow \quad -\frac{3\alpha_{\rm eff}(\partial t)^2}{4t^2} \qquad \alpha_{\rm eff} = \alpha_1 p^2 + \alpha_2$$

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volume stabilization $\mathcal{V} = \mathcal{V}_0$

with the potential of T_3

$$K \sim -\log(T_1 + \overline{T}_1) - 2\log(T_2 + \overline{T}_2) + \cdots$$

$$\mathcal{V} \sim t_1^{\frac{1}{2}} t_2$$

$$t_1 = \mathcal{V}_0^2 t_2^{-2} \quad \alpha_1 = \frac{1}{3}, \ \alpha_2 = \frac{2}{3}, \ p = -2$$

remaining flat direction realizes α-attractor with $\alpha_{\rm eff} = 2$

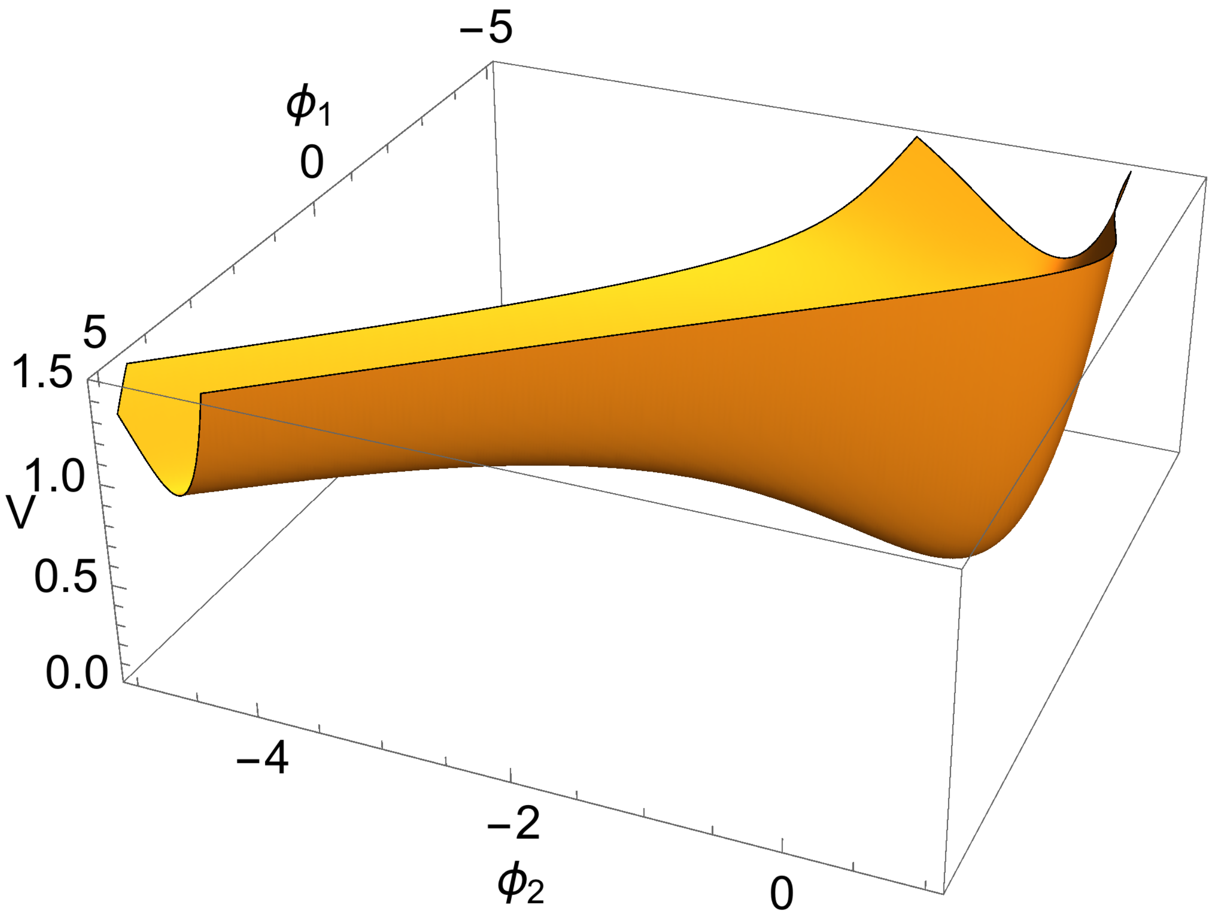
Simplified Fibre inflation

Kallosh, Linde, Roest, Westphal, YY
work in progress

$$\begin{aligned}\mathcal{G} =& K + \log|W|^2 \\ =& -\frac{1}{2}\log\left(\frac{(T_1+\overline{T}_1)^2}{4|T_1|^2}\right) - \log\left(\frac{(T_2+\overline{T}_2)^2}{4|T_2|^2}\right) + S + S + \mathcal{G}_{S\overline{S}}S\overline{S} + \log|W_0|^2\end{aligned}$$

$$\mathcal{G}_{S\overline{S}} = \frac{|W_0|^2}{3|W_0|^2 + V} \qquad V_{\rm eff} = e^{\mathcal{G}}(\mathcal{G}^I\mathcal{G}_I - 3)|_{a_i=0} = V$$

$$V = m^2\left(1 - \frac{1}{2}(T_2+\overline{T}_2)\right)^2 + M^2\left((T_1+\overline{T}_1)(T_2+\overline{T}_2)^2 - \mathcal{V}_0^2\right)^2$$



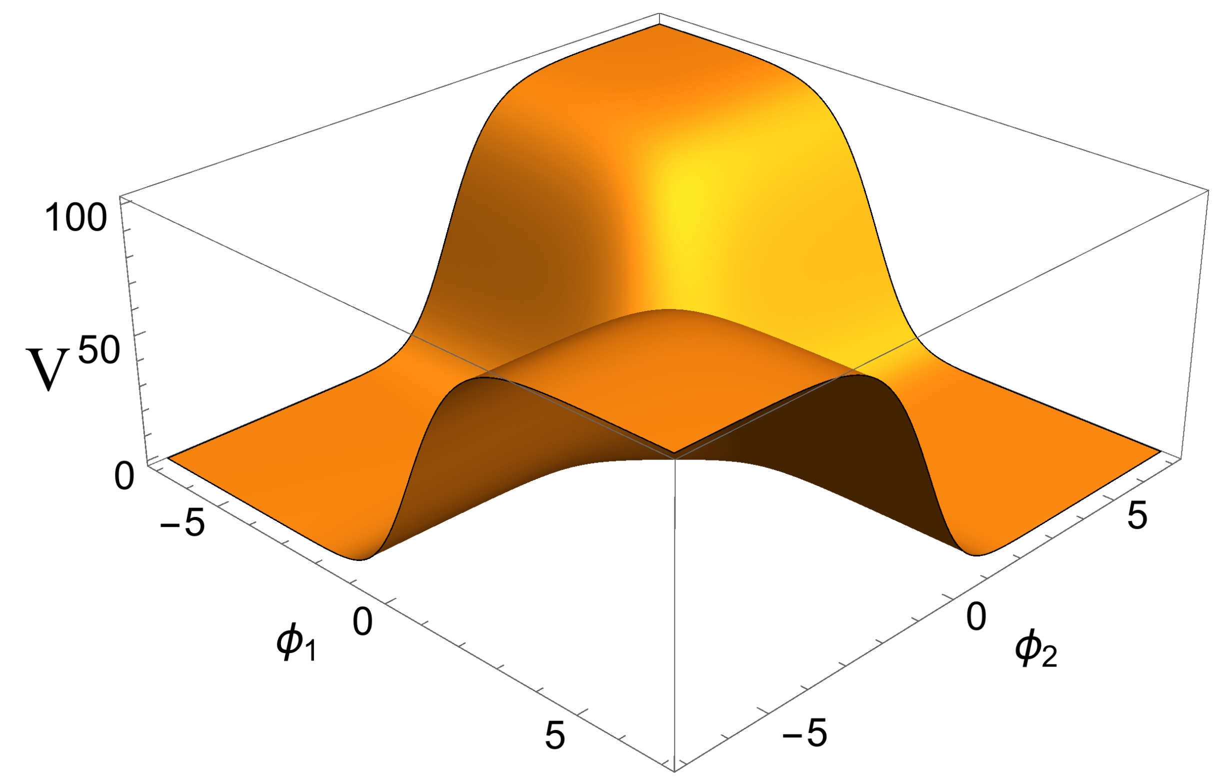
Due to the merger of two fields,
α=2 is realized
as in the original model

Cascade inflation in merger models

Cascade like potential

because of hierarchical structure

Kallosh, Linde, Roest, YY (2017)



Extreme case:

Planckian/string scale plateau

➡ inflation can take place at Planckian/string scale

before “observable” inflation

a new solution to an initial condition problem?

Summary

In string/ M-theory/ N=8 supergravity,
there are multiple moduli fields with disk geometry

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

By some dynamical constraints,
(originated from moduli stabilization in string theory)
an effective inflaton direction can have
large α= large "r"

$$\text{e.g. } t_1 = t_2^p \qquad -\frac{3\alpha_{\text{eff}}(\partial t)^2}{4t^2} \qquad \alpha_{\text{eff}} = \alpha_1 p^2 + \alpha_2$$