# STRING INFLATION & THE PLANCK DATA

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## OUTLINE:



## REFERENCES:

By now there is a wealth of string inflation review papers of which I'd like to mention:

- Burgess, Cicoli, Quevedo : 1306.3512
- Cicoli and Quevedo : 1108.2659
- Burgess and McAllister : 1108.2660
- Baumann : 0907.5424
- Silverstein and McAllister : 0710.2951

# 1 INFLATION (0605045)

Consider a generic parametrisation of the inflationary Lagrangian

$$\boxed{S = \int d^4x \sqrt{-g}\left[\frac{1}{2} M_p^2 R + P(X^{IJ}, \phi^J)\right]}$$

where $X^{IJ} = -\frac{1}{2} g^{\mu\nu} \partial_\mu \phi^I \partial_\nu \phi^J$ and $P$ is some function to be specified by the model.

Assuming the metric to take the FRW form

$$ds^2 = -dt^2 + a^2 dx_3^2$$

the evolution is determined by

$$\begin{cases} H^2 = \frac{8\pi G}{3}\left(2XP_X - P\right) \longrightarrow \text{Friedmann} \\ \dot{\rho} = -3H(\rho + P) \longrightarrow \text{Continuity} \end{cases}$$

where as usual the Lagrangian of the scalar field $P(X^{IJ}, \phi^J)$ acts as pressure and the energy density is defined as

$$\rho = 2XP_X - P$$

Inflation corresponds to an exponential expansion of spacetime
$\Leftrightarrow$ $H$ is almost constant

Define the "slow variation parameters" (generalised slow roll)

$$\epsilon = -\frac{\dot{H}}{H^2} \rightarrow \frac{XP_X}{M_p^2 H^2} \;;\; \eta = \frac{\dot{\epsilon}}{\epsilon H} \;;\; s = \frac{\dot{c}_s}{c_s H}$$

where the "sound speed" is $c_s^2 = \frac{dP}{dE} = \frac{P_X}{P_X - 2XP_{XX}}$

These are related but not equivalent to the usual slow roll parameters.
Designed to study inflation beyond slow roll scenarios (see DBI later)

$$P_k^{\zeta} = \frac{1}{8\pi^2 M_p^2} \frac{H^2}{c_s \epsilon}$$ evaluated at $c_s k = aH$ (horizon exit)

$$\boxed{P_k^h = \frac{2}{\pi^2} \frac{H^2}{M_p^2}}$$

$$\boxed{n_s - 1 = -2\epsilon - \eta - s}$$ spectral index

the all important tensor-to-scalar ratio is given by $\boxed{r = 16 c_s \epsilon}$

▶ Slow Roll

$$P(X,\phi) = X - V(\phi) \quad \text{with} \quad X = G_{IJ}\partial\phi^I\partial\phi^J$$

$$\epsilon = \epsilon_V \equiv \frac{1}{2}\left(\frac{V'}{V}\right)^2 \; ; \; \eta = -2\eta_V + 4\epsilon_V \quad \text{with} \quad \eta_V \equiv \frac{V''}{V}$$

$c_s = 1$

↳ Inflation proceeds via motion in a suitably flat potential

one can also have inflation without slow roll, as in DBI inflation, where the form of $P(X,\phi)$ gives rise to a speed limit for the inflaton field allowing for inflation in steep potentials.

# 2 WHAT DID WE LEARN FROM PLANCK 2013?

1303.5082
1303.5084

the picture that emerges from Planck 2013 is a rather simple one.

scalar perturbations are: ▶ Gaussian

$$\left\{\begin{array}{l} f_{NL}^{local} = 2.7 \pm 5.8 \\ f_{NL}^{equil} = -42 \pm 75 \\ f_{NL}^{ortho} = -25 \pm 39 \end{array}\right\}$$ consistent with zero

▶ Nearly scale invariant $n_s \sim 0.96$

▶ no evidence for running of the spectral index $\frac{dn_s}{d\log k} = -0.015 \pm 0.009$

▸ no evidence of gravitational waves from early universe : $r < 0.11$

these observational results can be well described by simple single field models built in a purely field theoretic framework.

# 3 CHALLENGES FOR INFLATION

## ■ the inflationary $\eta$-problem

For inflation to last long enough the $\epsilon$ parameter must be small and must not vary much

↳ $\eta \equiv \frac{\partial^2 V}{\partial \phi^2} \frac{M_p^2}{V} \ll 1 \longrightarrow m^2 \ll V_0/M_p^2$

$V \sim V_0 + \frac{m^2}{2}\phi^2$

so for inflation to last the inflaton must be lighter than H:

$$\boxed{m \ll \frac{\sqrt{V_0}}{M_p} = H}$$

one can choose this to hold at tree level but it won't necessarily hold at loop level

↳ quantum corrections to the action (from integrating out heavy modes) tend to drive the scalar masses towards the energy scale of the problem → in this case H.

The $\eta$ problem is nothing but the Hierarchy problem for inflation. Just like in the SM the radiative stability of the Higgs mass provides a window to physics at higher energies, the need to control quantum corrections to the inflaton mass motivate us to look for a UV embedding of inflation ⟶ String inflation

Since string inflation models will be built within $N=1$ SUGRA let us pause to see how the $\eta$-problem arises in this context.

In models where inflation is generated by F-terms we have

$$V = e^{K}\underbrace{\left(F_I \bar{F}^{\bar{I}} - 3|W|^2\right)}_{\equiv V_0}$$

Assume $V_0$ is naturally flat, such that $\begin{cases} \epsilon_0 = \frac{1}{2}\left(\frac{V_0'}{V_0}\right)^2 \ll 1 \\ \eta_0 = \frac{V_0''}{V_0} \ll 1 \end{cases}$

taking the Kähler potential to be at the simplest form: $K = \phi\phi^+$ such that the inflaton has canonical kinetic terms and defining $x \equiv \phi/M_p$ we can expand the full potential as

$$V = e^{x^2} V_0 \sim \left(1 + x^2 + \frac{x^4}{2} + \dots\right) V_0$$

$\hookrightarrow$ We can then show that:

$$\boxed{\epsilon = \epsilon_0 + 2\left(\frac{x(1+x^2)}{1+x^2+x^4/2}\right)^2 + \sqrt{2\epsilon_0}\,\frac{2x(1+x^2)}{1+x^2+x^4/2}}$$

and that

$$\boxed{\eta = \eta_0 + \sqrt{2\epsilon_0}\,\frac{4x(1+x^2)}{1+x^2+x^4/2} + \frac{2(1+3x^2)}{1+x^2+x^4/2}}$$

We can see that both in large field ($x \gg 1$) and small field ($x \ll 1$) models $\epsilon$ is always small.

The same does not happen for $\eta$, where we find

$$\hookrightarrow \begin{cases} \eta \sim \eta_0 + \sqrt{2\epsilon_0}\,4x + 2 \sim \mathcal{O}(1) & \text{for } x \ll 1 \\ \eta \sim \eta_0 + \sqrt{2\epsilon_0}\,\frac{8}{x} + \frac{12}{x^2} \ll 1 & \text{for } x \gg 1 \end{cases}$$

So for small field models $\eta \sim O(1)$ unless we arrange for $\eta_0 + 2 \simeq 0$.

For large field models there seems to be no issue but one cannot consistently neglect higher order terms in the expansion of $e^K$.

↳ must control higher order terms to have consistent EFT.

(if one does not expand $e^K$ in powers of $x$ one still finds the $\eta$-problem since $\eta \sim \eta_0 + \sqrt{2\varepsilon_0}\, 2\cancel{x} + 2 + 4x^2 + \dots$)

## Trans-Planckian motion

The standard approach in field theory is to define the action as a series in terms of $\frac{\Delta\phi}{M_p}$:
$$S = \int d^4x \sqrt{-g} \left( \sum_{m=0}^{\infty} C_m \left(\frac{\Delta\phi}{M_p}\right)^m + \dots \right)$$

Convergence of this series is automatic for small field models since by definition $\frac{\Delta\phi}{M_p} \ll 1$.

However some models of inflation require $\frac{\Delta\phi}{M_p} \gg 1$ (Large field) in which case the higher order terms become more important than the first few terms in the $\Delta\phi / M_p$ expansion of the action.

↳ the series does not converge.

One way out for large field models is to use some symmetry to forbid the higher order terms in the $\Delta\phi/M_p$ expansion → e.g. Axionic shift symmetry in Axion monodromy inflation.

Why the interest in the harder to control large field models?

↳ Usually large field displacements are required to achieve observable tensor signal from inflation

$$\frac{\Delta\phi}{M_p} \sim O(1) \sqrt{\frac{r}{0.01}} \quad \rightarrow \underline{\text{LYTH Bound}}$$

## Eternal inflation and the measure problem

Once started inflation can be hard to end. Regions of spacetime where inflation ends will be completely subdominant if inflation continues elsewhere → Hard to count infinities and define probabilities in an eternally inflating universe
↳ measure problem

A more pragmatical, and immediately testable, stance is to merely focus on a single patch where inflation has ended (like the one we seem to live in) and compute observables there.

## Initial conditions problem

Inflation is very sensitive to the initial conditions of the inflaton field
↳ e.g. In slow roll models, it must be in the flat part of the potential and have small kinetic energy

We are still lacking a good understanding of how probable this is.

# $\boxed{4}$ WHY STRING INFLATION?

Single field models built in a purely field theoretical framework are sufficient to explain the Planck 2013 data.

↳ Why should we consider more complicated setups like string inflation models?

- CMB physics ⇔ quantum gravity in the sky
  so inflation is an opportunity to explore beyond SM+GR
- there is only so much we can learn in the relatively unconstrained EFT approach.
- UV embedding of inflation may help to address some of its known issues ($\eta$-problem, trans planckian motion)

# 5 STRING INFLATION MODELS

Depending on the origin of the inflaton field, string inflation models split into two broad cathegories:

- Open string models
- Closed string models

## 5.1 OPEN STRING MODELS

the inflaton is a brane position modulus parametrising the separation between 2 branes or a brane-antibrane pair

→ $D3$-$\overline{D3}$ inflation

Inflaton is the relative position of a $D3\,\overline{D3}$ pair

$D3/\overline{D3}$ are spacetime filling and point like in the compact space

Inflationary potential originates from the Coulomb interaction between $D3$ and $\overline{D3}$.

$$V \sim V_0 \left(1 - \mu^4/\phi^4\right)$$

to meet slow roll criteria we are faced with the fact that

$\epsilon, \eta \ll 1 \Rightarrow$ inter brane separation must be larger than the radius of the compact space

$\Downarrow$

Hard to consistently find slow roll regime (for a critical assessment of this issue see 0308055)

# → WARPED D-brane Inflation

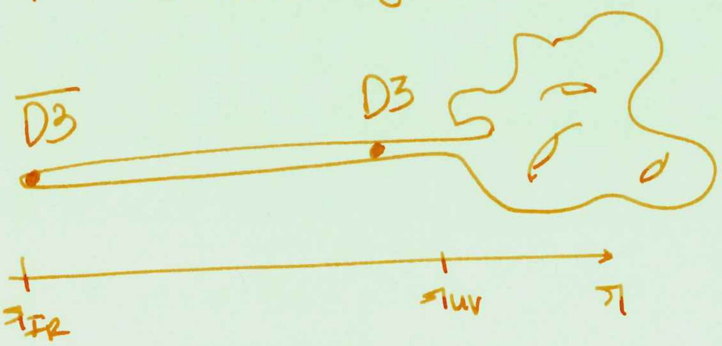
The problem with $D3\overline{D3}$ inflation can be cured if one introduces warping in the compact space.

10D Spacetime is a product of a non-compact 4D space and a compact warped CY3 with a throat.

↓

this is where inflation will happen

The setup is the following




Inflation happens as the D3 approaches the $\overline{D3}$ and it ends when the pair annihilate.

The potential for the inflaton has a similar form as in $D3\overline{D3}$ inflation but crucially the warping allows for consistent slow roll solutions.

It is a small field model ( $V_{throat} < V_{total} \Rightarrow \Delta\phi < 1$ )

For this to be a complete description of inflation it must also incorporate moduli stabilisation.

↳ This turns out to be a rather constraining requirement as in the absence of tuning the physics that stabilises the moduli also gives unreasonably large mass to the inflaton → $\eta$ - problem again

## → Inflection Point inflation

Same setup as warped D-brane inflation but more precise treatment of the problem of moduli stabilisation.

Inclusion of the D7 branes involved in moduli stabilisation significantly changes the potential:

$$V \sim V_0\left(1 - \frac{\lambda_3}{3}\phi^3 + \dots\right)$$

Inflation now happens at an inflection point.

$n_s - 1 = -4/N_e$ and so for $50 < N_e < 60$ we find $\begin{cases} 0.92 < n_s < 0.93 \\ r \lesssim 10^{-6} \end{cases}$

A bit to small for Planck data we can impose a $\mathbb{Z}_2$ symmetry to have $\phi^4$ rather than $\phi^3$ in $V$ which drives these values up towards the data.

## → DBI inflation (0404084)

Inflation due to motion of a brane in a strongly warped region of the compact space.

Inflaton is the position of the brane moving along the throat.

This scenario <u>does not rely on slow roll</u> but rather on non canonical kinetic terms which imply the <u>existence of a speed limit</u> in the warped spacetime.

The action takes the following form

$$S_{DB7} = \int d^4x \sqrt{-g}\left[f^{-1}(\phi)\sqrt{1+f(\phi)g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi} - f^{-1}(\phi) + V(\phi)\right]$$

the $\sqrt{\dots}$ induces a speed limit that the inflaton cannot exceed:

$$1 - f(\phi)\dot{\phi}^2 \geq 0 \Rightarrow \boxed{\dot{\phi}^2 \leq 1/f(\phi)}$$

$f \sim \lambda/\phi^4$

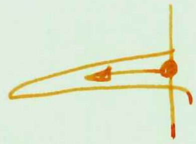
$\lambda \to$ Flux dependent parameter

Note that the existence and the value of the speed limit is independent from the scalar potential.

2 types of scalar potentials have been studied

$$V(\phi) = \begin{cases} m^2\phi^2 \equiv V_{UV}, & m \gg M_p/\sqrt{\lambda} \quad \to \text{UV Model} \\ V_0 - m^2\phi^2 \equiv V_{IR}, & m \sim H \quad \to \text{IR Model} \end{cases}$$

- UV model



UV to IR motion

- Planckian field range
- detectable gravitational waves
- does not work for D3 as originally proposed $\to$ must consider $Dp$, $p>3$

- IR model

IR to UV motion

- small field model
- no gravity waves: $r < 10^{-7}$
- $n_s - 1 = -4/N_e$
- $\dfrac{dn_s}{d\log k} = -4/N_e^2$
- since motion is not slow roll $\to$ can generate non gaussianities.

DBI and generalised slow roll:

$$P = -f^{-1}\sqrt{1-2Xf} + f^{-1} - V \quad ; \quad \rho = 2XP_X - P = \frac{f^{-1}}{\sqrt{1-2Xf}} - f^{-1} + V \quad \text{Recall } X \equiv \dot{\phi}^2/2$$

1st gen. slow roll parameter:

$$\epsilon \ll 1 \Rightarrow \frac{\rho+P}{\rho} \ll 1 \Leftrightarrow f^{-1}\left(-\sqrt{1-2Xf} + \frac{1}{\sqrt{1-2Xf}}\right) \times \frac{1}{-f^{-1} + \frac{f^{-1}}{\sqrt{1-2Xf}} + V} \ll 1$$

$\to$ Holds as long as $V$ dominates $\rho$ even if $\phi$ is rolling fast.

# 5.2 CLOSED STRING INFLATION

In these models the inflaton is either the real or imaginary part of a closed string modulus.

real → modulus

imaginary → Axion

typically built in the context of IIB orientifold compactifications.

## Axions

Axions are good inflaton candidates since the (discrete) shift symmetry helps to control higher order terms in the action alleviating the $\eta$-problem.

A single axion in a periodic potential of the form

$$V(a) = \Lambda^4 \left[1 - \cos\left(\frac{a}{f_a}\right)\right]$$

is not a good inflaton candidate as slow roll would imply $f_a \gg M_p$

↳ single axion potential is not flat enough. More sophisticated constructions are necessary.

- **Racetrack inflation** (0406230)

Combines inflaton with moduli stabilisation (1st to do it)

In its original formulation the inflaton is the imaginary part of the (complex) volume modulus $T \equiv \tau + i b$.

F-term potential that follows from

$$W = W_0 + A e^{-aT} + B e^{-bT} \quad ; \quad K = -2 \log\left[\left(\frac{T+\bar{T}}{2}\right)^{3/2}\right]$$

develops a saddle point where inflation takes place

Very fine tuned scenario.

observationally: → small field model

- $n_s \sim 0.96$
- $M_{inf} \sim 10^{14}$ GeV
- $r \sim 10^{-8}$
- unobservable $f_{NL}$

▶ **N-flation** (0507205)

Large numbers of axions ($N \sim 100$) drive inflation when any one of the individual axions would not give rise to sufficient Ne. taken together they self damp and slow roll for long enough

↳ A model of assisted inflation (9804177) where fields with too steep potentials to drive inflation on their own act collectively to increase H (and so the friction term) to allow for slow roll inflation.

String inspired rather than string derived scenario:
- large numbers of axions make explicit constructions hard
- hard to keep axions light and their corresponding moduli heavy

Amenable for statistical treatment (0512102)

Large numbers of axions might be inconsistent with dS bounds on entropy (1203.5476)

observationally: $0.93 \lesssim n_s \lesssim 0.95$

$r \lesssim 10^{-3}$

▸ Axion Monodromy (0803.3085; 0808.0706)

Warped branes "unwarp" the compact axionic direction → linear potential

D5: $S_{DBI}^{D5} = -\frac{1}{g_s} \int d^4x \sqrt{-g} \sqrt{L_2^4 + b^2} \sim$ linear potential in the limit of large b

Volume of the 2 cycle wrapped by the D5 brane

NS5

$S_{DBI}^{NS5} \sim \frac{-1}{g_s} \int d^4x \sqrt{g} \sqrt{L_2^4 + g_s^2 c^2}$ → ≠ axion, same story

Effective potential for axion in monodromy constructions

$$V \sim \mu^3 \phi + \Lambda^4 \cos(\phi/f)$$

Inflation happens along a trans-planckian trajectory

↳ Large tensor signal

Shift symmetry controls the potential over super-planckian range.

observationally: $0.97 < n_s < 0.98$

$0.04 < r < 0.07$

# KÄHLER MODULI INFLATION

In IIB compactifications with flux the Kähler moduli are exactly flat directions due to no-scale cancellations.

Tree level: $K = -2 \log \mathcal{V} + K_{cs} + K_S$ , $W = W_{flux}$

$$V_F = e^K \left( D_A W \overline{D_B W} K^{A\bar{B}} - 3|W|^2 \right) \longrightarrow = 0$$

$$\begin{cases} S, U \text{ stab. SUSIC} \\ W = W(S,U) \\ K_A K_{\bar{B}} K^{A\bar{B}} = 3 \end{cases}$$

kahler moduli potential is generated by <u>subleading effects</u> → small perturbation around a vanishing potential → <u>rather flat potentials</u>

the main advantage of KMI is that the physics that stabilises the geometry (which is an essential requirement of any controlled string inflation construction) is also the physics that gives us inflation

↳ <u>Economical approach</u>

Even though these models start with many scalar fields we can still generate effective single field models as preferred by the data.

Most constructions rely on the large volume scenario of IIB orientifolds

↳ use of ~~non~~ perturbative contributions to $K$ ⊕ non-perturbative contributions to $W$

$$K = -2\log\left(\mathcal{V} + \hat{\xi}/2\right) + K_S + K_U \ ; \quad W = W_0 + \sum_{i=1}^{\tilde{n}} A_i e^{-a_i T_i}$$

↳ AdS minimum at exponentially large volumes

↓

Excellent control over the SUGRA approximation

Depending on the geometric origin of the inflaton and on the physics that generates the scalar potential we may have:

- blow-up inflation
- fibre inflation
- poly-instanton inflation

# ▸ BLOW-UP inflation

original construction of inflation in LVS

Needs at least 3 Kähler moduli (4 if we want to build the SM in the model)


$$\mathcal{V} \sim \tau_1^{3/2} - \tau_2^{3/2} - \tau_3^{3/2}$$

$$W = W_0 + A_2\, e^{-a_2 T_2} + A_3\, e^{-a_3 T_3}$$

$\downarrow$

the scalar potential stabilises all 3 Kähler d.o.f.

choose initial conditions such that $\tau_1$ and $\tau_2$ are @ the minimum while $\tau_3$ is away from the minimum.

the role of $\tau_2$ is to keep the volume stable during inflation at

$$\langle \mathcal{V} \rangle \sim e^{a\tau_2}$$

$\tau_3$ is the inflaton field

the mass spectrum @ the minimum is:

$$m_1^2 \sim \frac{M_p^2}{\mathcal{V}^3} \qquad m_2^2 \sim m_3^2 \sim \frac{M_p^2}{\mathcal{V}^2} \qquad \text{(up to factors of } \log \mathcal{V}\text{)}$$

So the initial conditions are such that $\begin{cases} m_3 \sim 0 \ll m_1 \ll m_2 \\ m_1, m_2 \gg H \end{cases}$

$\downarrow$

can integrate out $\tau_1$ and $\tau_2$ and have only <u>single field dynamics</u>.

the effective single field potential takes the approximate form

$$V(\phi) \sim V_0 - \beta \left(\frac{\phi}{M_p \mathcal{V}}\right)^{4/3} e^{-a\mathcal{V}^{2/3}(\phi/M_p)^{4/3}}$$

exponential potential ensures $\begin{cases} \epsilon \ll 1 \\ \eta \ll 1 \end{cases}$ provided $\mathcal{V}^{2/3}\phi^{4/3} \gg M_p^{4/3}$

$\Leftrightarrow \phi \gg M_s$

observationally: small field model with no tensor modes

$\eta \sim -1/N_e$ , $\epsilon < 10^{-12}$ , $\alpha_s \sim -4/N_e^2$

$0.96 < n < 0.967$ ; $|r| < 10^{-10}$ , $-0.006 < \frac{dy}{d\ln k} < -0.0078$

meeting the COBE-WMAP normalisation $\Rightarrow \mathcal{V} \sim 10^{8} - 10^{7}$

$\downarrow$

only of the 3 KMI models that can have SUSY @ TeV and inflation which generates the correct amplitude for the scalar perturbations.

<u>Still affected by $\eta$-problem</u>: integrating out UV physics may generate extra contributions to K

$\hookrightarrow \delta V_{loop} \sim \frac{1}{\sqrt{\tau_2}\, \mathcal{V}^3} \sim \frac{1}{\varphi^{2/3} \mathcal{V}^{10/3}}$

$$\delta\eta = \frac{\delta V}{V_0} \sim \mathcal{O}(1)$$

Can be circumvented by choice of brane configurations $\rightarrow$ <u>tuning</u>.

## ▸ Fibre inflation (0808.0691)

Available when compactification space is a K3 fibration over a $\mathbb{P}_1$ base with $h_{11} = 3$.

$$\mathcal{V} \sim \sqrt{\tau_1}\, \tau_2 - \tau_3^{3/2} \qquad \begin{cases} K = -2\lg(\mathcal{V} + \hat{\xi}/2) \\ W = W_0 + A_3\, e^{-a_3 T_3} \end{cases}$$

$\hookrightarrow$ Leading contributions to F-term potential are independent of $\tau_1$.

We have 3 moduli and 2 stabilisation conditions that follow from the LVS potential

$\hookrightarrow$ one flat direction in the $(\tau_1, \tau_2)$ plane

use this feature to inflate along the $\tau_1$-direction.

But first we must $\underline{\underline{\text{kill } z_1}}$. this can be done by considering loop corrections to the action which enter as new contributions to the Kähler potential

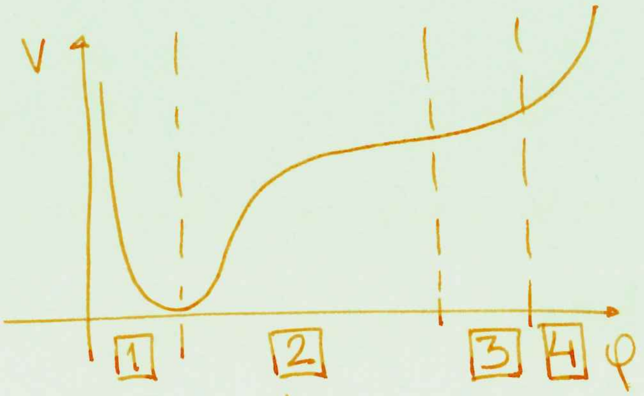
$$\hookrightarrow \delta V_{g_s} = \left(\frac{A}{z_1^2} - \frac{B}{\mathcal{V}\sqrt{z_1}} + \frac{C z_1}{\mathcal{V}^2}\right)\frac{W_0^2}{\mathcal{V}^2}$$

once again the mass hierarchy at the LVS minimum reduces the dynamics to single field since

$$m_1 \sim 0 \ll m_2 \ll m_3$$

in terms of the canonically normalised inflaton field $\varphi = \frac{\sqrt{3}}{2}\log z_1$ the potential takes the form

$$V_{inf} \sim \frac{1}{\langle\mathcal{V}\rangle^{10/3}}\left(C_0\, e^{k\hat{\varphi}} - C_1\, e^{-k\hat{\varphi}/2} + C_2\, e^{-2k\hat{\varphi}} + \text{lup}\right)$$




inflation

in the inflationary region $\quad V \sim \frac{1}{\langle\mathcal{V}\rangle^{10/3}}\left(3 - 4\, e^{-\hat{\varphi}/\sqrt{3}}\right)$

the slow roll parameters have the following hierarchy $\quad \epsilon = \frac{3}{2}\eta^2$

and so $\quad r = 6(n_s - 1)^2 \longrightarrow$ tensors in the sky!

observationally: $0.965 < n_s < 0.97$

$0.005 < r < 0.007$

no observable $f_{NL}$

COBE normalisation $\Rightarrow \mathcal{V} \sim 10^3 - 10^4\, l_s^6 \longrightarrow$ way too small for TeV SUSY

No $\eta$-problem → loop effects which are usually problematic are the very origin of the inflationary potential.

## ▸ Poly-instanton inflation (1110.6182)

Same geometry as fibre inflation but ≠ origin for the inflationary potential

$V_{inf}$ is generated non-perturbatively by a superpotential of the form

$$W \sim W_0 + A\, e^{-a\left(T_3 + C e^{-2\pi T_1}\right)}$$

↓ instanton corrections to an instanton

can be thought as a mix between blowup inflation and fibre inflation

As before, the mass hierarchy of the LVS potential reduces the dynamics to single field:

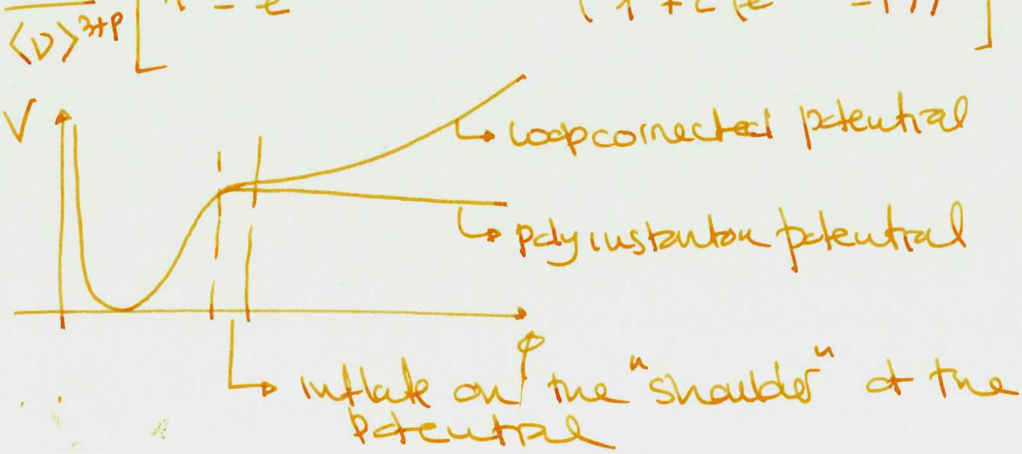
$$m_1 \ll m_2 \ll m_3 \quad \underline{\text{and}} \quad H \sim m_1 \ll m_2 \ll m_3$$

the potential is given by

$$V_{inf} \sim \frac{F}{\langle V \rangle^{3+p}} \left(1 - \left(1 - 2\pi \hat{\tau}_1\right) e^{-2\pi \hat{\tau}_1}\right)$$

or in terms of the canonically normalised modulus:

$$V_{inf} \sim \frac{F}{\langle V \rangle^{3+p}} \left[1 - e^{-c\left(e^{2/\sqrt{3}\hat{\phi}} - 1\right)} \left(1 + c\left(e^{\frac{2\hat{\phi}}{\sqrt{3}}} - 1\right)\right)\right]$$



inflation happens closer to the minimum than in blow-up inflation $\longrightarrow$ $\eta$ problem less of an issue

Exponential structure of the potential ensures flatness without tuning.

Slow-roll parameters obey $\quad \epsilon \sim \dfrac{\eta^2}{(\log V)^2} \quad$ and $\quad \epsilon \ll |\eta| \ll 1$

observationally: $0.95 \lesssim n_s \lesssim 0.97$ , $r \lesssim 10^{-5}$

## $\boxed{6}$ SUMMARY

CMB is a great probe (the best one we've got) of very high energy physics so it makes sense to use it to test stringy constructions

Essential to go beyond the EFT approach to have a controlled description of inflation

At present there are several string inflation models compatible with data

tensor-to-scalar ratio is the best hope of distinguishing between different models

$\hookrightarrow$ more to come in 2014 when Planck release the analysis with their own polarization measurements