Large Field Inflation from D-branes

Based on:
D. Escobar, A.L., F. Marchesano, D. Regalado
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Aitor Landete

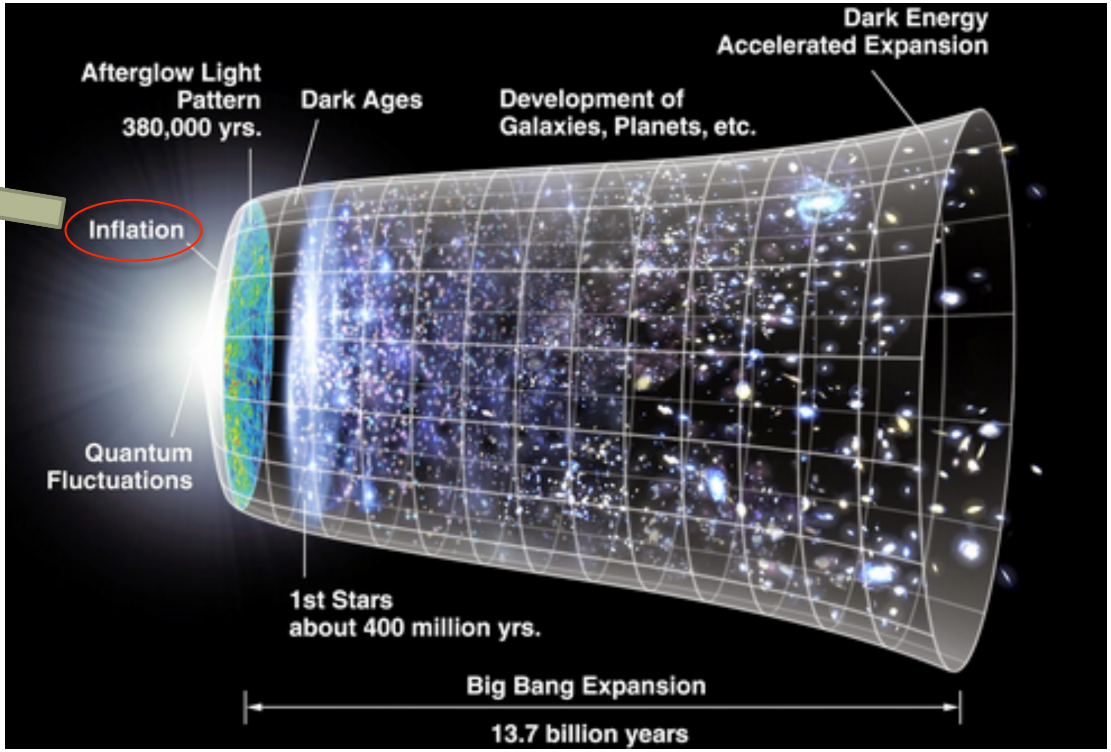
Overview

- Introduction
  - Inflation
  - Axion monodromy
  - F-term axion monodromy
- Inflation from D-branes
  - Setup of our model
  - Moduli stabilization
  - Masses analysis
- Results
  - Single-field inflation scenario
  - Consistency with Planck bounds
- Conclusions

Motivation

Inflation

Inflation is the theory that explains the exponentially expansion of the universe after the Big Bang



Solves

Horizon Problem

Flatness Problem

Explains Homogeneity

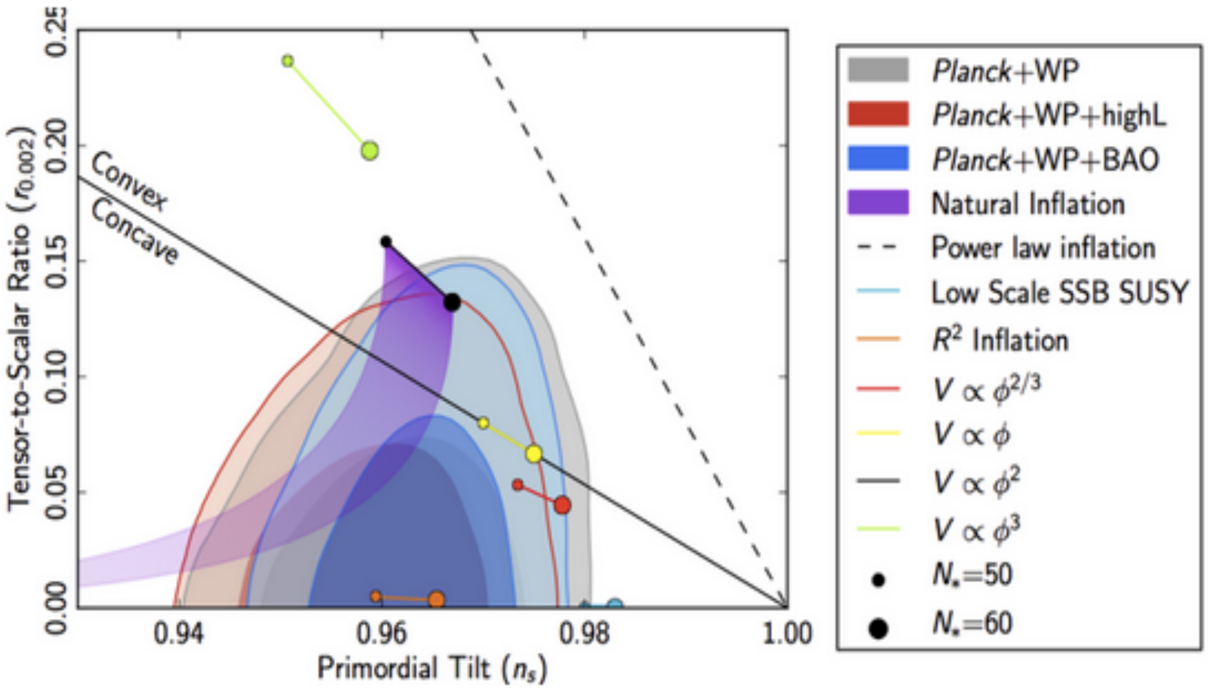
Chaotic Inflation

$$V = \frac{\phi^n}{M_{Pl}^{4-n}}$$

Linde '81

Motivation

Inflation



How we embed this theory in String Theory?

Axions, Kahler Moduli, Warped Branes…

Constrained by Planck Collaboration

Chaotic Inflation

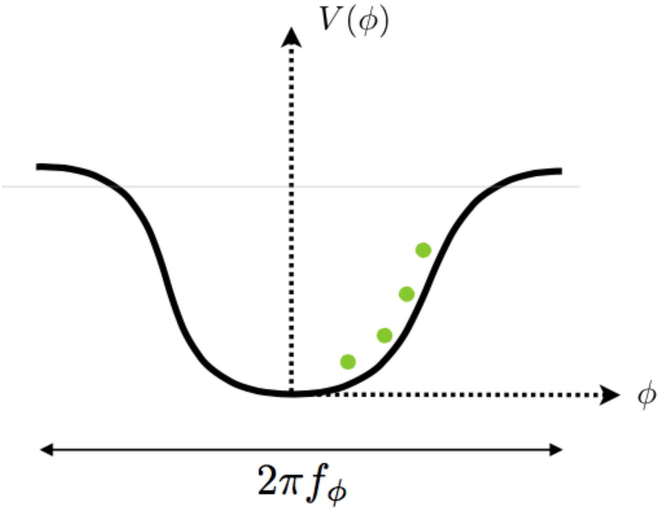
$$V = \frac{\phi^n}{M_{Pl}^{4-n}}$$

Linde '81

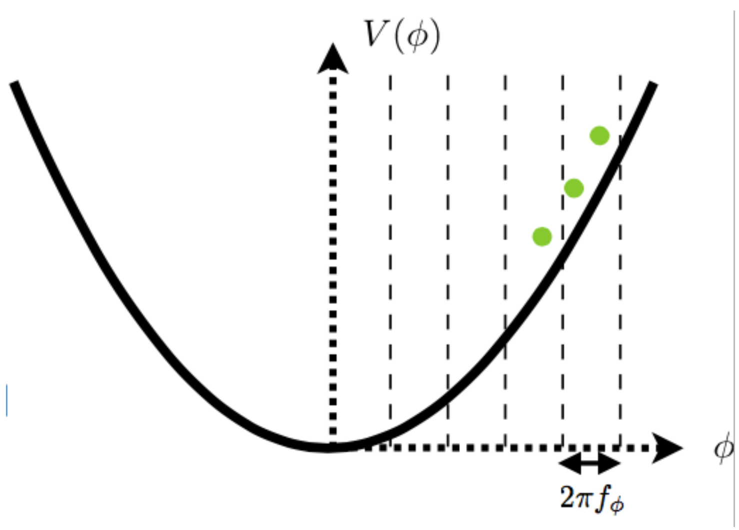
Motivation

Axion monodromy

String axions are promising inflaton candidates. Equipped with **a continuous shift symmetry to all orders in perturbation theory**, the axion potential is stable against radiative corrections



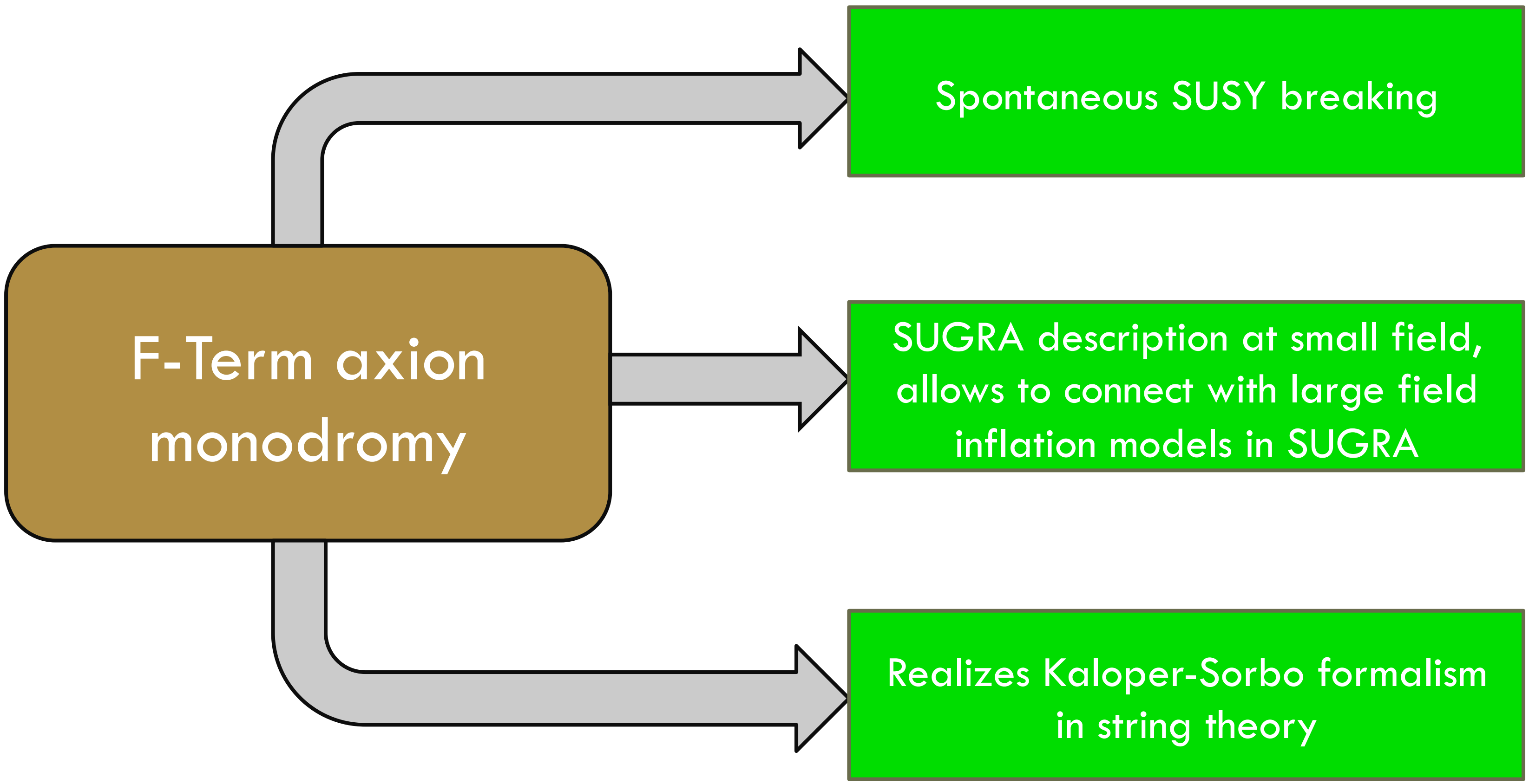
The basic idea of monodromy Inflation is that inflation can persist through many cycles around the configuration space. **The effective field range is then much larger than the fundamental period**, but the axion shift symmetry protects the structure of the potential over each individual cycle



Silverstein & Westphal '08

Motivation

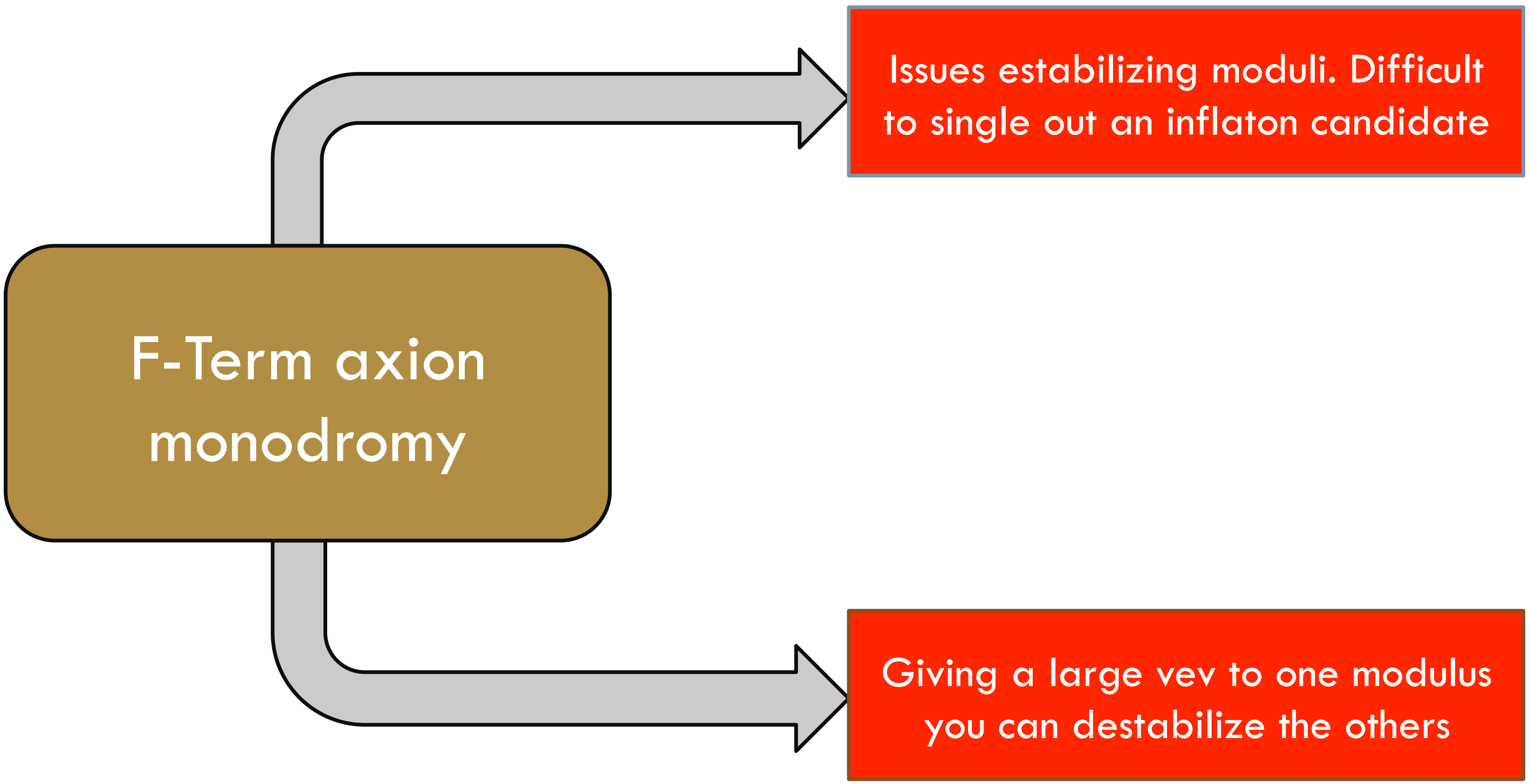
F-term axion monodromy



Marchesano, Shiu & Uranga '14

Motivation

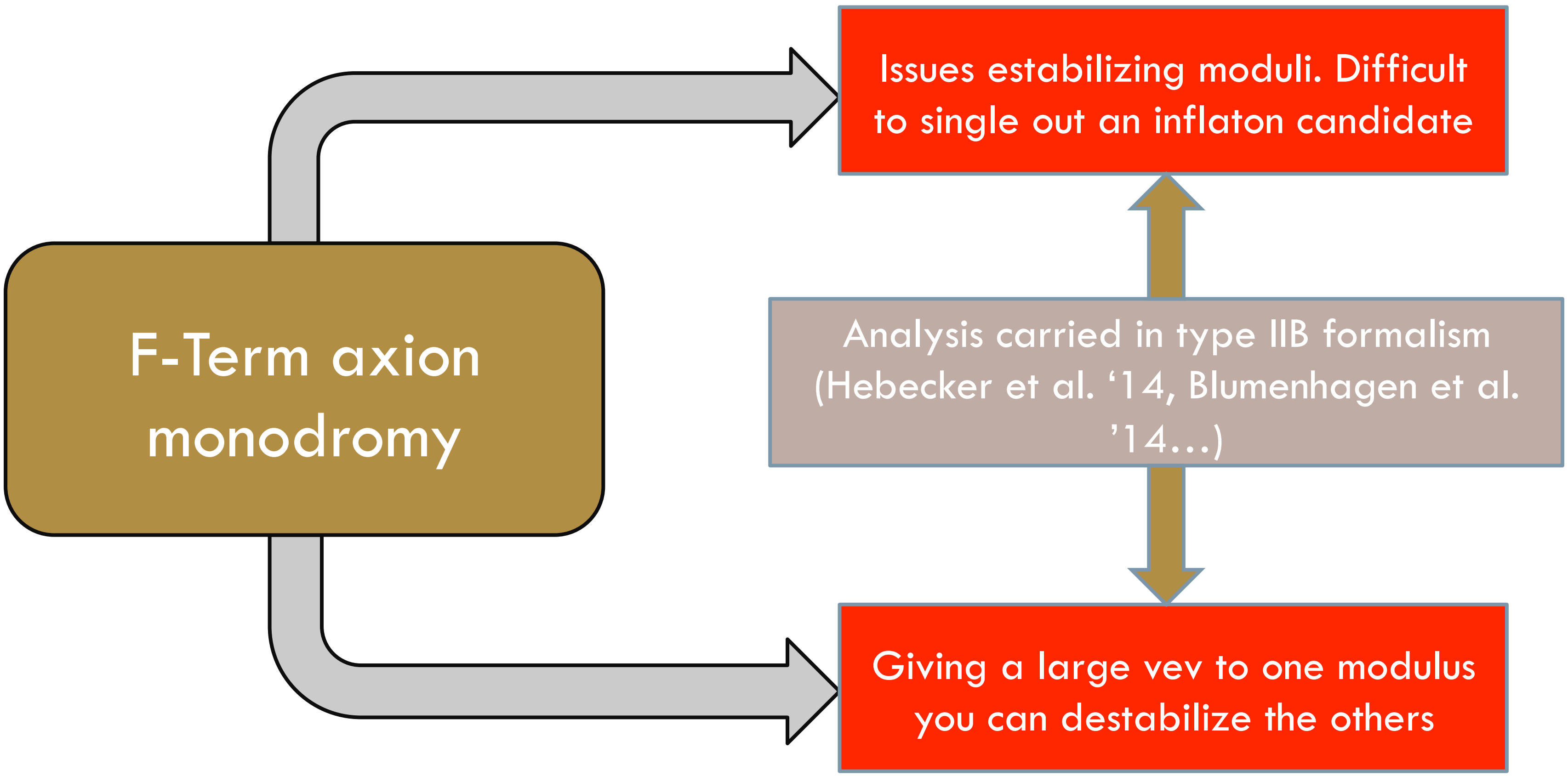
F-term axion monodromy



Marchesano, Shiu & Uranga '14

Motivation

F-term axion monodromy



Marchesano, Shiu & Uranga '14

Inflation from D-branes

Setup

4d **type IIA** compactifications with O6-planes and background fluxes

D6-brane wrapping a special lagrangian 3-cycle Π_3 of the compactification manifold such that

$$b_1(\Pi_3) = 1$$

$$J_c = B + iJ$$

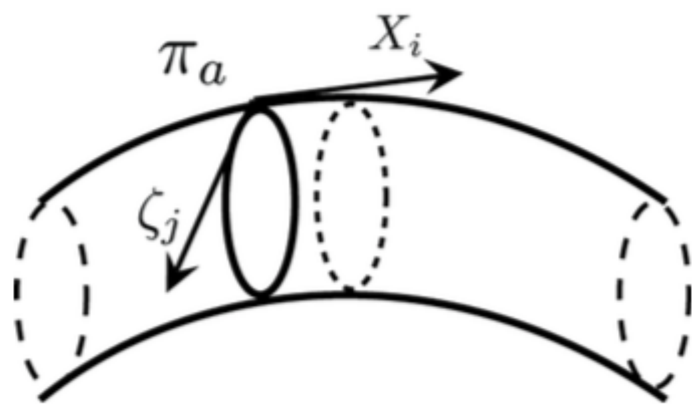
Complexified brane position modulus

$$A + [\iota_X J_c]_{\Pi_3} = \Phi \zeta$$

$$b_1(\Pi_3) = 1$$

$$\int_{\Pi_2} J_c = \sum_a n_a T^a = T$$

$[\Pi_2]$ non trivial in the homology of M_6



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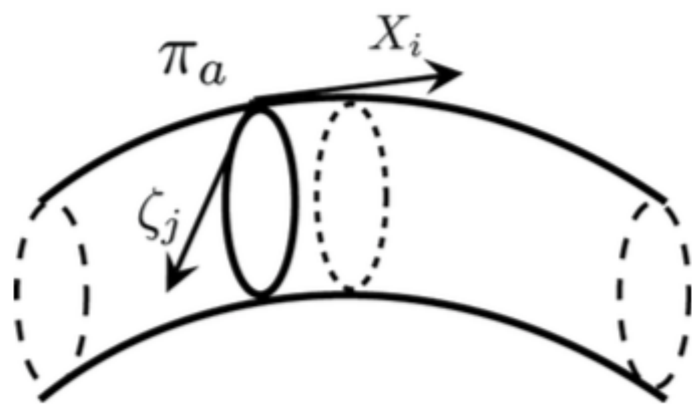

$$J_c = B + iJ$$

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Marchesano, Regalado & Zoccarato '14

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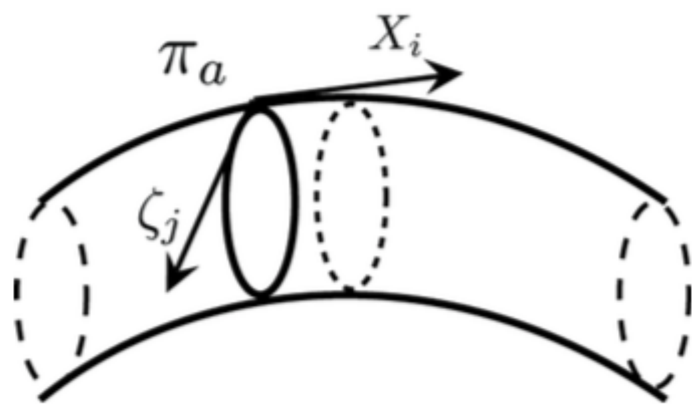
$$W_{\text{inf}} = \Phi T$$

Inflation from D-branes

Setup

4d **type IIA** compactifications with O6-planes and background fluxes

D6-brane wrapping a special lagrangian 3-cycle Π_3 of the compactification manifold such that $b_1(\Pi_3) = 1$



$J_c = B + iJ$

Complexified brane position modulus

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Marchesano, Regalado & Zoccarato '14

$b_1(\Pi_3) = 1$

$$\int_{\Pi_2} J_c = \sum_a n_a T^a = T$$

$$W_{\text{inf}} = \Phi T$$

$[\Pi_2]$ non trivial in the homology of M_6

Does not require any two-cycle of M_6 shrinking to vanishing size

$T = T^1 - T^2$

Motivation

Inflation & SUGRA

- Chaotic inflation is builded in SUGRA using the following setup

Stabilizer field

$$W = S f(X)$$

$$K = K\left(S, \bar{S}, X, \bar{X}\right)$$

The Kähler potential is invariant under

$$S \to -S$$

$$X \to \bar{X}$$

$$X \to X + a \in \mathbb{R}$$

$$V = e^K\left(K^{\alpha\bar{\beta}} D_\alpha W D_{\bar{\beta}} \bar{W} - 3|W|^2\right)$$

$$S = 0 = \mathrm{Im}\left(\Phi\right)$$

$$\boxed{V = f^2\left(\frac{X}{\sqrt{2}}\right)}$$

Kawasaki, Yamaguchi & Yanagida '00

Kallosh, Linde & Rube '10

Inflation from D-branes

Setup

$$V = e^K\left(K^{\alpha\bar\beta}D_\alpha W D_{\bar\beta}\bar W - 3|W|^2\right)$$

$$K_K = -\log\left(\frac{i}{6}\mathcal{K}_{abc}(T^a-\bar T^a)(T^b-\bar T^b)(T^c-\bar T^c)\right)$$
$$K_Q = -2\log\left(\frac{1}{2i}\mathcal{F}_{\hat K\hat L}\left[N^{\hat K}-\bar N^{\hat K}+\frac{i}{4}Q^{\hat K}\Phi\bar\Phi\right]\cdot\left[N^{\hat L}-\bar N^{\hat L}+\frac{i}{4}Q^{\hat L}\Phi\bar\Phi\right]\right)$$

Satisfies the conditions imposed in SUGRA

$$W_{\rm mod} = W_{\rm flux} + W_{\rm D2} + W_{\rm WS}$$

$$W = W_{\rm mod} + \Phi T$$

$$W = Sf(X)$$

$$\Phi \to -\Phi$$
$$T \to \bar T$$
$$T \to T + a \in \mathbb{R}$$

We identify

Φ stabilizer

Re T
Inflaton candidate

$$b = \int_{\Pi_2} B$$

$$J_c = B + iJ$$

$$\int_{\Pi_2} J_c = \sum_a n_a T^a = T$$

We want to understand the interplay between the inflationary potential and the moduli stabilization

Inflation from D-branes

Mod. Stabil

$$V = e^K \left(K^{\alpha\bar\beta} D_\alpha W D_{\bar\beta}\bar W - 3|W|^2 \right)$$

$$\begin{aligned} K_K &= -\log\left(\frac{i}{6}\mathcal{K}_{abc}(T^a-\bar T^a)(T^b-\bar T^b)(T^c-\bar T^c)\right) \\ K_Q &= -2\log\left(\frac{1}{2i}\mathcal{F}_{\hat K\hat L}\left[N^{\hat K}-\bar N^{\hat K}+\frac{i}{4}Q^{\hat K}\Phi\bar\Phi\right]\cdot\left[N^{\hat L}-\bar N^{\hat L}+\frac{i}{4}Q^{\hat L}\Phi\bar\Phi\right]\right) \end{aligned}$$

$$W_{\mathrm{mod}} = W_{\mathrm{flux}} + W_{\mathrm{D2}} + W_{\mathrm{WS}}$$

W_{mod} does not depend on T

b flat direction

We assume

F-terms vanish and almost all moduli are stabilized with a very small or vanishing value of W^0

Inflation from D-branes

Mod. Stabil

$$V = e^K \left(K^{\alpha\bar\beta} D_\alpha W D_{\bar\beta} \bar W - 3|W|^2 \right)$$

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Switch on W_{inf}

$$V = V_Q + V_K - 3e^K |W|^2$$

$$W_{\rm mod} = W_{\rm flux} + W_{\rm D2} + W_{\rm WS}$$

We assume

W_{mod} does not depend on T

b flat direction

F-terms vanish and almost all moduli are stabilized with a very small or vanishing value of W^0

$$\begin{aligned} D_N W_{\rm mod} &= 0 \\ D_{T^a} W_{\rm mod} &= 0 \end{aligned}$$

$$\Delta V = e^K \left(K^{\Phi\bar\Phi} |\partial_\Phi W_{\rm inf}|^2 + (K^{T\bar T} + 4({\rm Re}\ T)^2) |\partial_T W_{\rm inf}|^2 \right) + 3e^K \left[|W_{\rm inf}|^2 + |W^0_{\rm mod}|^2 - |W^0_{\rm mod} + W_{\rm inf}|^2 \right]$$

Inflation from D-branes

Mod. Stabil

$$\Delta V = e^K \left(K^{\Phi\bar\Phi}|\partial_\Phi W_{\rm inf}|^2 + (K^{T\bar T} + 4(\mathrm{Re}\,T)^2)|\partial_T W_{\rm inf}|^2 \right)$$
$$+ 3e^K \left[|W_{\rm inf}|^2 + |W^0_{\rm mod}|^2 - |W^0_{\rm mod} + W_{\rm inf}|^2 \right]$$

NOT positive definite

Energetically favoured
small W^0
large Re T

$$\Phi = \mathrm{Im}\,T = 0$$

$$\Delta V = e^K K^{\Phi\bar\Phi}|T|^2$$

Cuadratic potential

Inflation from D-branes

Masses

How to supress the inflaton mass with respect the other closed string moduli?

Decrease the value of respect K^{TT}

Set the D6-brane in a **warped region**

Enhance the constants Q^K

$$\Delta V = e^K K^{\Phi\bar{\Phi}} |T|^2$$

$$\mathcal{V}_{\mathcal{M}_6} \sim 10^3$$
$$\mathcal{V}_{\Pi_3} \sim 10$$
$$g_s^2 \sim 0.1$$

$$m_{\rm inf} \sim Z_{\rm D6}^{-1/2} 10^{-4} M_{\rm pl}$$

$Z \sim 100$

Gives a realistic inflaton mass

Inflation from D-branes

Masses

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How we **enhance** the mass of the **saxionic partner**?

Cuadratic terms in the potential arising from V_T

Single-Field Inflation

Inflation from D-branes

Masses

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Single-Field Inflation

No enhancement implies multi-field inflation

Inflation from D-branes

DBI reduction

The inflaton will take **trans-Plankian vacuum expectation value** at the beginning of inflation

It is **necessary to take into account Planck supressed corrections** to the quadratic potential given by SUGRA

Dimensional reduction of the DBI action which sumes over all α' corrections to the potential

$$V = c\left(\sqrt{1 + a\left(\frac{\phi_b}{M_{\rm pl}}\right)^2} - 1\right) M_{\rm pl}^4$$

Single-Field case

Inflation from D-branes DBI reduction

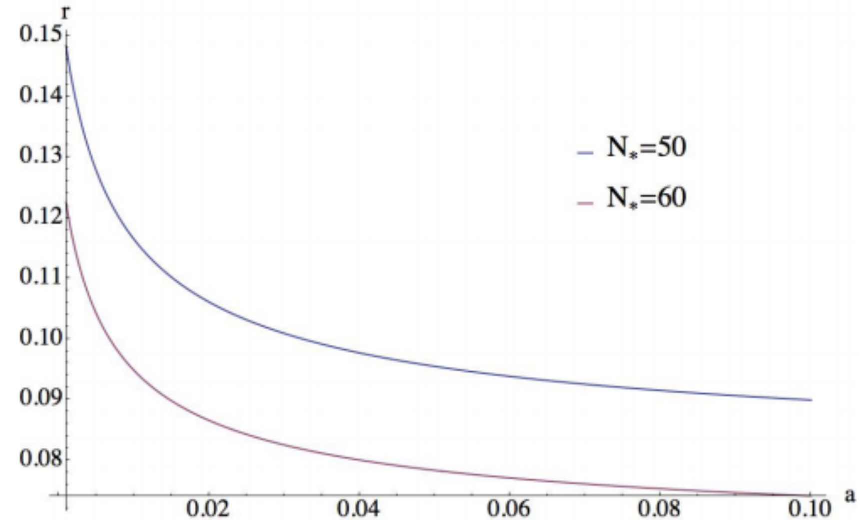
$$c \sim 10^{-2} g_s^3 \frac{\mathcal{V}_{\Pi_3}}{\mathcal{V}_{\mathcal{M}_6}}$$
$$a^{-1} \sim g_s^{-1} K_{\Phi\bar{\Phi}} K_{T\bar{T}} \mathcal{V}_{\Pi_3} \mathcal{V}_{\mathcal{M}_6}$$

$$a \sim 10^{-1} - 10^{-3}$$
$$\mathcal{V}_{\mathcal{M}_6} \sim 10^3$$
$$\mathcal{V}_{\Pi_3} \sim 10$$
$$g_s^2 \sim 0.1$$

Typical mass of the inflaton with these scales and also we satisfy Planck bounds

$$V = c\left(\sqrt{1 + a\left(\frac{\phi_b}{M_{\rm pl}}\right)^2} - 1\right) M_{\rm pl}^4$$

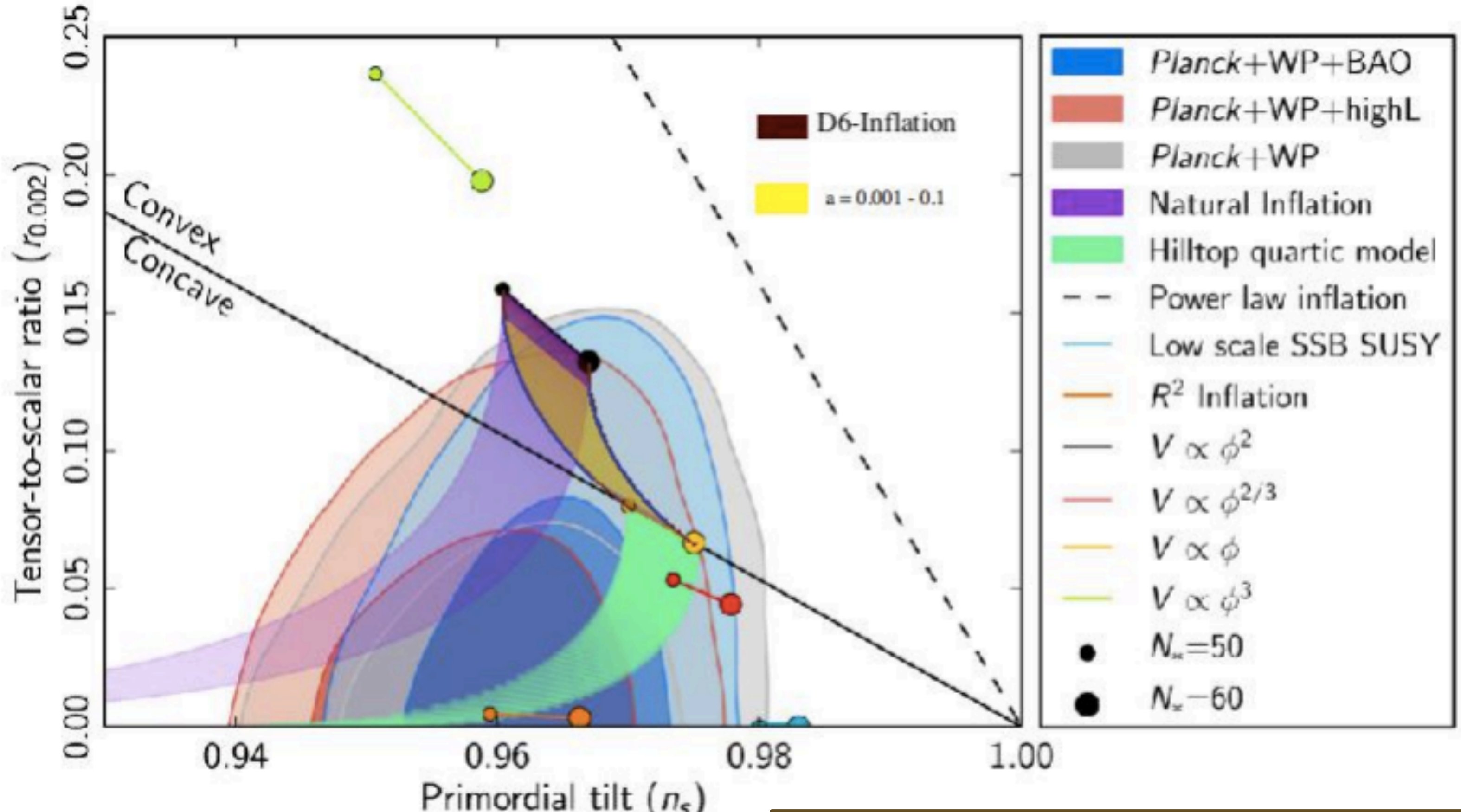
Single-Field case



Our model interpolates between quadratic chaotic inflation ($a \approx 10^{-3}$) and linear chaotic inflation ($a \approx 10^{-1}$)

Inflation from D-branes

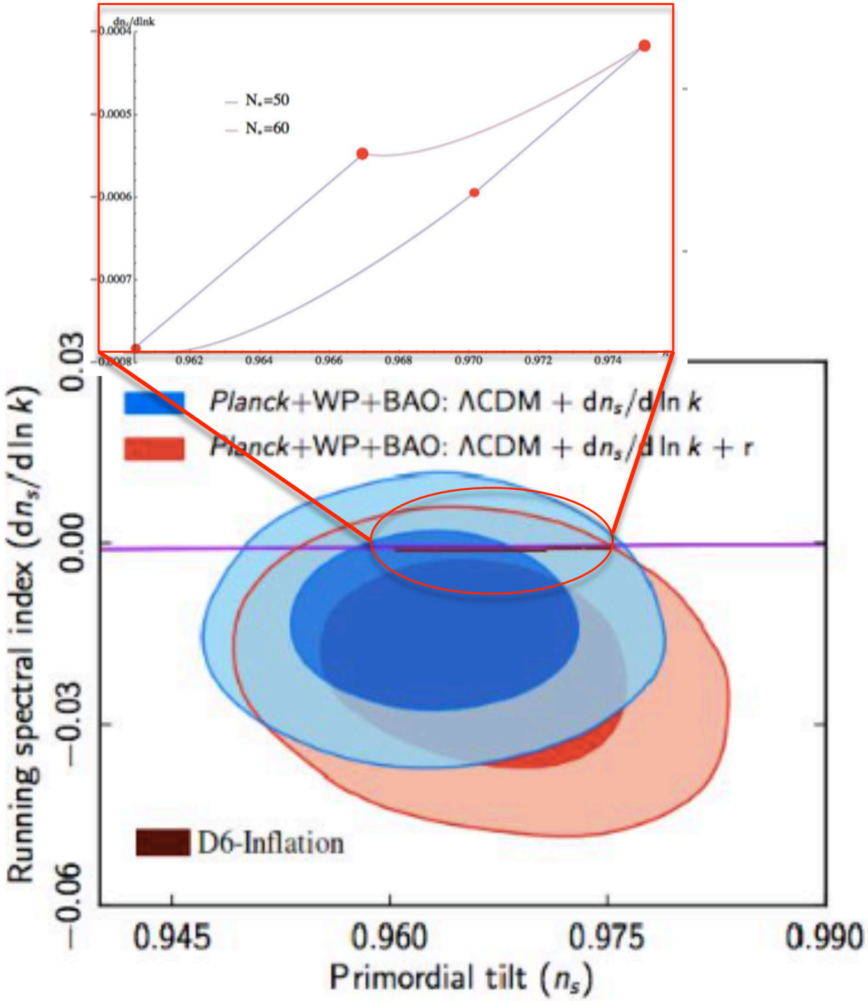
Results

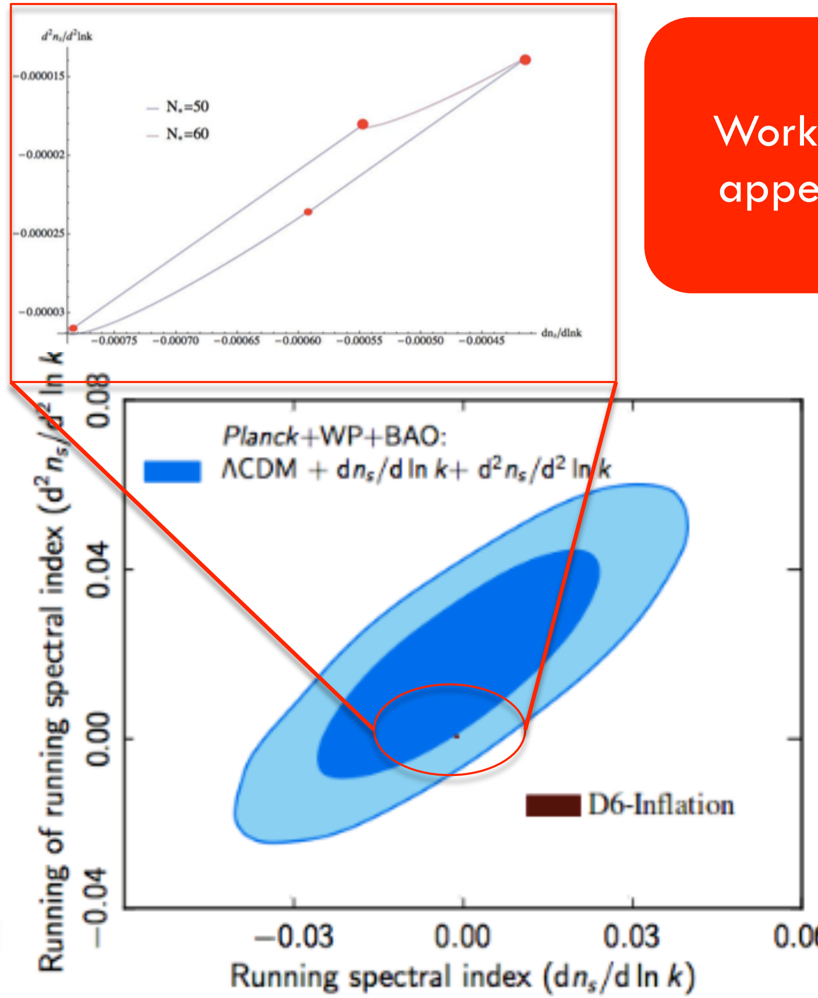


Escobar, A.L. , Marchesano & Regalado '15

Inflation from D-branes

Results





Work to appear

Conclusions

- We have been able to develop a model in type IIA with O6-planes and background fluxes which interpolates between quadratic chaotic inflation and linear chaotic inflation.
- We see that our model satisfies, in the single-field scenario, all the bounds stablished by the Planck collaboration.
- Our model matches with well-stablished models of inflation in SUGRA in the small field regime.
- We have been able to carry out the moduli stabilization in a 2-step process where the enhancement of the mass of the saxionic partner allows us to settle a single-field inflation scenario or a multi-field inflation scenario (work to appear)

Thank you for your attention!