Backreaction Issues in Axion Monodromy and Minkowski 4-forms

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I.V., [arXiv:1611.00394 [hep-th]]

Bielleman,Ibanez,Pedro,I.V.,Wieck [arXiv:1611.07084 [hep-th]]

Hamburg Workshop, February 2017

Transplanckian field ranges

Relevant for:

- Large field inflation (detectable tensor modes)
- Cosmological relaxation [Graham,Kaplan,Rajendran'15]

→ Axion $\Delta\phi > M_p$

Challenge for string theory:

- Technical difficulties

[Banks et al.'03]

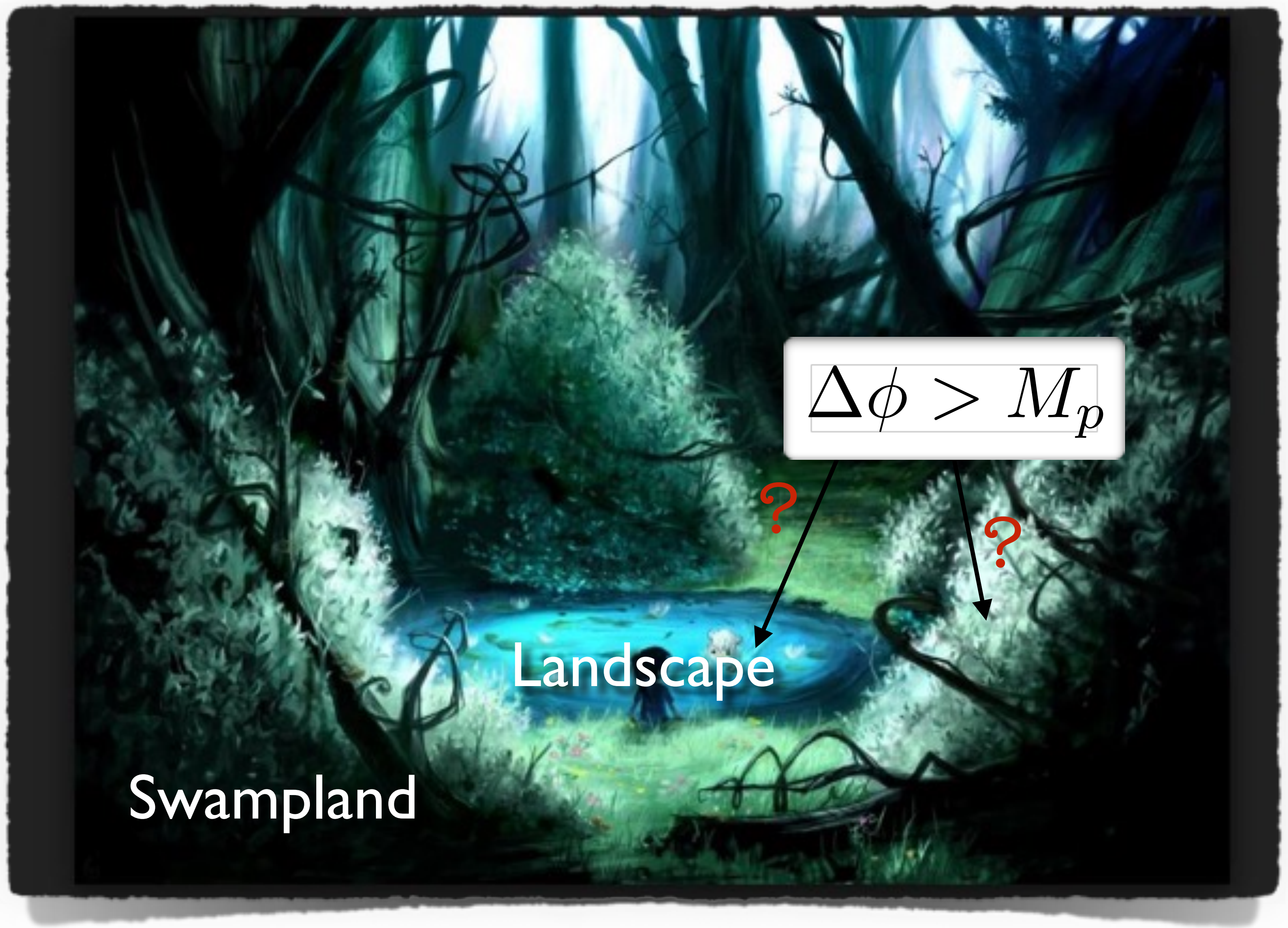
Decay constant $f > M_p \longrightarrow$ effective theory out of control
$(\phi \to \phi + 2\pi f)$ (strong coupling or small volume)

- In conflict with quantum gravity

Weak Gravity Conjecture (WGC) [Arkani-Hamed et al.'06]

Transplanckian field ranges!?

Are they possible in a consistent theory of quantum gravity?



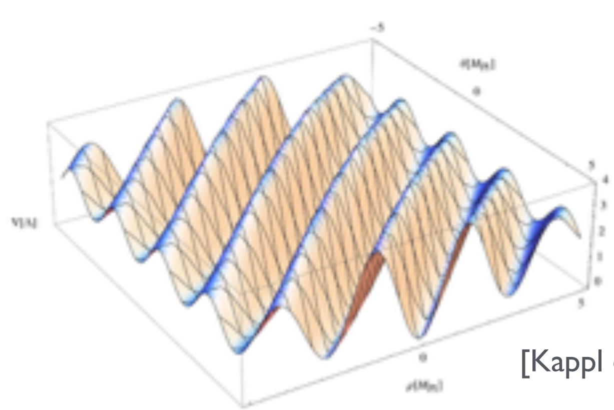
Transplanckian field ranges

Current proposals in string theory:

Natural inflation with multiple axions

[Dimopoulos et al,Kim-Nills-Peloso,McAllister et al…]

Periodic potential



[Kappl et al]

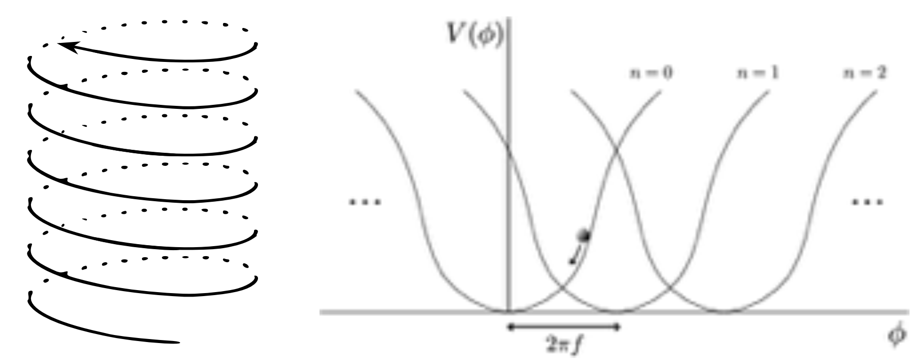
Constraints from WGC

[Rudelius,Heidenreich,Reece,Montero,Ibanez,Uranga,IV,Brown, Cottrell,Shiu,Soler,Bachlechner,Long,McAllister,Hebecker,Mangat ,Rompineve,Witowski,Junghans,Palti,Saraswat…]

Axion monodromy

[Silverstein et al., Flauger et al…]

Multi-branched potential



Constraints from RSC

[Oouri-Vafa et al.'06] [Klaewer-Palti,'16]

(see Blumenhagen's talk)

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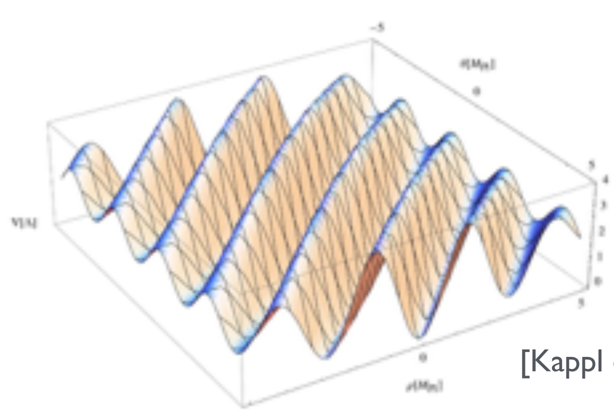

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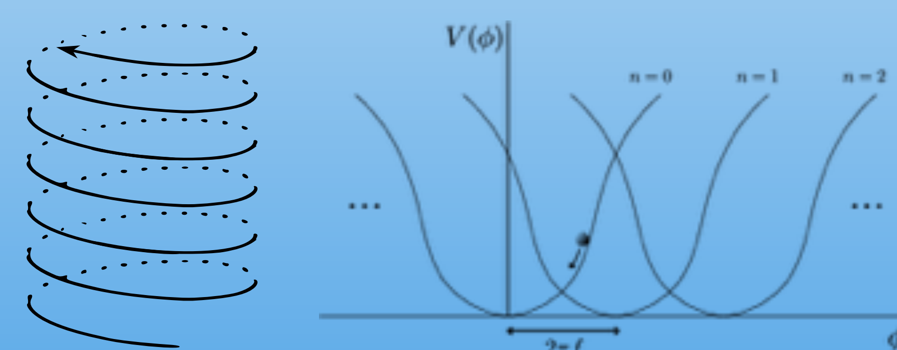

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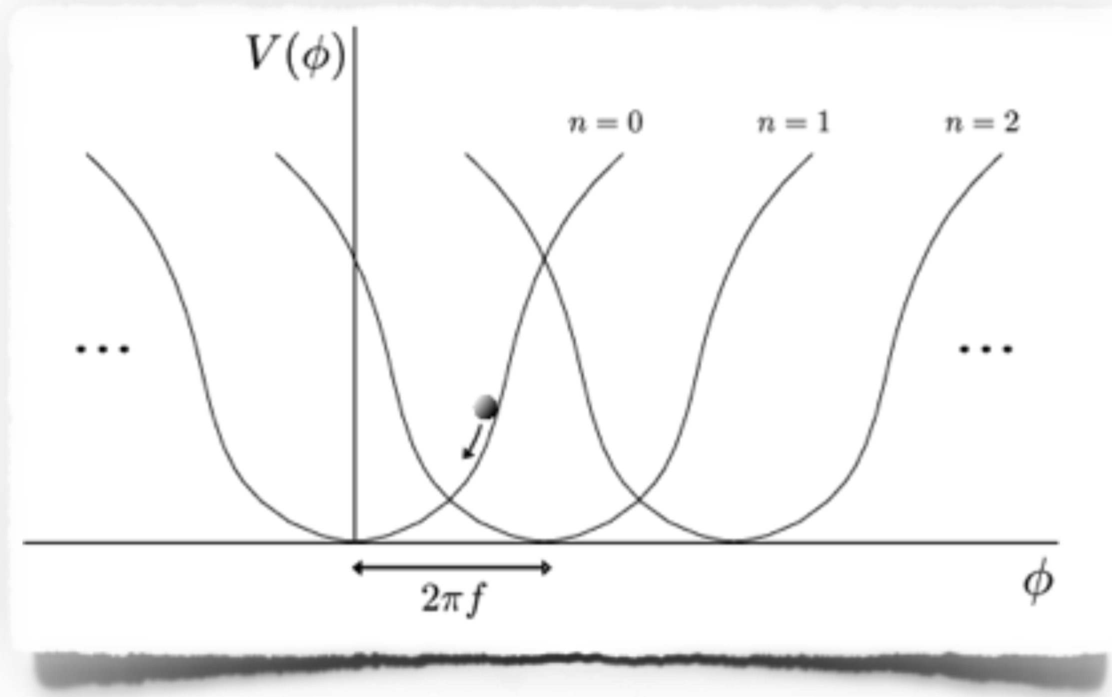
Axion Monodromy

Induce a non-periodic potential for an axion



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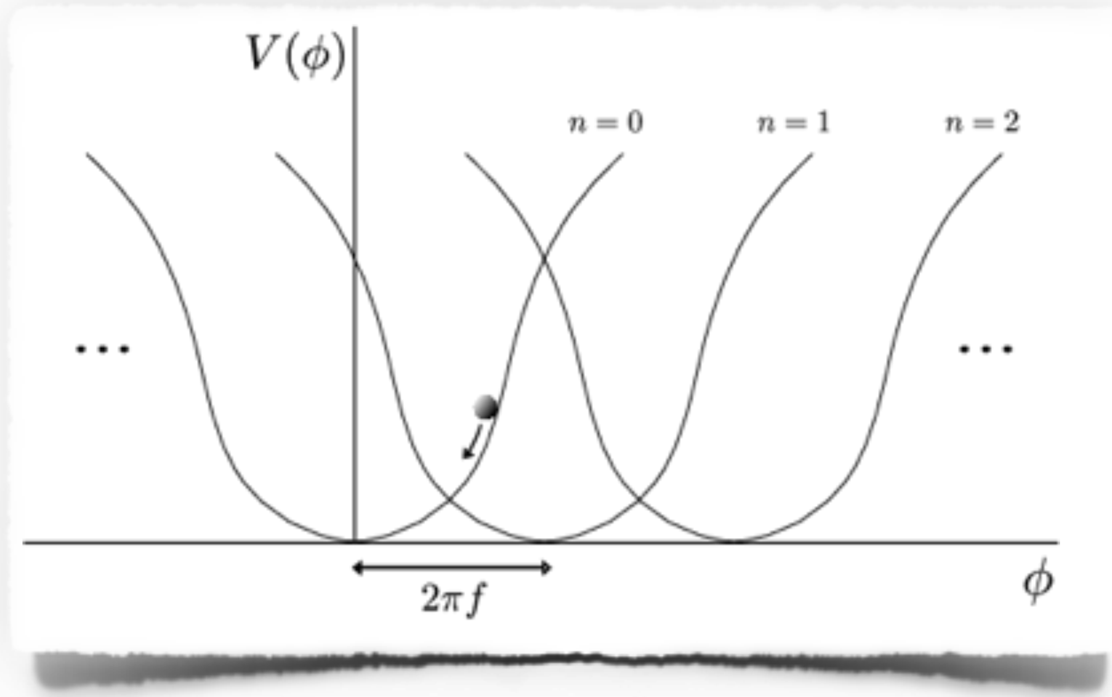

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4d Kaloper-Sorbo description:

Coupling the axion to a 3-form gauge field $F_4 = dC_3$

$$\mathcal{L} = -f^2 (d\phi)^2 - |F_4|^2 + mF_4\phi$$

Integrating out C_3

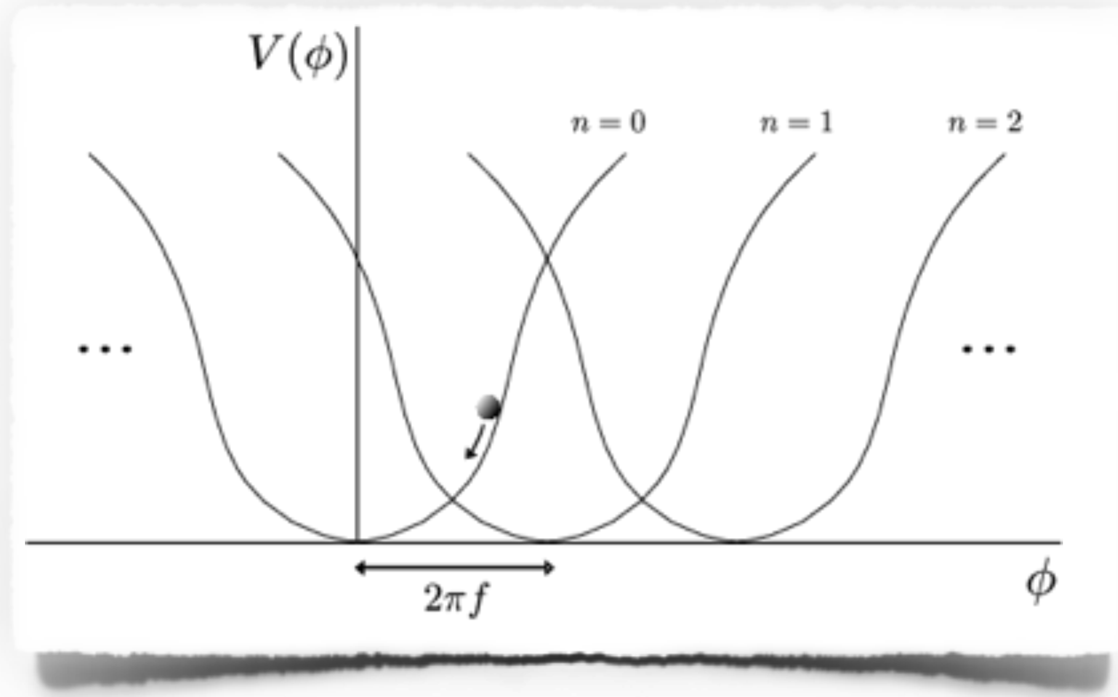
$$*F_4 = n + m\phi \longrightarrow V = \frac{1}{2}(n+m\phi)^2$$

[Dvali'05]
[Kaloper,Sorbo'09]
...

we get a multi-branched potential invariant under

$$\phi \to \phi + 2\pi f \quad , \quad n \to n - 2\pi m f$$

Axion Monodromy



Higher dimensional operators

✓ Potential protected by gauge invariance of the 3-form field

$$\delta V \sim \sum_n \left(\frac{F_4^2}{M_p^4}\right)^n \sim \sum_n \left(\frac{V_0}{M_p^4}\right)^n$$

[Kaloper,Sorbo,Lawrence]

Tunneling between branches

Mediated by membranes charged under C_3 that shift n

WGC $\longrightarrow$ membrane tension

✓ Tunneling negligible for inflation

[Franco et al/Brown et al/Hebecker et al.]
[Ibanez,Montero,Uranga,IV]

Axion Monodromy

Bottom-up

4d Kaloper-Sorbo description

Parametrically large field ranges are disfavoured, but the problems are not tied to the Planck mass.

No obstruction for large field inflation.

(No problem with WGC…)

Top-bottom

Technical difficulties related to backreaction

[McAllister et al] [Blumenhagen et al][Hebecker et al.] [Dudas,Wieck] [Buchmuller et al] [Marchesano et al.]

Problems with the Refined Swampland Conjecture

[Baume,Palti] [Klaewer,Palti]

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[Baume,Palti] [Klaewer,Palti]

A Kaloper-Sorbo coupling does not guarantee a transplanckian field range

What is missing in the Kaloper-Sorbo description?

Sugra generalisation of Kaloper-Sorbo

$$V = \sum_i Z_{ij}(s^a) F_4^i F_4^j + \sum_i F_4^i \rho_i(\phi^a) + V_{loc}(s^a) + \mathcal{O}(\cos\phi^a)$$

saxions axions

Example in string theory: [Bielleman,Ibanez,IV'15] [Marchesano et al.'16]

Flux-induced 4d scalar potential of Type IIA/B Calabi-Yau orientifolds.

- 4-forms and axions from higher RR and NSNS p-forms:

$$F_p = F_4 \wedge \omega_{p-4} + \langle F \rangle\, \omega_p \quad ; \quad \phi = \int_{\Sigma_p} C_p$$

- Discrete axion shift symmetry comes from large gauge transformations

All perturbative axion dependence comes from couplings to 4-forms, through shift invariant functions $\rho_i(\phi^a)$

Sugra generalisation of Kaloper-Sorbo

$$\boxed{V = \sum_i Z_{ij}(s^a) F_4^i F_4^j + \sum_i F_4^i \rho_i(\phi^a) + V_{loc}(s^a) + \mathcal{O}(\cos\phi^a)}$$

saxions axions

$$*F_4^i = Z^{ij}(s^a)\rho_j(\phi^a) \;\rightarrow\; V = Z^{ij}(s^a)\rho_i(\phi^a)\rho_j(\phi^a)$$

Outline:

- Clarify differences between KS and supergravity/string version
- Describe backreaction effects in terms of 4-forms
  - Type IIA closed string sector
  - Open string models

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I **Non-linear couplings** ➡ Generic scalar potentials

Kaloper-Sorbo: $\rho(\phi) = n + m\phi \longrightarrow$ mass term

In general: $\rho_i(\phi^a) \longrightarrow$ mass and interaction terms

ex. $\rho_i = e_i + k_{ijk}\phi^j q^k - \frac{m}{2} k_{ijk}\phi^j \phi^k$

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2 **Multiple 4-forms** → Higher order corrections

$$\delta V = \sum_n \Big(\prod_i (F_4^2)^i\Big)^n \longrightarrow$$ not as powers of V, but of the different $\rho_i(\phi^a)$

Discrete shift symmetry cannot be broken

Periodic corrections

$$\cancel{\left(\frac{\phi}{M_p}\right)^n} \qquad \left(\frac{\rho(\phi)}{M_p}\right)^n \checkmark$$

Sugra generalisation of Kaloper-Sorbo

$$V = \sum_i Z_{ij}(s^a) F_4^i F_4^j + \sum_i F_4^i \rho_i(\phi^a) + V_{loc}(s^a) + \mathcal{O}(\cos\phi^a)$$

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3 **Field-dependent metrics** → Backreaction effects

Minima of the saxions (during inflation):

$\langle s \rangle \propto \rho(\phi)$ ⟶ Modify scalar potential and kinetic term

Metric $Z_{ij}(s^a)$ related to field space metric of scalar manifold

Metrics of 4-forms in string theory are such that backreaction effects forbid transplanckian field ranges?

Back-reaction on the inflaton metric

Kinetic term of the inflaton: $K_{\phi\phi}(s)(\partial\phi)^2$

Minima of the saxions: $\langle s \rangle \propto \rho(\phi)$

$\rightarrow$ Backreaction $K_{\phi\phi}(s(\phi))$

s : saxion

ϕ : inflaton

If $K = -log(s)$; $S = s + i\phi$

$$\Delta\phi = \int K_{S\bar{S}}^{1/2} d\phi \simeq \int \frac{1}{s(\phi)} d\phi \sim \int \frac{1}{\rho(\phi)} d\phi \longrightarrow$$ Reduce field range

At best, $\rho(\phi) \propto \phi \rightarrow \Delta\phi \propto log(\phi)$ for large field

[Bumenhagen et al.'15]
[Baume,Palti'16]
[Klaewer,Palti'16]

Behaviour predicted by the Swampland Conjecture

[Oouri-Vafa et al.'06]

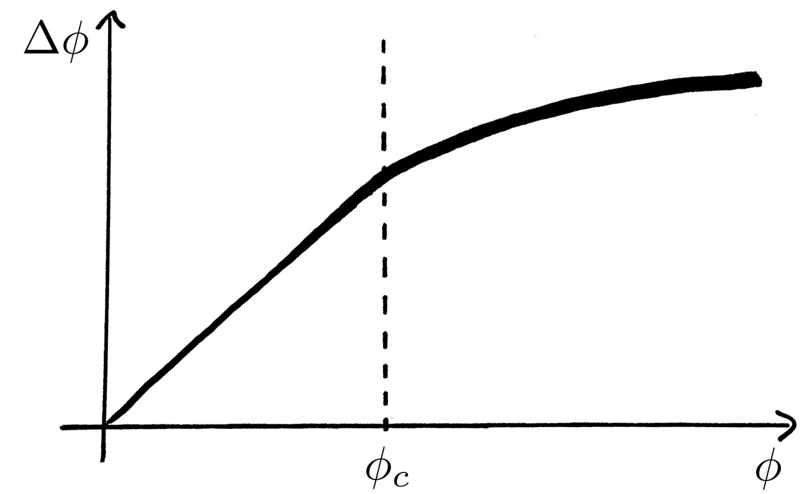
Back-reaction on the inflaton metric

How far can we delay backreaction? Logarithmic behaviour tied to M_p ?

$$\partial_s V = 0 \to s = s_0 + \delta s(\phi) \;\; ; \;\; \delta s(\phi) \simeq \lambda\phi$$

Critical value $\phi_c \, : \, \delta s(\phi_c) \approx s_0$

$$\phi_c \simeq s_0/\lambda$$



Effective field range before backreaction effects dominate:

$$\delta\phi \simeq \int_0^{\phi_c} K^{1/2}_{S\bar{S}}(s_0) d\phi \simeq \frac{\phi_c}{s_0} \sim \frac{1}{\lambda} \quad \text{in } M_p \text{ units}$$

If $\lambda \sim 1 \; (\phi_c \sim s_0) \longrightarrow$ Backreaction effects tied to Mp

IIA flux compactifications

4d scalar potential of IIA on orientifold flux CY compactifications:

Upon integrating all 3-forms out: $V = Z^{ij}(s^a)\rho_i(\phi^a)\rho_j(\phi^a)$

IIA flux compactifications

4d scalar potential of IIA on orientifold flux CY compactifications:

Upon integrating all 3-forms out:

$$V_{RR}+V_{NS}=\frac{e^{K_{cs}}}{s}\left[\frac{1}{2k}|\rho_0|^2+\frac{g_{ij}}{8k}\rho^i\rho^j+2kg_{ij}\tilde{\rho}^i\tilde{\rho}^j+k|\rho_m|^2+\frac{1}{k}c_{IJ}\rho_h^I\rho_h^J\right]$$

$$\rho_0=e_0+b^ie_i-\frac{m}{6}k_{ijk}b^ib^jb^k+k_{ijk}\frac{1}{2}q_ib^jb^k-h_0c_3^0-h_ic_3^i \quad \rightarrow F_4$$

$$\rho_i=e_i+k_{ijk}b^jq^k-\frac{m}{2}k_{ijk}b^jb^k \quad \rightarrow F_6$$

$$\tilde{\rho}_i=q_i-mb_i \quad \rightarrow F_8$$

$$\rho_m=m \quad \rightarrow F_{10}$$

Axions: b^i, c_3^0, c_3^i

Internal fluxes: e_0, e_i, q_i, m, h_I

Minimisation of the potential:

Minima of axions $\longrightarrow$ $\rho_0=0$ and

$$(I) \quad \tilde{\rho}^i=0$$

$$(II) \quad k_{ijl}\frac{g^{jk}}{8k}\rho_k+2kg_{il}\rho^m=0$$

Minima of saxions $\longrightarrow$ $s_0\sim\dfrac{\rho_i^{3/2}}{\rho_{h_0}\sqrt{\rho_m}}\,,\quad u_0\sim\dfrac{\rho_i^{3/2}}{\rho_{h_1}\sqrt{\rho_m}}\,,\quad t_0\sim\dfrac{\rho_i^{1/2}}{\sqrt{\rho_m}}$

IIA flux compactifications

Inflaton = RR axion: $\phi = c_3^0 \longrightarrow \rho_0 \neq 0$

$$K_{\phi\phi} = \frac{1}{s_0}$$

At large field: $s = \dfrac{\rho_0(\phi)}{h_0} \longrightarrow$ $\boxed{\Delta\phi \to log(\phi)}$

Critical value: $\rho_0 > t\rho_i \longrightarrow \phi_c = s_0 \longrightarrow$ $\boxed{\delta\phi \sim 1 \quad \text{in } M_p \text{ units}}$

$(\lambda \sim 1)$

Back-reaction effects tied to M_p

in agreement with [Baume,Palti]

(Same for Inflaton = NS axion)

Open string models

[Hebecker et al/Arends et al'14]
[Ibanez,Marchesano,I.V.'14]

Inflaton $\phi =$ open string field (D7 position modulus)

$$s = s_0 + \delta s(\phi) \;\; ; \quad \delta s(\phi) \simeq \lambda\phi \;\; \text{with} \;\; \lambda = \frac{m_\phi}{m_s}$$

➡ Saxion parametrising $K_{\phi\bar{\phi}}$ belongs to a different supermultiplet than ϕ

➡ Inflaton mass can be set to zero without destabilising the saxion

	s	ϕ
f	✓	✗
μ	✓	✓

and $\quad f \gg \mu$

Hierarchy between different sources of stabilisation (f, μ)

Open string models

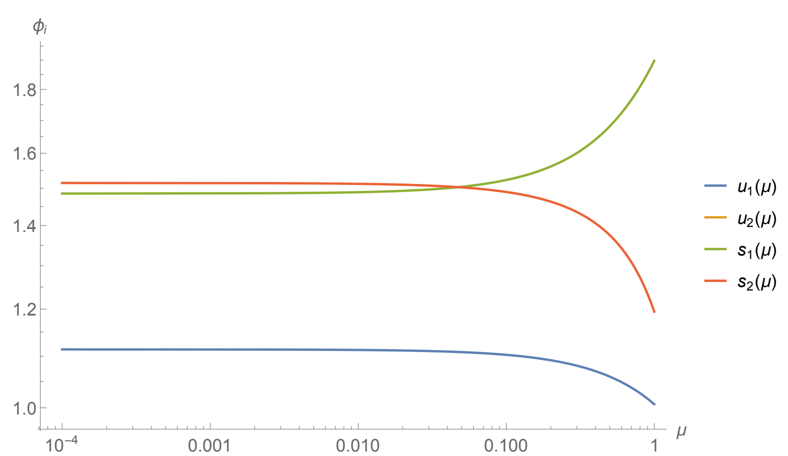
Higgs-otic inflation

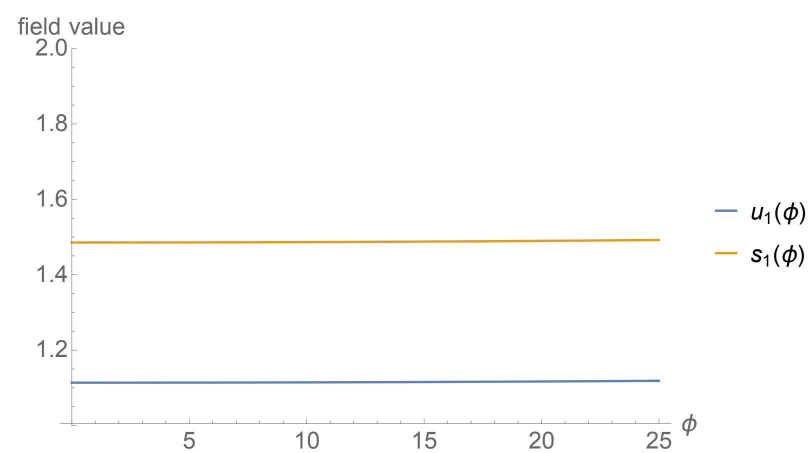
[Bielleman,Ibanez,Pedro,I.V.,Wieck'16]

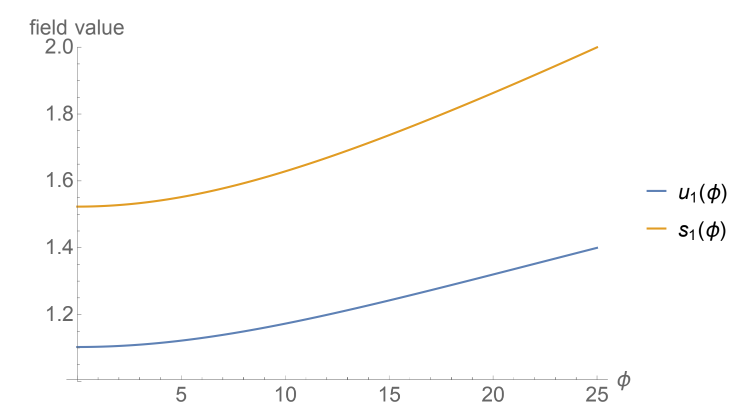
Inflaton: Position modulus of a D7-brane on a Type IIB orientifold flux background

$$K = -2\log\left[(U+\bar{U})\right] - \log\left[(U+\bar{U})(S+\bar{S}) - \frac{1}{2}(\Phi+\bar{\Phi})^2\right] - 3\log(T+\bar{T})$$

$$W = \mu\Phi^2 + W_0 + Ae^{-aT} \quad \text{with} \quad W_0 = e_0 + ie_1U + imU^3 + ih_0S + \mu SU + \bar{h}_0SU^3$$







Masses and vevs of u, s almost independent of μ

Critical value ϕ_c highly depends on μ

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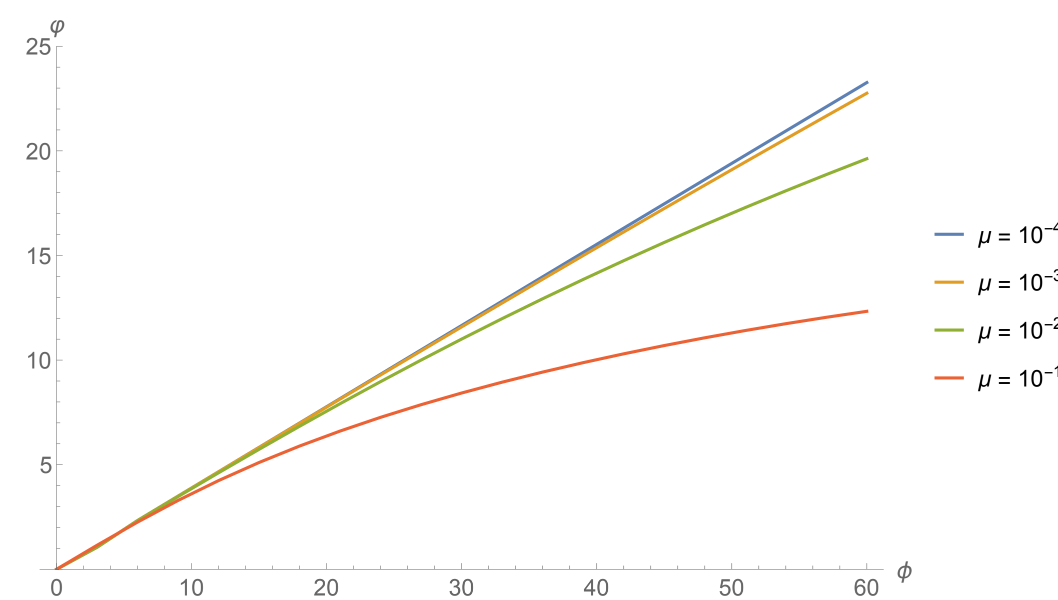
Therefore, $\phi_c \cancel{\sim} s_0$ but

$$\phi_c \sim s_0/\lambda \quad \text{with} \quad \lambda \sim \frac{m_\phi}{m_s} \sim \frac{\mu}{\text{fluxes}}$$

Field range before backreaction dominates

$$\delta\phi \sim 1/\lambda > 1 \quad \text{if} \quad \mu \ll \text{fluxes}$$

flux dependent!



Back-reaction effects not necessarily tied to M_p

Open string models

- Higgs-otic inflation is an example where the logarithmic behaviour can be pushed far away in field distance by tuning the fluxes

In general:

$$s = s_0 + \delta s(\phi) \;\; ; \quad \delta s(\phi) \simeq \lambda \phi \quad \text{with} \quad \lambda = \left(\frac{m_\phi}{m_s}\right)^p$$

$p = 0 \rightarrow$ IIA closed string sector, non-geometric IIB backgrounds…

$p = 1 \rightarrow$ Higgs-otic inflation (KKLT + D7's), non-geometric IIB with D7's…

(See Blumenhagen's talk)

Is this flux tuning possible?

Not for μ a flux integer…

[Blumenhagen,IV,Wolf] (to appear)

Support for the Refined Swampland Conjecture?

Caution! see also [Hebecker et al.'14] [Landete et al.'17]

Summary

✦ Axion monodromy models in string theory can be described in terms of a generalisation of Kaloper-Sorbo with:

- Coupling the 4-form to shift invariant functions
- Multiples 4-forms and axions.
- Non-canonical metrics for the 4-forms depending on the saxions.

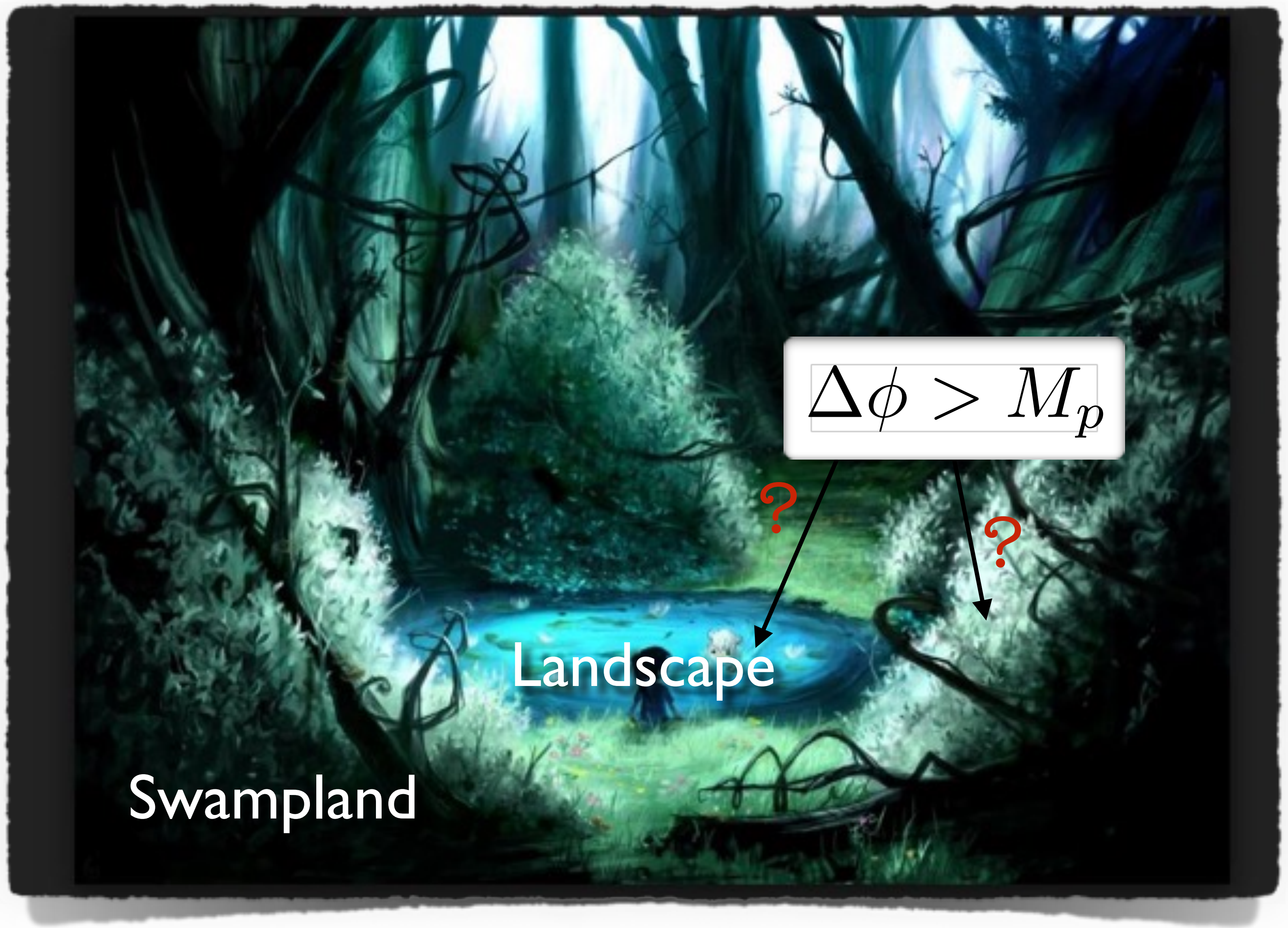
✦ The field dependent metrics give rise to back-reaction problems.

They can backreact on the Kahler metric of the inflaton leading to a logarithmic scaling of the field distance at large values.

Inflaton → Closed string sector IIA/B: $\delta\phi \sim M_p$

Inflaton → Open string sector: $\delta\phi$ flux-dependent

Thank you!



4-forms in IIA flux compactifications

4d scalar potential of IIA on orientifold flux CY compactifications:

$$V_{RR} = \frac{e^{K_{cs}}}{2s}\Big[\overbrace{-kF_4^0\wedge *F_4^0 + 2F_4^0\rho_0}^{F_4} - \overbrace{4kg_{ij} * F_4^i \wedge F_4^i + 2F_4^i\rho_i}^{F_6} - \overbrace{\frac{1}{4k}g_{ij}\tilde F_4^i \wedge *\tilde F_4^j + 2\tilde F_4^i\tilde\rho_j}^{F_8} + \overbrace{kF_4^m\rho_m}^{F_{10}}\Big]$$

$$V_{NS} = e^{K_{cs}}\frac{s^2}{k}c_{IJ}H_4^I\wedge *H_4^J$$

$$\rho_0 = e_0 + b^i e_i - \frac{m}{6}k_{ijk}b^ib^jb^k + k_{ijk}\frac{1}{2}q_ib^jb^k - h_0c_3^0 - h_ic_3^i$$

$$\rho_i = e_i + k_{ijk}b^jq^k - \frac{m}{2}k_{ijk}b^jb^k$$

$$\tilde\rho_i = q_i - mb_i$$

$$\rho_m = m$$

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$$V_{RR}+V_{NS} = \frac{e^{K_{cs}}}{s}\left[\frac{1}{2k}|\rho_0|^2 + \frac{g_{ij}}{8k}\rho^i\rho^j + 2kg_{ij}\tilde\rho^i\tilde\rho^j + k|\rho_m|^2 + \frac{1}{k}c_{IJ}\rho_h^I\rho_h^J\right]$$

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Minima of saxions $\longrightarrow$ $s_0 \sim \dfrac{\rho_i^{3/2}}{\rho_{h_0}\sqrt{\rho_m}}\,,\quad u_0 \sim \dfrac{\rho_i^{3/2}}{\rho_{h_1}\sqrt{\rho_m}}\,,\quad t_0 \sim \dfrac{\rho_i^{1/2}}{\sqrt{\rho_m}}$

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Are they possible in a consistent theory of quantum gravity?