On Type IIA Cosmology From Geometric Fluxes

Marco Zagermann
(Leibniz University Hannover)

Based on : 0812.3551 (Caviezel, Koerber, Körs, Lüst, Wrase, M.Z.)
0806.3458 (Caviezel, Koerber, Körs, Lüst, Tsimpis, M.Z.)
(0812.3886 (Flauger, Paban, Robbins, Wrase))
+ Work in progress

Corfu, September 11, 2009

An important problem in string phenomenology:

Moduli stabilization

$\Rightarrow \mathbf{V}(\varphi^{\mathbf{i}})$

An important problem in string phenomenology:

Moduli stabilization

$\Rightarrow \mathbf{V}(\varphi^{\mathbf{i}})$

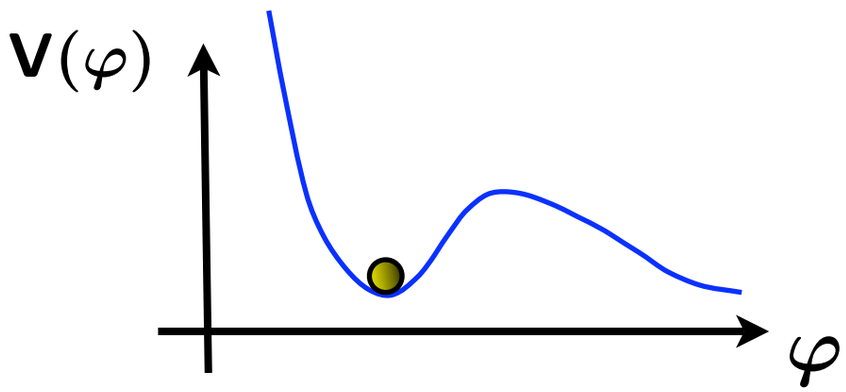
Particularly interesting:

$\mathbf{V}(\varphi^{\mathbf{i}}) > \mathbf{0}$

Positive potential energy for:

(i) de Sitter vacua

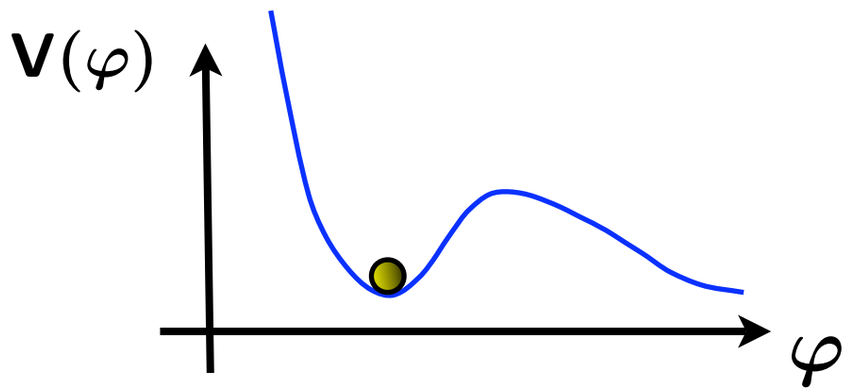
($\Lambda>0 \Rightarrow$ Today's accelerated expansion)



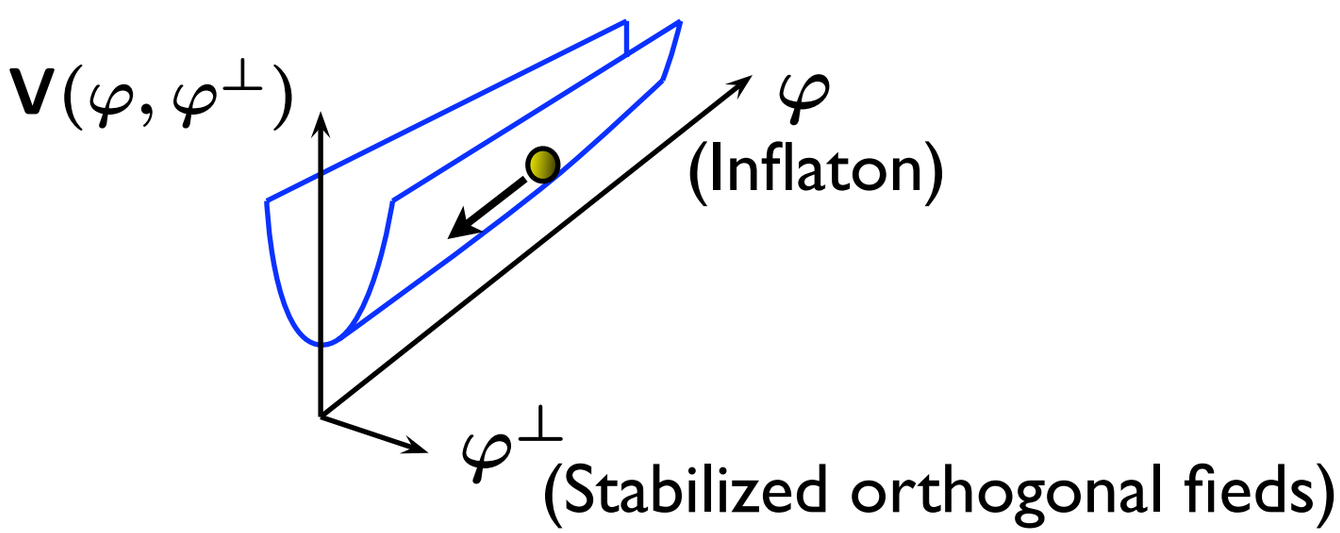
Positive potential energy for:

(i) de Sitter vacua

(Λ>0 $\Rightarrow$ Today's accelerated expansion)



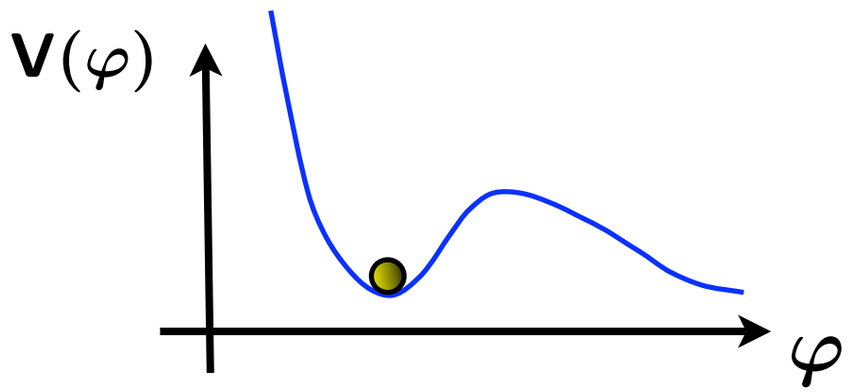
(ii) Slow-roll inflation



Positive potential energy for:

(i) de Sitter vacua

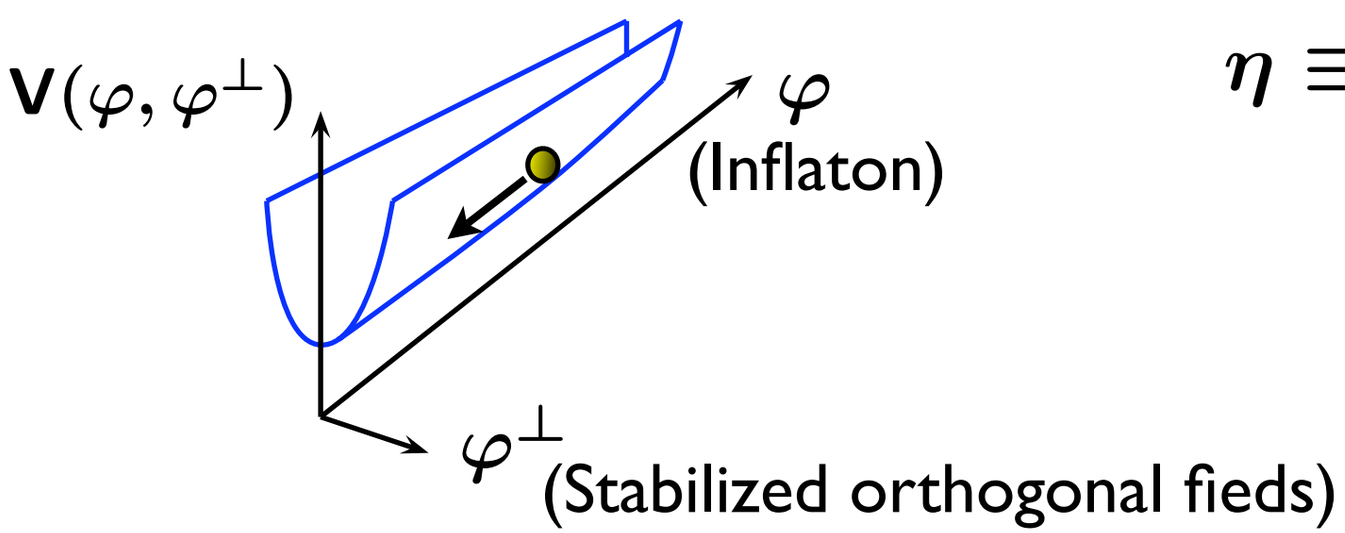
($\Lambda>0 \Rightarrow$ Today's accelerated expansion)



(ii) Slow-roll inflation

$$\epsilon \equiv \frac{1}{2}\, g^{ij}\, \frac{(\partial_{\varphi^i} V)\,(\partial_{\varphi^j} V)}{V^2}$$

$$\eta \equiv \text{Min. eig.val.} \left(\frac{\nabla^i \partial_j V}{V} \right)$$

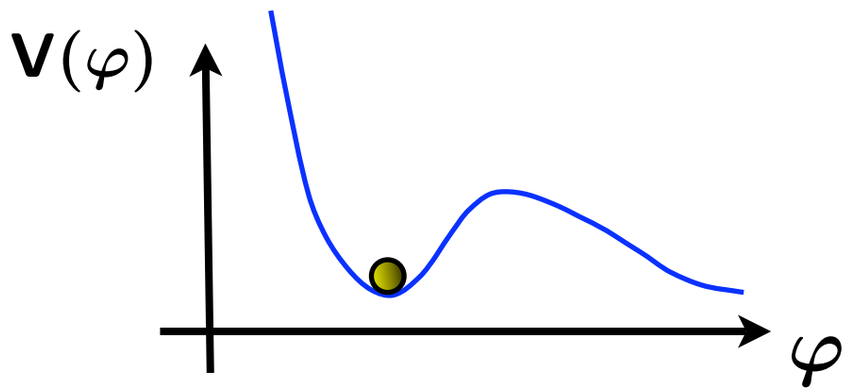


$$\boxed{\epsilon,\, |\eta| \ll 1}$$

Positive potential energy for:

(i) de Sitter vacua

(Λ>0 $\Rightarrow$ Today's accelerated expansion)

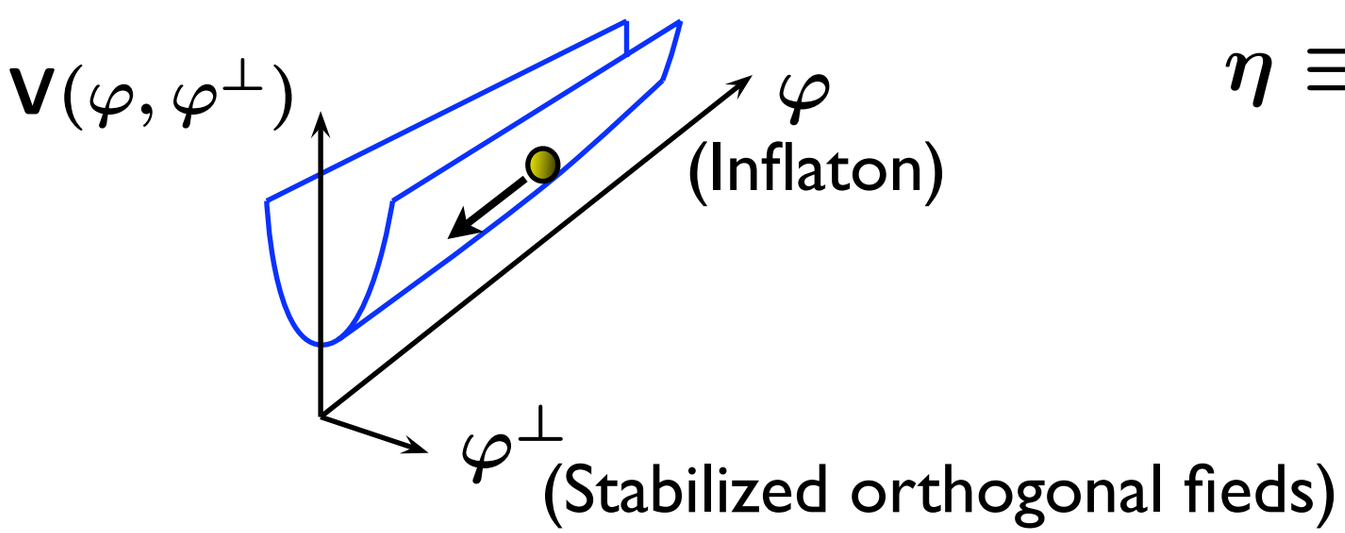


$$\epsilon = 0, \quad \eta > 0$$

(ii) Slow-roll inflation

$$\epsilon \equiv \frac{1}{2}\, g^{ij}\, \frac{(\partial_{\varphi^i} V)\,(\partial_{\varphi^j} V)}{V^2}$$

$$\eta \equiv \text{Min. eig.val.} \left(\frac{\nabla^i \partial_j V}{V} \right)$$



$$\epsilon, |\eta| \ll 1$$

A general problem:

Typical scalar potentials receive many contributions and corrections

A general problem:

Typical scalar potentials receive many contributions and corrections

Often:

Subtle interplay of

classical and quantum effects

↓ ↓

E.g. KKLT; LARGE Volume; KKLMMT...

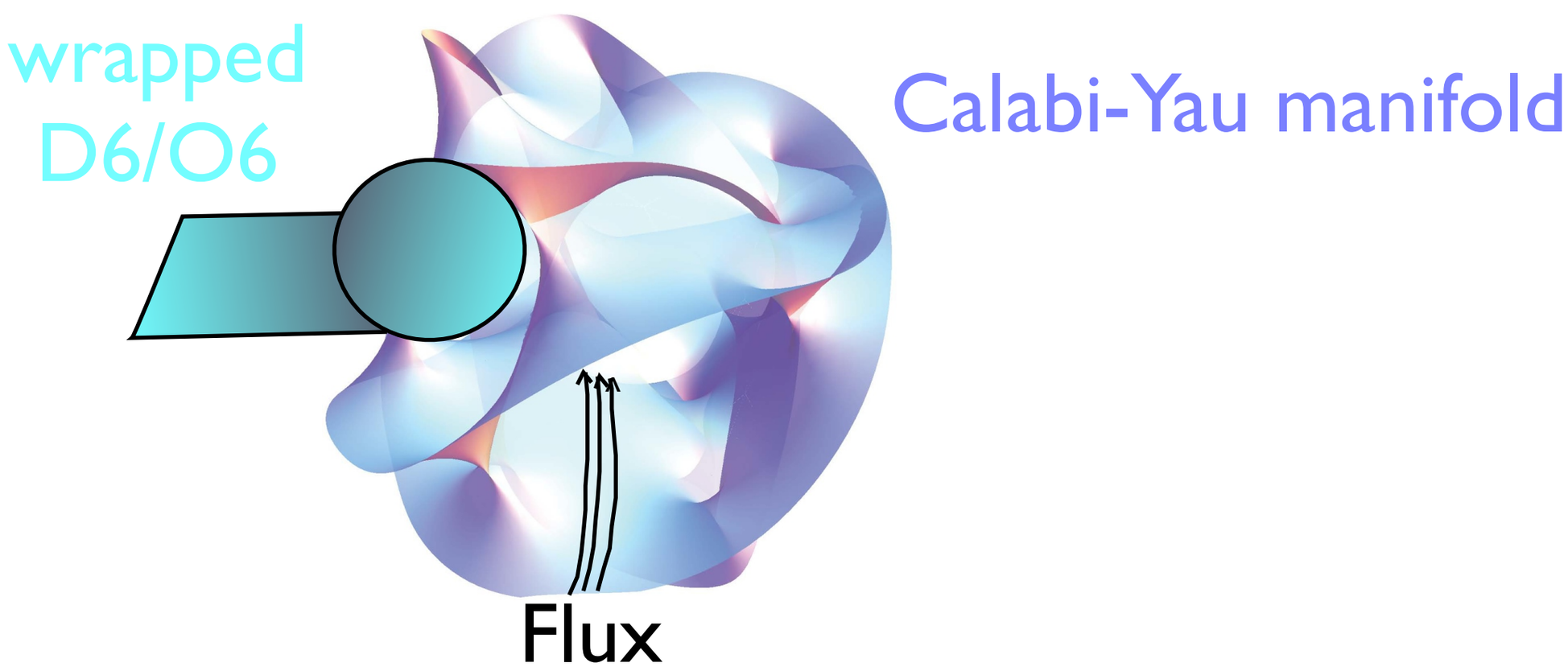
Cf. also Ramos-Sanchez' talk

Easy Hard to compute precisely

A nice laboratory:

Type IIA on Calabi-Yau spaces with

- Magnetic fluxes of p-form field strengths
- D6-branes/O6-planes



Observation:

All geometric moduli can be stabilized at tree-level

Grimm, Louis (2004); Kachru, Kashani-Poor (2004)

Observation:

All geometric moduli can be stabilized at tree-level

Grimm, Louis (2004); Kachru, Kashani-Poor (2004)

In special cases:

- All moduli stabilized
- Parameterically controlled classical regime

$\Rightarrow$ Quantum corrections small

Derendinger, Kounnas, Petropoulos, Zwirner (2004, 2005)
Villadoro, Zwirner (2005)
de Wolfe, Giryavets, Kachru, Taylor (2005)

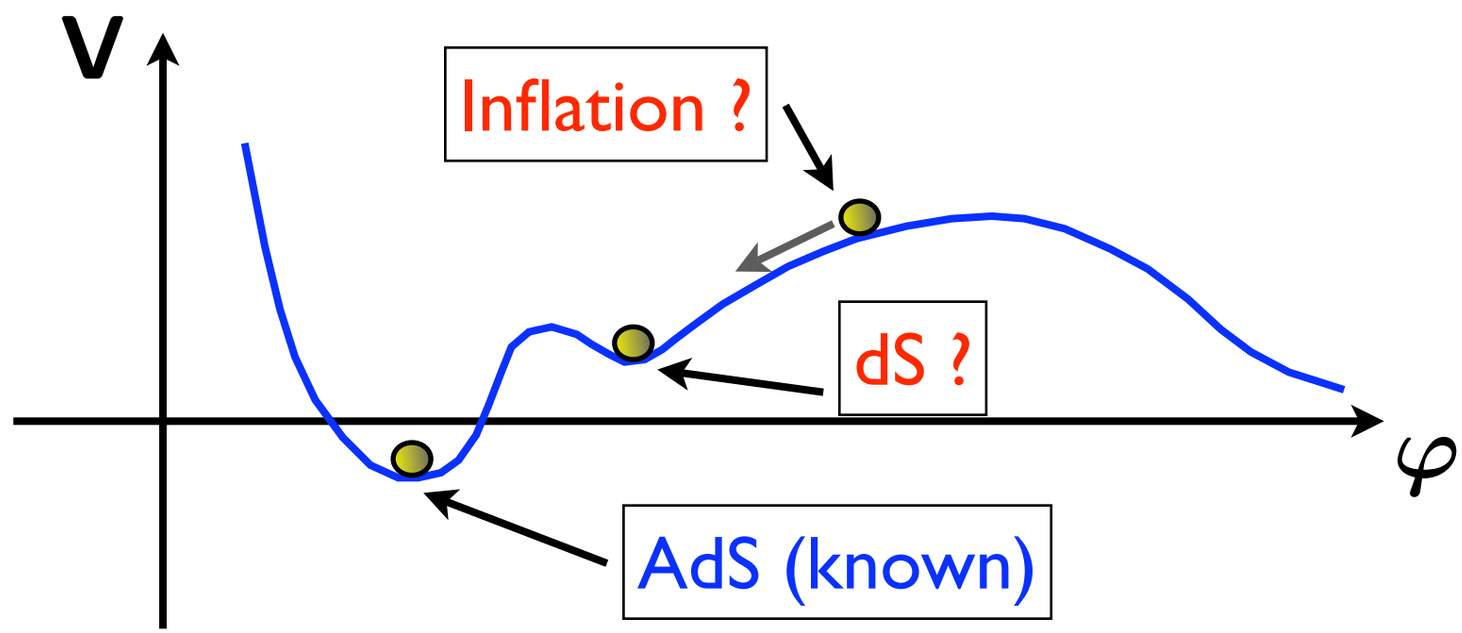
Unfortunately...

All these stabilized vacua have

$\Lambda<0$ ($\Rightarrow$AdS)

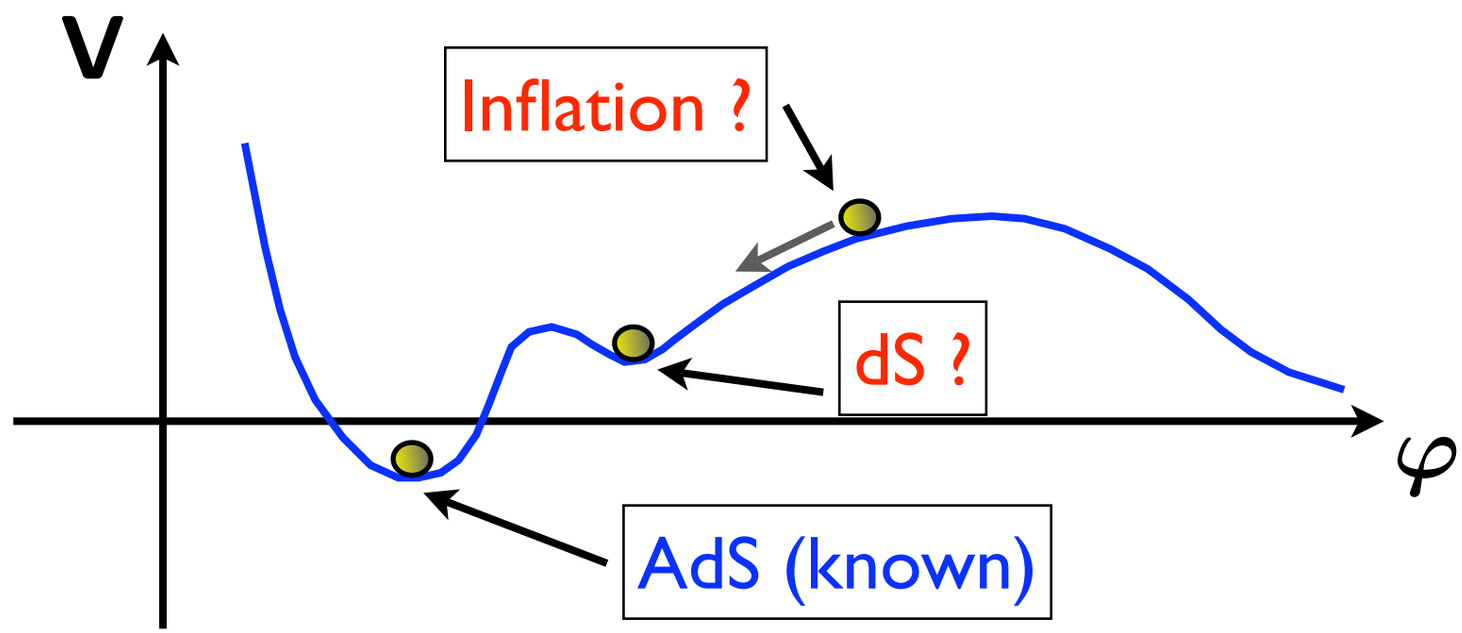
Two possibilities:

(i) Search for dS/inflation away from AdS vacuum

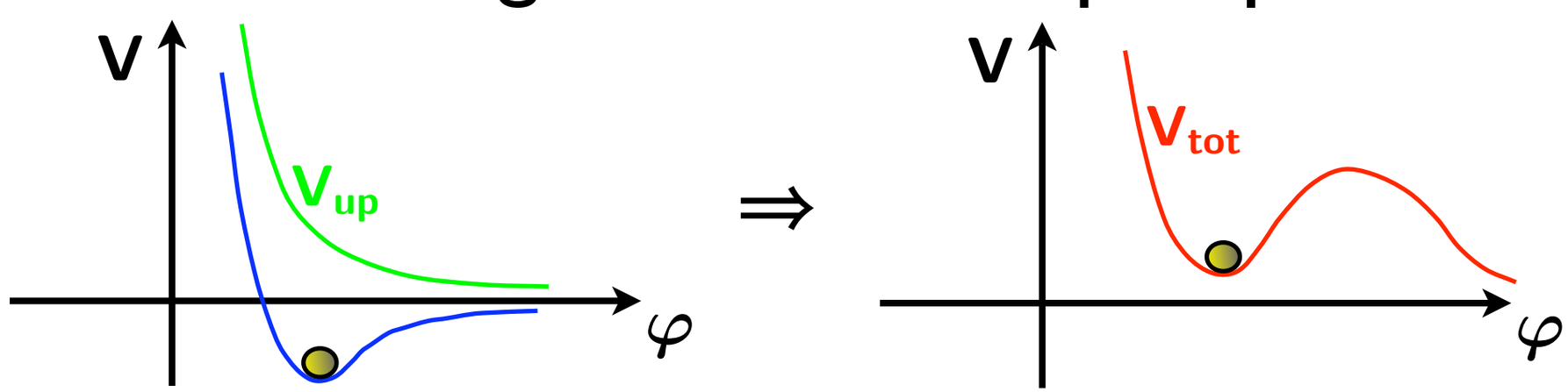


Two possibilities:

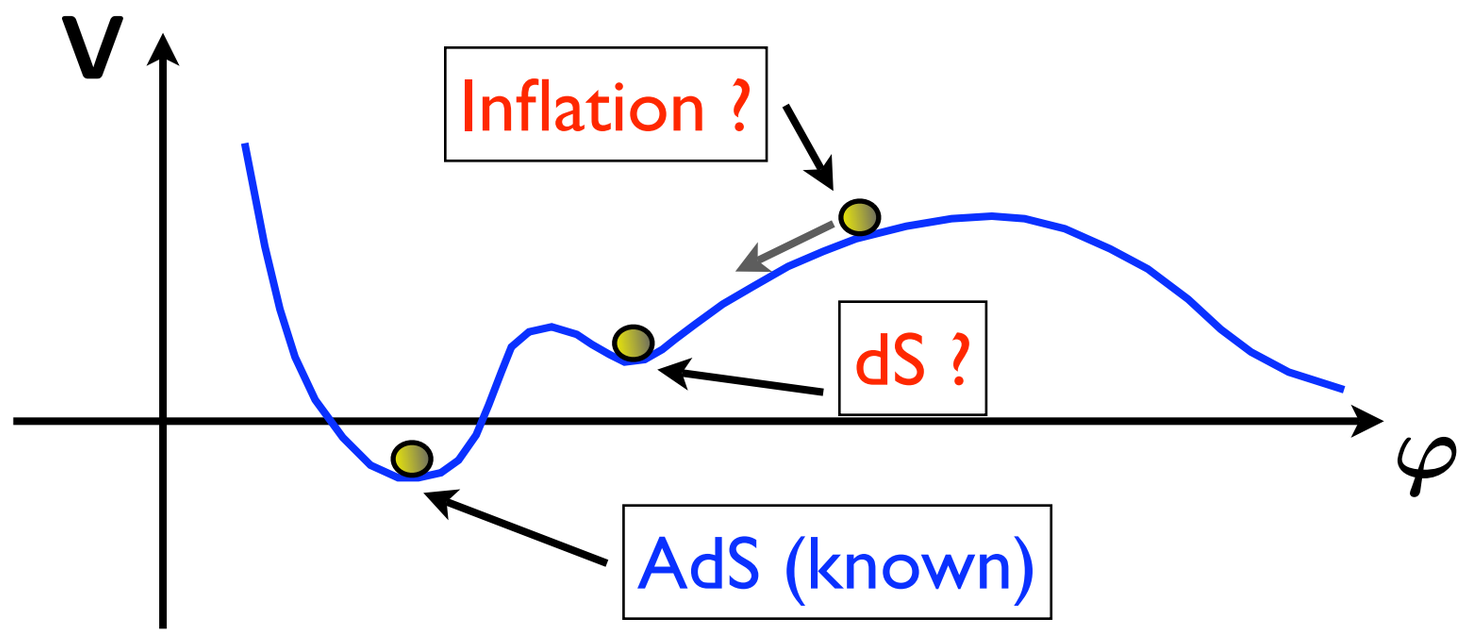
(i) Search for dS/inflation away from AdS vacuum



(ii) Add additional ingredients ⇒ "Uplift potentials"



(i) dS or inflation away from AdS vacuum?



(i) dS or inflation away from AdS vacuum?

No-go theorem:

Classical IIA compactifications with

- $\mathcal{M}^{(6)}$ = Calabi-Yau (→Ricci-flatness)
- O6/D6 sources
- p-form fluxes (incl. Romans' mass)

⇒No de Sitter vacua and no slow-roll inflation !

Hertzberg, Kachru, Taylor, Tegmark (2007)

Note: Due to the O6-planes (→ negative tension), this goes beyond no-go theorems by

Gibbons (1985)
de Wit, Smit, Hari Dass (1987)
Maldacena-Nuñez (2000)

Cf. also Wesley, Steinhardt (2008)
Townsend, Wohlfarth (2003)

Sketch of proof:

Consider scaling of potential w.r.t.

$$\rho \equiv (\mathbf{Vol})^{1/3}$$

$$\tau \equiv \mathbf{e}^{-\phi}\sqrt{\mathbf{Vol}} \qquad (\phi = \text{10D Dilaton})$$

Sketch of proof:

Consider scaling of potential w.r.t.

$$\rho \equiv (\mathbf{Vol})^{1/3}$$

$$\tau \equiv \mathbf{e}^{-\phi}\sqrt{\mathbf{Vol}} \qquad (\phi = \text{10D Dilaton})$$

$$\mathbf{V}(\rho,\tau,\ldots) = \underbrace{\mathbf{V}_3}_{\propto\, \rho^{-3}\tau^{-2}} \;+\; \sum_{\mathbf{p}=0,2,4,6} \underbrace{\mathbf{V}_\mathbf{p}}_{\propto\, \rho^{3-\mathbf{p}}\tau^{-4}} \;+\; \underbrace{\mathbf{V}_{\mathbf{O6/D6}}}_{\propto\, \pm\tau^{-3}}$$

$\mathbf{H}_3$ $\mathbf{F}_\mathbf{p}$

$$\Rightarrow \quad \mathbf{DV} \equiv (-\rho\partial_\rho - 3\tau\partial_\tau)\mathbf{V} \geq 9\mathbf{V}$$

$$\mathbf{DV} \equiv (-\rho\partial_\rho - 3\tau\partial_\tau)\mathbf{V} \geq 9\mathbf{V}$$

$$\epsilon = \mathbf{V}^{-2}\left[\frac{(\mathbf{DV})^2}{39} + (\textbf{positive})\right]$$

$$\mathbf{DV} \equiv (-\rho\partial_\rho - 3\tau\partial_\tau)\mathbf{V} \geq 9\mathbf{V}$$

$$\epsilon = \mathbf{V}^{-2}\left[\frac{(\mathbf{DV})^2}{39} + (\textbf{positive})\right]$$

$\Rightarrow$ $\boxed{\epsilon \geq \frac{27}{13}}$ whenever $\boxed{\mathbf{V} > 0}$ $\Rightarrow$

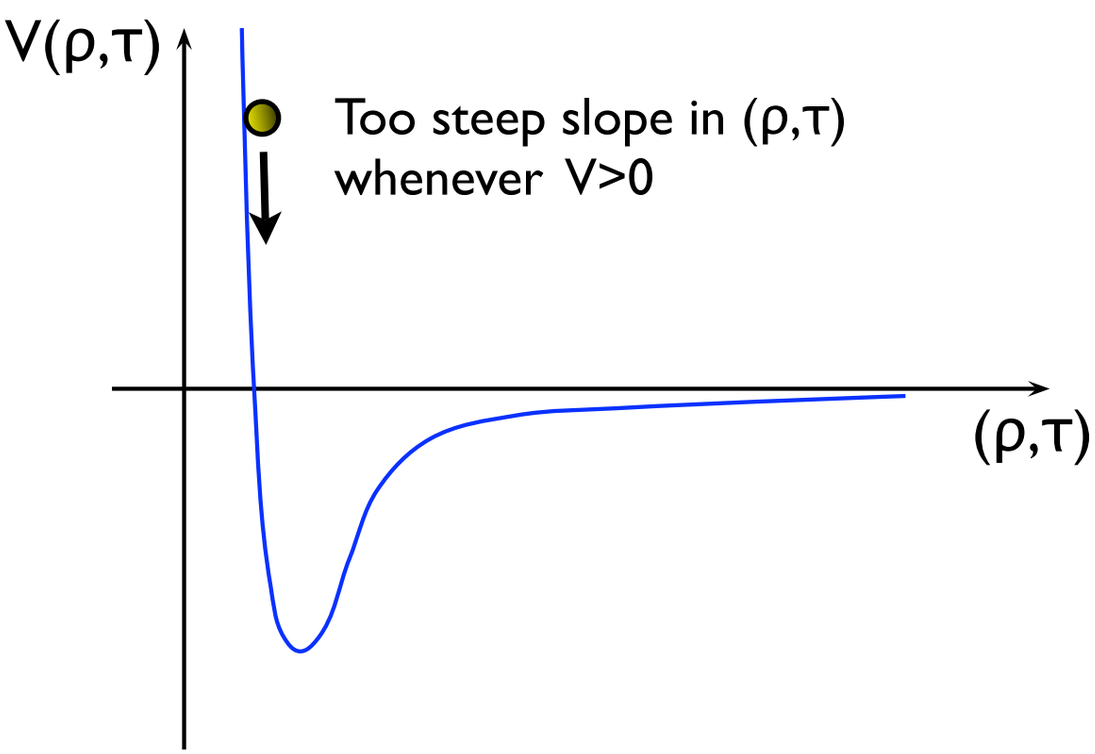
No inflation

No de Sitter

$$\mathrm{DV} \equiv (-\rho\partial_\rho - 3\tau\partial_\tau)\mathrm{V} \geq 9\mathrm{V}$$

$$\epsilon = \mathrm{V}^{-2}\left[\frac{(\mathrm{DV})^2}{39} + (\text{positive})\right]$$

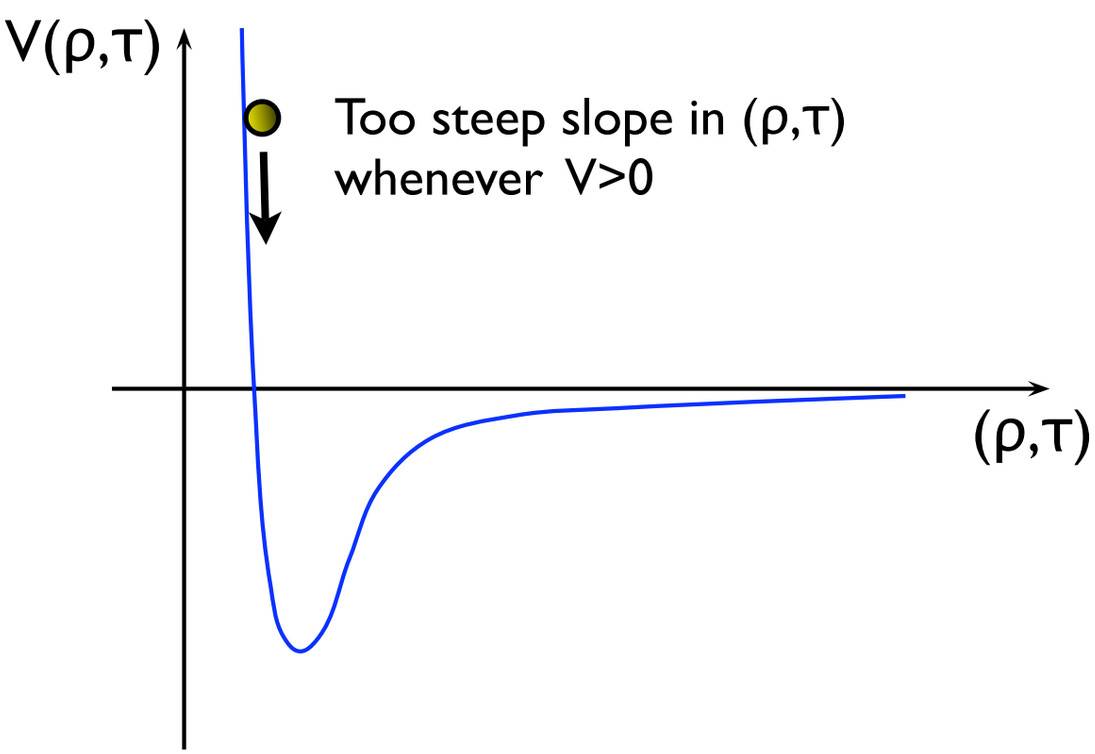
$\Rightarrow$ $\boxed{\epsilon \geq \frac{27}{13}}$ whenever $\boxed{\mathrm{V} > 0}$ $\Rightarrow$ No inflation No de Sitter

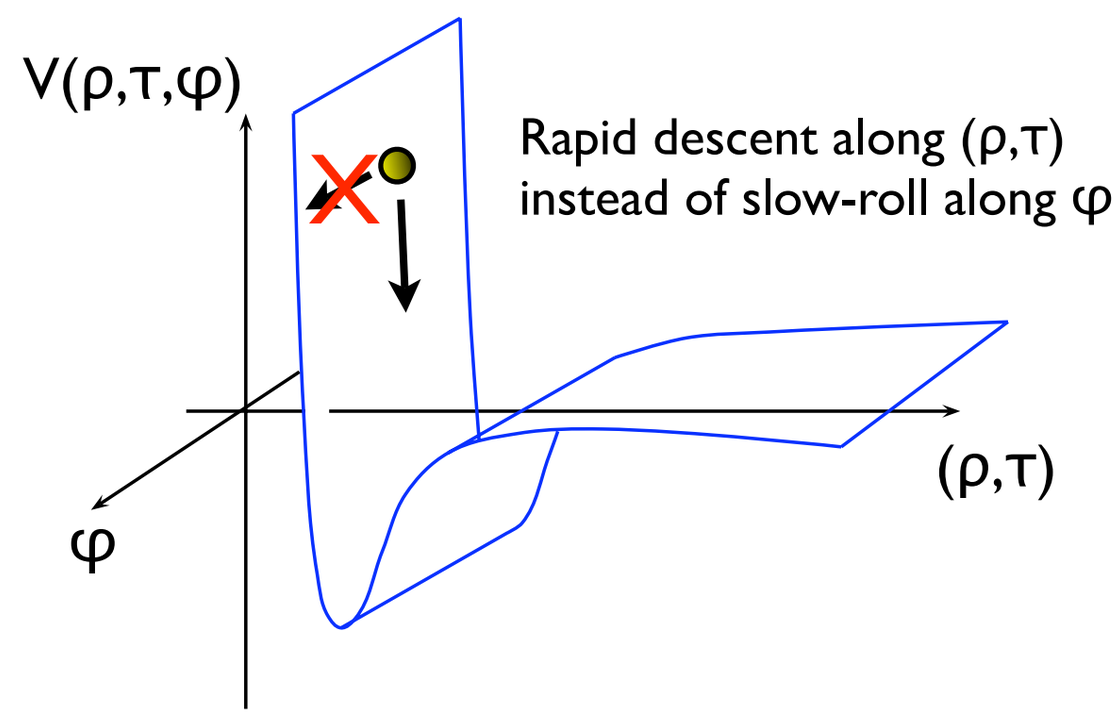


$$\mathrm{DV} \equiv (-\rho\partial_\rho - 3\tau\partial_\tau)\mathrm{V} \geq 9\mathrm{V}$$

$$\epsilon = \mathrm{V}^{-2}\left[\frac{(\mathrm{DV})^2}{39} + (\text{positive})\right]$$

$\Rightarrow$ $\boxed{\epsilon \geq \frac{27}{13}}$ whenever $\boxed{\mathrm{V} > 0}$ $\Rightarrow$ $\boxed{\text{No inflation} \quad \text{No de Sitter}}$





Possible caveats:

- Quantum corrections

  E.g. Saueressig, Theis, Vandoren (2005); Palti, Tasinato, Ward (2008)

- Additional classical ingredients
  - "Geometric fluxes" ("Torsion")
    (= geometric twisting away from CY $\Rightarrow R_{mn} \neq 0$)
  - O4-planes
  - D8-branes
  - NS5-branes
  - KK5-monopoles
  - "Nongeometric fluxes"

    ⋮

Silverstein (2007):

For classical de Sitter vacua add, e.g.:

- Geometric fluxes
  (Particular twisted torus)
- KK5-monopoles
- Fractional Chern-Simons invariants

Some issues to keep in mind:

- High SUSY breaking scale
- No large mass gap to KK modes
- Tadpole cancellation?
- Backreaction under control?

What is the minimal controllable setup?

What is the minimal controllable setup?

Best understood extra ingredient:

Geometric fluxes

$\Rightarrow$ Are they sufficient ?

Three complementary works:

(i) Haque, Shiu, Underwood, Van Riet (2008)

$$\mathcal{M}^{(6)} = (\mathrm{Nil}_3 \times \mathrm{Nil}_3')/\mathcal{O}$$

(ii) Caviezel, Koerber, Körs, Lüst, Wrase, M.Z. (2008)

$\mathcal{M}^{(6)}$ = Cosets with SU(3)-structure

(iii) Flauger, Paban, Robbins, Wrase (2008)

$\mathcal{M}^{(6)}$ = More general twisted tori

Three complementary works:

(i) Haque, Shiu, Underwood, Van Riet (2008)

$$\mathcal{M}^{(6)} = (\mathrm{Nil}_3 \times \mathrm{Nil}_3')/\mathcal{O}$$

(ii) Caviezel, Koerber, Körs, Lüst, Wrase, M.Z. (2008)

$\mathcal{M}^{(6)}$ = Cosets with SU(3)-structure ← This talk

(iii) Flauger, Paban, Robbins, Wrase (2008)

$\mathcal{M}^{(6)}$ = More general twisted tori

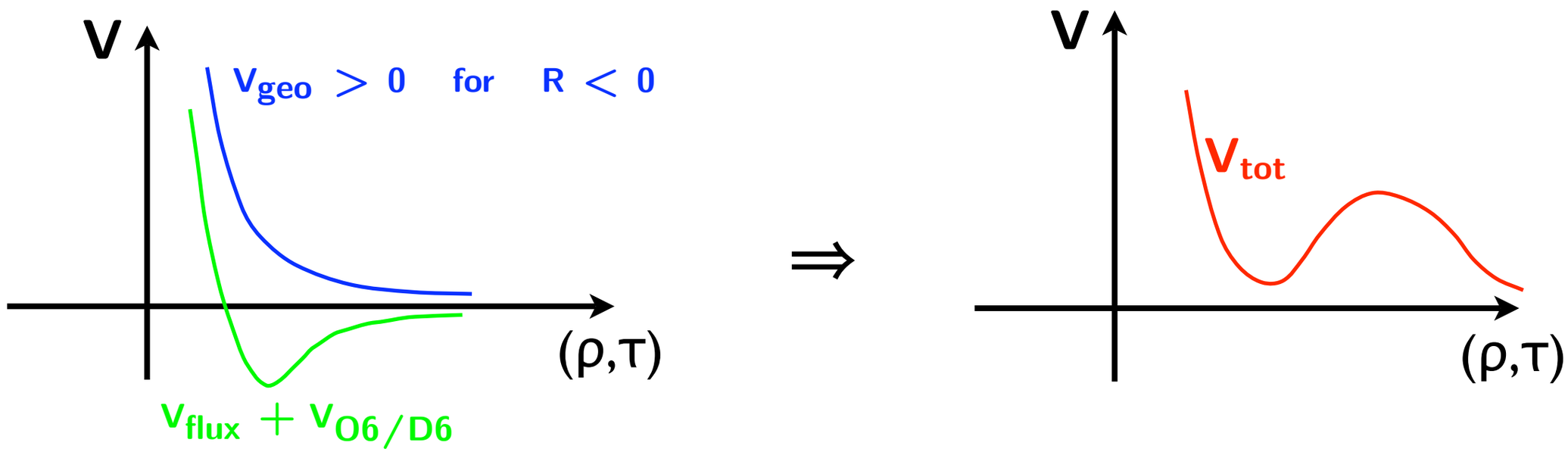
Geometric fluxes

$$\mathbf{V}_{\mathbf{geo}} \propto -\mathbf{R} \propto \rho^{-1}\tau^{-2}$$

Geometric fluxes

$$V_{geo} \propto -R \propto \rho^{-1}\tau^{-2}$$

⇒ Effective uplift term for R<0

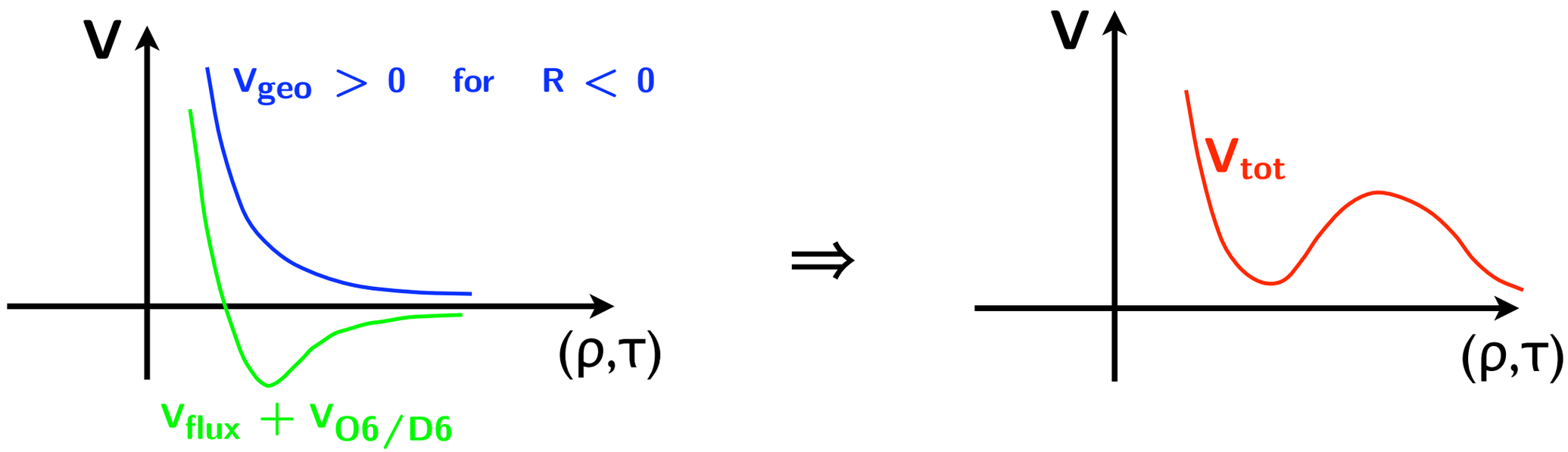


⇒ May help to remove steep fall-off in (ρ,τ)

Geometric fluxes

$$V_{geo} \propto -R \propto \rho^{-1}\tau^{-2}$$

⇒ Effective uplift term for R<0



⇒ May help to remove steep fall-off in (ρ,τ)

But: Are all orthogonal field directions also ok?

$\Rightarrow$ Need a setup in which

$$\mathbf{V} = \mathbf{V}(\rho, \tau, \varphi^{\perp})$$

is well understood

A well-controlled setup:

Caviezel, Koerber, Körs, Lüst, Tsimpis, M.Z. (2008)

cf. also House, Palti (2005)

$\mathcal{M}^{(6)}$ = Coset space G/H with (G-invariant) SU(3)-structure (+ orientifolding)

A well-controlled setup:

Caviezel, Koerber, Körs, Lüst, Tsimpis, M.Z. (2008)

cf. also House, Palti (2005)

$\mathcal{M}^{(6)}$ = Coset space G/H with (G-invariant) SU(3)-structure (+ orientifolding)

SU(3)-structure:

$\Rightarrow$ $\mathcal{M}^{(6)}$ admits globally well-defined spinor η

$\Rightarrow$ 4D, N=1 supergravity action

$\Rightarrow$ For $\nabla\eta \neq 0$: No CY $\Rightarrow$ $R_{mn} \neq 0$ $\Rightarrow$ $V_{geo} \neq 0$

Cf. Tsimpis' talk

A well-controlled setup:

Caviezel, Koerber, Körs, Lüst, Tsimpis, M.Z. (2008)

cf. also House, Palti (2005)

$\mathcal{M}^{(6)}$ = Coset space G/H with (G-invariant) SU(3)-structure (+ orientifolding)

SU(3)-structure:

$\Rightarrow$ $\mathcal{M}^{(6)}$ admits globally well-defined spinor η

$\Rightarrow$ 4D, N=1 supergravity action

$\Rightarrow$ For $\nabla\eta \neq 0$: No CY $\Rightarrow$ $R_{mn} \neq 0$ $\Rightarrow$ $V_{geo} \neq 0$

Early work: Gurrieri, Louis, Micu, Waldram;
Dall'Agata, Prezas; Lüst, Tsimpis; Behrndt, Cvetič;
Gauntlett, Martelli, Waldram;
Graña, Minasian, Petrini, Tomasiello;...

A well-controlled setup:

Caviezel, Koerber, Körs, Lüst, Tsimpis, M.Z. (2008)

cf. also House, Palti (2005)

$\mathcal{M}^{(6)}$ = Coset space G/H with (G-invariant) SU(3)-structure (+ orientifolding)

SU(3)-structure:

$\Rightarrow \mathcal{M}^{(6)}$ admits globally well-defined spinor η

$\Rightarrow$ 4D, N=1 supergravity action

$\Rightarrow$ For $\nabla\eta \neq 0$: No CY $\Rightarrow R_{mn} \neq 0 \Rightarrow V_{geo} \neq 0$

Problem:

$J_{mn} \equiv i\eta_+^\dagger \gamma_{mn} \eta_+ \qquad \Omega_{mnp} \equiv \eta_-^\dagger \gamma_{mnp} \eta_+$

$\nabla\eta \neq 0 \Rightarrow dJ, d\Omega \neq 0$ $\Rightarrow$ Expansion basis, moduli?

A well-controlled setup:

Caviezel, Koerber, Körs, Lüst, Tsimpis, M.Z. (2008)

cf. also House, Palti (2005)

$\mathcal{M}^{(6)}$ = Coset space G/H with (G-invariant) SU(3)-structure (+ orientifolding)

SU(3)-structure:

$\Rightarrow$ $\mathcal{M}^{(6)}$ admits globally well-defined spinor η

$\Rightarrow$ 4D, N=1 supergravity action

$\Rightarrow$ For $\nabla\eta \neq 0$: No CY $\Rightarrow$ $R_{mn} \neq 0$ $\Rightarrow$ $V_{geo} \neq 0$

Coset space structure:

$\Rightarrow$ Natural expansion basis: G-invariant forms

$\Rightarrow$ Explicit 4D action (consistent truncation)

Cassani, Kashani-Poor (2009)

Restriction to semisimple and Abelian group factors

$\Rightarrow$ **7 Models:**

Koerber, Lüst, Tsimpis (2008)

$$\frac{G_2}{SU(3)}, \quad \frac{Sp(2)}{S(U(2)\times U(1))}, \quad \frac{SU(3)}{U(1)\times U(1)}, \quad \frac{SU(3)\times U(1)}{SU(2)}, \quad \frac{SU(2)^2}{U(1)} \times U(1)$$

$$SU(2) \times U(1)^3, \quad SU(2) \times SU(2)$$

Restriction to semisimple and Abelian group factors

$\Rightarrow$ **7 Models:** Koerber, Lüst, Tsimpis (2008)

$$\frac{G_2}{SU(3)}, \quad \frac{Sp(2)}{S(U(2)\times U(1))}, \quad \frac{SU(3)}{U(1)\times U(1)}, \quad \frac{SU(3)\times U(1)}{SU(2)}, \quad \frac{SU(2)^2}{U(1)} \times U(1)$$

$$SU(2) \times U(1)^3, \quad SU(2) \times SU(2)$$

R < 0 possible $\Rightarrow$ Evade old no-go!

$\Rightarrow$ de Sitter or inflation?

Or are there new no-go's?

A refined no-go theorem

Cf. Flauger, Paban, Robbins, Wrase (2008)

<u>Old no-go:</u> $\mathbf{V}_{\mathbf{geo}} = \mathbf{0}, \qquad \mathbf{V} = \mathbf{V}(\tau, \rho, \ldots)$

$\Rightarrow \varepsilon \geq 27/13$

A refined no-go theorem

Cf. Flauger, Paban, Robbins, Wrase (2008)

<u>Old no-go:</u> $\mathbf{V}_{\mathbf{geo}} = \mathbf{0}, \qquad \mathbf{V} = \mathbf{V}(\tau, \rho, \ldots)$

$\Rightarrow \varepsilon \geq 27/13$

<u>Refined no-go:</u> $\mathbf{V}_{\mathbf{geo}} \neq \mathbf{0}, \qquad \mathbf{V} = \mathbf{V}(\tau, \sigma, \ldots)$

Violates old no-go

Different Kähler modulus

A refined no-go theorem

Cf. Flauger, Paban, Robbins, Wrase (2008)

<u>Old no-go:</u> $\mathbf{V_{geo} = 0}, \qquad \mathbf{V = V}(\tau, \rho, \ldots)$

$\Rightarrow \varepsilon \geq 27/13$

<u>Refined no-go:</u> $\mathbf{V_{geo} \neq 0}, \qquad \mathbf{V = V}(\tau, \sigma, \ldots)$

Violates old no-go

Different Kähler modulus

If:

(i) $\kappa_{\mathbf{ijk}} = \kappa_{\mathbf{0ab}} \quad \Rightarrow \quad \boxed{\sigma \equiv \sqrt{\frac{\rho^3}{\mathbf{k}^0}}}$

A refined no-go theorem

Cf. Flauger, Paban, Robbins, Wrase (2008)

<u>Old no-go:</u> $\mathbf{V}_{\mathbf{geo}} = \mathbf{0}, \qquad \mathbf{V} = \mathbf{V}(\tau, \rho, \ldots)$

$\Rightarrow \varepsilon \geq 27/13$

<u>Refined no-go:</u> $\mathbf{V}_{\mathbf{geo}} \neq \mathbf{0}, \qquad \mathbf{V} = \mathbf{V}(\tau, \sigma, \ldots)$

Violates old no-go

Different Kähler modulus

If:

(i) $\kappa_{\mathbf{ijk}} = \kappa_{\mathbf{0ab}} \quad \Rightarrow \quad \boxed{\sigma \equiv \sqrt{\frac{\rho^3}{\mathbf{k}^0}}}$

(ii) $-\sigma\partial_\sigma\left[2\tau^2\rho^3\mathbf{V}_{\mathbf{geo}}\right] \geq \mathbf{0}$

$\Rightarrow \quad \boxed{\epsilon \geq 2}$ for $\boxed{V > 0}$

Our cosets:

(i) $\kappa_{\mathbf{ijk}} = \kappa_{\mathbf{0ab}}$ is always satisfied

$\Rightarrow$ Can define σ

Our cosets:

(i) $\kappa_{\mathrm{ijk}} = \kappa_{0\mathrm{ab}}$ is always satisfied

$\Rightarrow$ Can define σ

(ii) $-\sigma\partial_\sigma\left[2\tau^2\rho^3 \mathrm{V}_{\mathrm{geo}}\right] \geq 0$ is always satisfied except for

$$\boxed{\mathcal{M}^{(6)} = \mathrm{SU}(2)\times\mathrm{SU}(2)}$$

Our cosets:

(i) $\kappa_{\mathrm{ijk}} = \kappa_{0\mathrm{ab}}$ is always satisfied

$\Rightarrow$ Can define σ

(ii) $-\sigma\partial_\sigma\left[2\tau^2\rho^3 \mathrm{V}_{\mathrm{geo}}\right] \geq 0$ is always satisfied except for

$\mathcal{M}^{(6)}$ =SU(2)×SU(2)

Only remaining candidate.
(The others have $\varepsilon \geq 2$)

SU(2)×SU(2)

Numerically: $\varepsilon \approx 0$ with $V > 0$

But:

$$\eta \leq -2.4$$

(Large tachyonic direction)

Interestingly:

- Tachyon is combination of all moduli
- Not the tachyon of (?)

Covi, Gomez-Reino, Gross, Louis, Palma, Scrucca (2008)

Also:

- NS5, D4, D8 can not be added in these models
- No F-term uplifting à la "O'KKLT" possible

  Cf. Kallosh, Linde (2006), Kallosh, Soroush (2006)
- KK5-Monopole ? ⇒ Drastic modification of geometry

  See also Villadoro, Zwirner (2007)

⇒ So far nothing really worked...

Summary

Type IIA on CY + p-form fluxes + D6/O6:

- Tree-level moduli stabilization in AdS
- No-go against dS and inflation (HKKT)

→ $V > 0$ is too steep in (ρ,τ)

Summary

Type IIA on CY + p-form fluxes + D6/O6:

- Tree-level moduli stabilization in AdS
- No-go against dS and inflation (HKKT)

→ $V > 0$ is too steep in (ρ,τ)

⇒ Quantum effects or/and additional classical ingredients

- Best understood: Geometric fluxes (deviation from CY)

Studied cosets with SU(3)-structure

⇒ Refined no-go in (σ,τ): $\varepsilon \geq 2$ except for SU(2)×SU(2)

SU(2)×SU(2): $\varepsilon \approx 0$, but $\eta \leq -2.4$

Consistent with other works:

Haque, Shiu, Underwood, Van Riet (2008)

Flauger, Paban, Robbins, Wrase (2008)

$\Rightarrow$ Geometric fluxes may help in (ρ,τ)-plane, but certainly do not automatically take care of all moduli $\Rightarrow$ Many dangerous directions

Consistent with other works:

Haque, Shiu, Underwood, Van Riet (2008)

Flauger, Paban, Robbins, Wrase (2008)

$\Rightarrow$ Geometric fluxes may help in (ρ,τ)-plane, but certainly do not automatically take care of all moduli $\Rightarrow$ Many dangerous directions

More recent works:

Roest (2009), Dall'Agata, Villadoro, Zwirner (2009)

$\Rightarrow$ N=4 gauged supergravity

de Carlos, Guarino, Moreno (2009)

$\Rightarrow$ Non-geometric fluxes?

Danielsson, Haque, Shiu, Van Riet (2009)

$\Rightarrow$ 10D point of view

Consistent with other works:

Haque, Shiu, Underwood, Van Riet (2008)

Flauger, Paban, Robbins, Wrase (2008)

$\Rightarrow$ Geometric fluxes may help in (ρ,τ)-plane, but certainly do not automatically take care of all moduli $\Rightarrow$ Many dangerous directions

More recent works:

Roest (2009), Dall'Agata, Villadoro, Zwirner (2009)

$\Rightarrow$ N=4 gauged supergravity

de Carlos, Guarino, Moreno (2009)

$\Rightarrow$ Non-geometric fluxes?

Danielsson, Haque, Shiu, Van Riet (2009)

$\Rightarrow$ 10D point of view

So far no geometrical tree-level de Sitter...

IIB on SU(2)-structure manifolds with

- O5/O7-planes
- F_p-fluxes (p=1,3,5)

Cf. Lüst, Tsimpis (2009), Tsimpis' talk

T-dual to IIA with D6 with possibly non-geometric fluxes

- Moduli stabilization ok
- Some new no-go theorems

Wrase, M.Z., ...

Type IIB:

$$\boxed{\begin{aligned}\rho &\equiv (\mathbf{Vol})^{1/3}\\ \tilde{\tau} &\equiv \mathbf{e}^{-\phi}\end{aligned}} \Rightarrow \boxed{\begin{aligned}\mathbf{V}_{\mathbf{H}_3} &\propto \tilde{\tau}^{-2}\rho^{-6}\\ \mathbf{V}_{\mathbf{F}_3} &\propto \tilde{\tau}^{-4}\rho^{-6}\\ \mathbf{V}_{\mathbf{D3/O3}} &\propto \pm\tilde{\tau}^{-3/2}\rho^{-6}\end{aligned}}$$

$$\Rightarrow \boxed{-\rho\partial_\rho \mathbf{V} = \mathbf{6V}} \Rightarrow \boxed{\mathbf{V} = \mathbf{0}}$$

Cf. e.g. Hertzberg, Kachru, Taylor, Tegmark (2007)

⇔No-scale structure of ISD Flux vacua in IIB

Giddings, Kachru, Polchinski (2001)

Haque, Shiu, Underwood, Van Riet (2008):

$$\boxed{V_{geo} \text{ and } V_{F_1} \text{ may help}}$$

$\Rightarrow$ Need 1-cycles $\Rightarrow$ No CY

SU(3)-structure also nontrivial

(e.g. $\Omega \wedge J = 0$)

But:

$\exists$ Explicit solutions in IIB on SU(2)-structure manifolds

E.g. Lüst, Tsimpis (2009)

Tried SU(2)-structure with O7/O5-planes

$\Rightarrow$ Moduli stabilization + no-go's Wrase, M.Z., ...