De Sitter Vacua from a D-term Generated Racetrack Uplift

arXiv:1407.7580 [hep-th]
with Yoske Sumitomo

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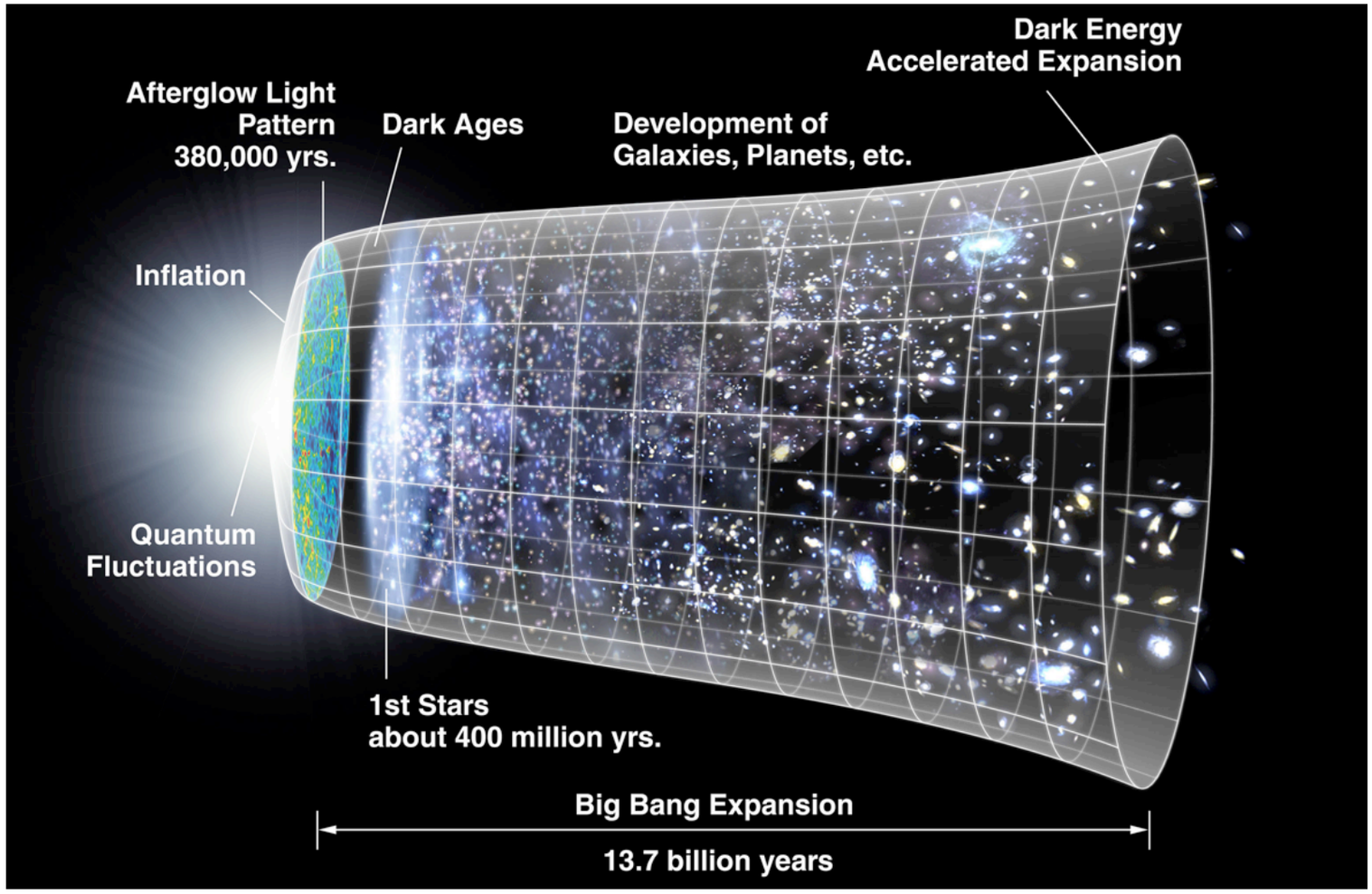
Outline

1. De Sitter vacua in type IIB

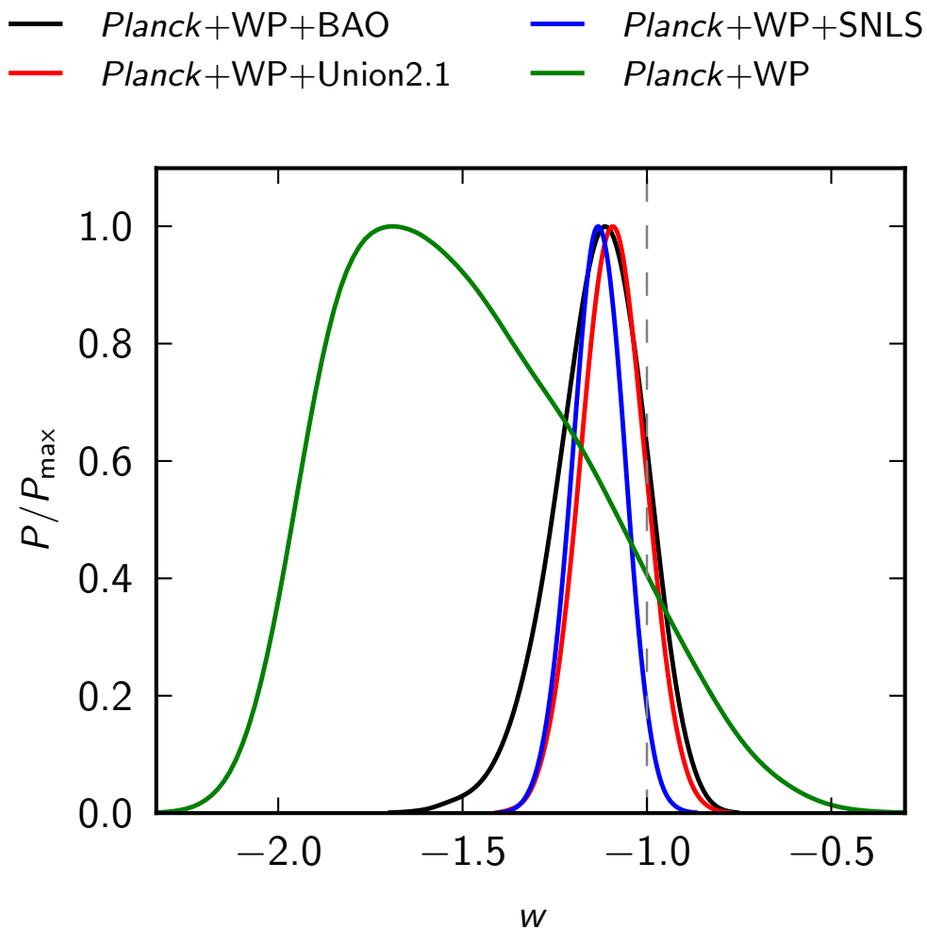
2. D-term generated Racetrack uplift

3. Conclusions & Outlook

Dark Energy



After Planck:



[Planck 13]

Planck+WMAP+BAO (also SNe):

$$w = \frac{p}{\rho} = -1.13^{+0.24}_{-0.25}$$

agrees with cosmological constant $w = -1$

Moduli Stabilization

- Compactification from 10D to 4D results in many many moduli ϕ_a
- 5th forces and cosmological constraints:
  $m_{\phi_a} \gtrsim 30\ \mathrm{TeV} \Rightarrow$ Stabilization required
- CC is very small $\langle V \rangle \sim \Lambda \sim 10^{-120} \mathrm{M_P^4}$
  $\Rightarrow$ Tuning necessary in absence of dynamical mechanism
- $\mathcal{P} \equiv \frac{\#\text{stable points}}{\#\text{critical points}} \sim e^{-\mathcal{O}(1)N^2}$
  $\Rightarrow$ Hierarchical structure preferred

[Aazami, Easther 05], [Dean Majumdar 08], [Borot, Eynard, Majumdar, Nadal10], [Marsh, McAllister, Wrase 12], [Chen, Shiu, Sumitomo, Tye 12], [Bachlechner, Marsh, McAllister, Wrase 12]

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$\Rightarrow$ **Type IIB**

Type IIB models

Type IIB has no-scale structure:

[Cremmer, Ferrara, Kounnas, Nanopoulos 83], [Giddings, Kachru, Polchinski 01], [Grimm, Louis 04]

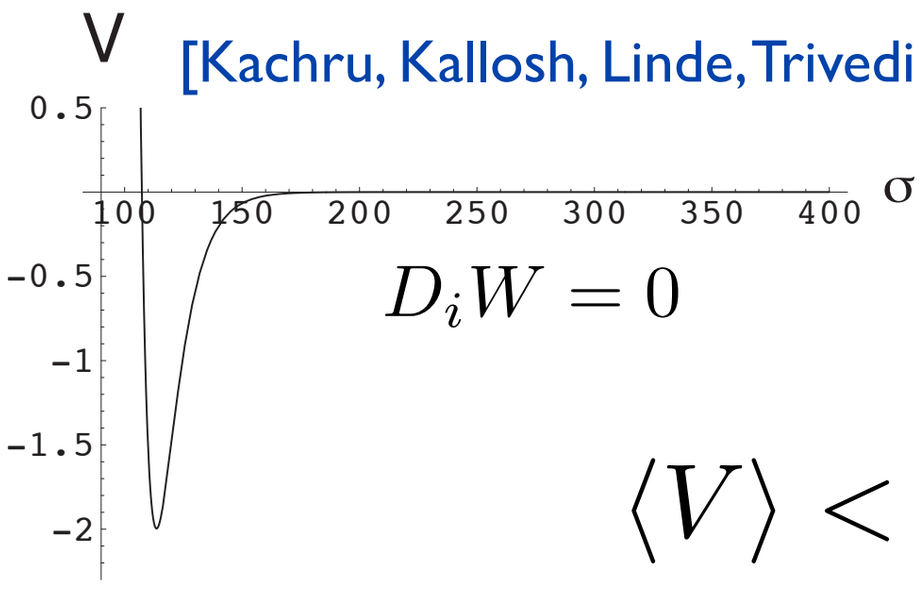
$$V = e^k \left(K^{a\bar{b}} D_a W \, \overline{D_b W} - 3W^2 \right) = \underbrace{V_{\text{Flux}}}_{\mathcal{O}(\mathcal{V}^{-2})} + \underbrace{V_{\text{NP}} + V_{\alpha'}}_{\mathcal{O}(\mathcal{V}^{-3})}$$

and V_{Flux} positive semi-definite

$\Rightarrow$ Flux stabilized moduli can be integrated out

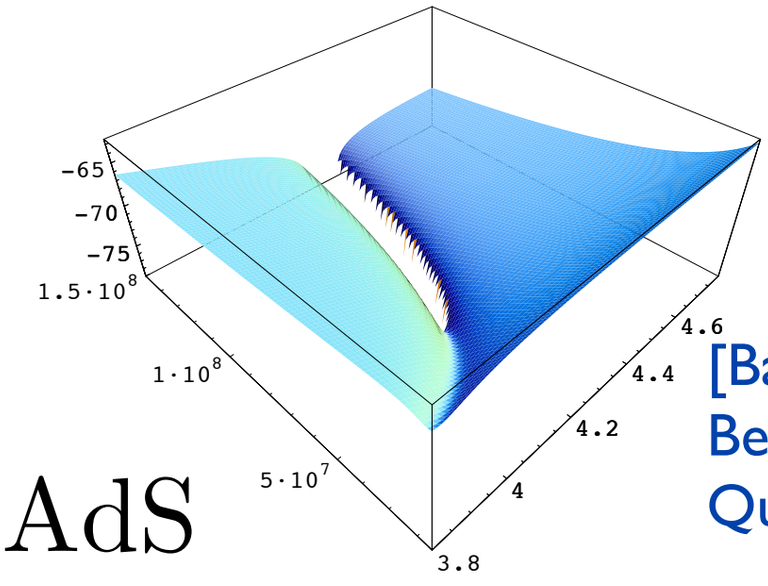
KKLT:

[Kachru, Kallosh, Linde, Trivedi 03]



$$D_i W = 0$$

Large Volume scenario (LVS):



$$\partial_i V = 0$$

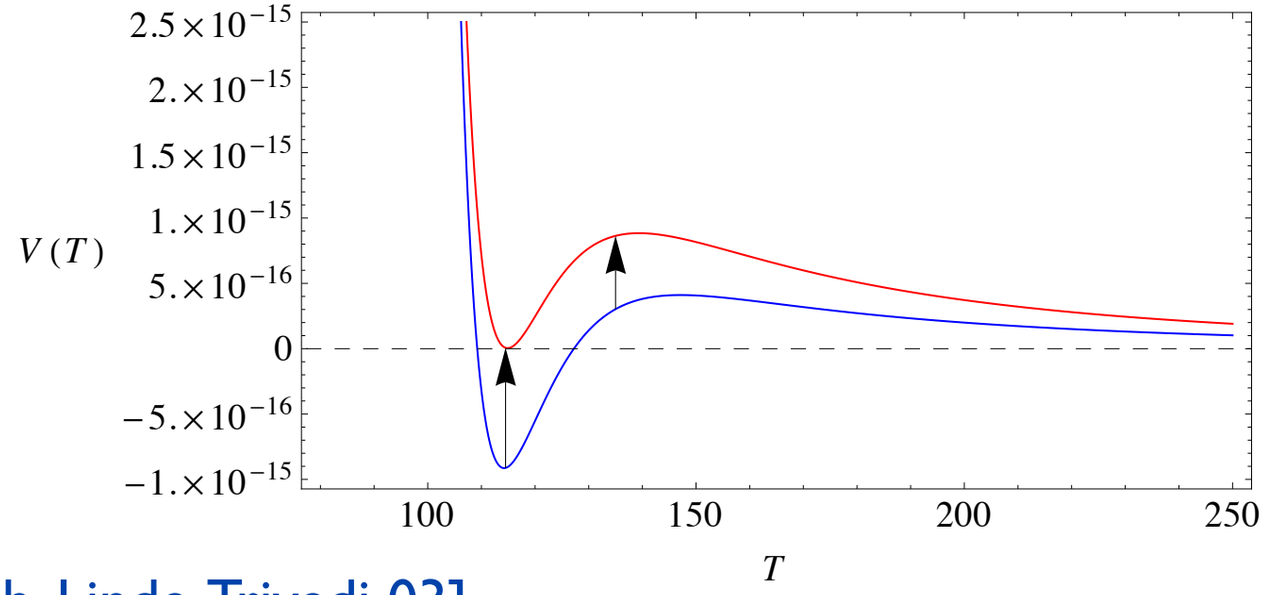
[Balasubramanian, Berglund, Conlon, Quevedo 05]

$$\langle V \rangle < 0 \Rightarrow \text{AdS}$$

De Sitter uplifting

- Anti D3 branes

$$V = \underbrace{V_{SUGRA}}_{\mathcal{O}(\mathcal{V}^{-3})} + \underbrace{V_{D3-\overline{D3}}}_{\mathcal{O}(\mathcal{V}^{-4/3})}$$



[Kachru, Pearson, Verlinde 01], [Kachru, Kallosh, Linde, Trivedi 03]

- Complex structure sector $V = V_{\rm NP} + V_{\alpha'} + V_{\rm Flux}$

$$V_{\rm Flux} = e^K \left|D_{S,U_i} W_0\right|^2 \sim \mathcal{O}(\mathcal{V}^{-1})$$

[Saltman, Silverstein 04], [Danielsson, Dibitetto 13], [Blaback, Roest, Zavala, 13], [Kallosh, Linde, Vercnocke, Wrase 14]

- negative curvature of manifold [Silverstein 07]

$\Rightarrow$ Tuning required

De Sitter uplifting

- D-terms via magnetic flux on D7 branes

$$V = V_{\rm NP} + V_{\alpha'} + V_D$$ [Burgess, Kallosh, Quevedo 03], [Cremades, Garcia del Moral, Quevedo 07], [Krippendorf, Quevedo 09]

$$V_D = \frac{1}{{\rm Re}(f_D)} \left(\sum_j c_{D\,j} \hat{K}_j \varphi_j - \xi_D \right)^2 \sim \mathcal{O}(\mathcal{V}^{-8/3})$$

for $\langle \varphi \rangle \neq 0$

- non-perturbative dilaton effects [Cicoli, Maharana, Quevedo, Burgess 12]

$$W = W_0(S) + A\, e^{-aT_s} + B\, e^{-b(S+h\rho)}$$

$$\langle \rho \rangle = 0 \ \text{via} \ V_D = 0\,, \quad \langle s \rangle \neq 0 \ \text{via} \ D_S W = 0$$

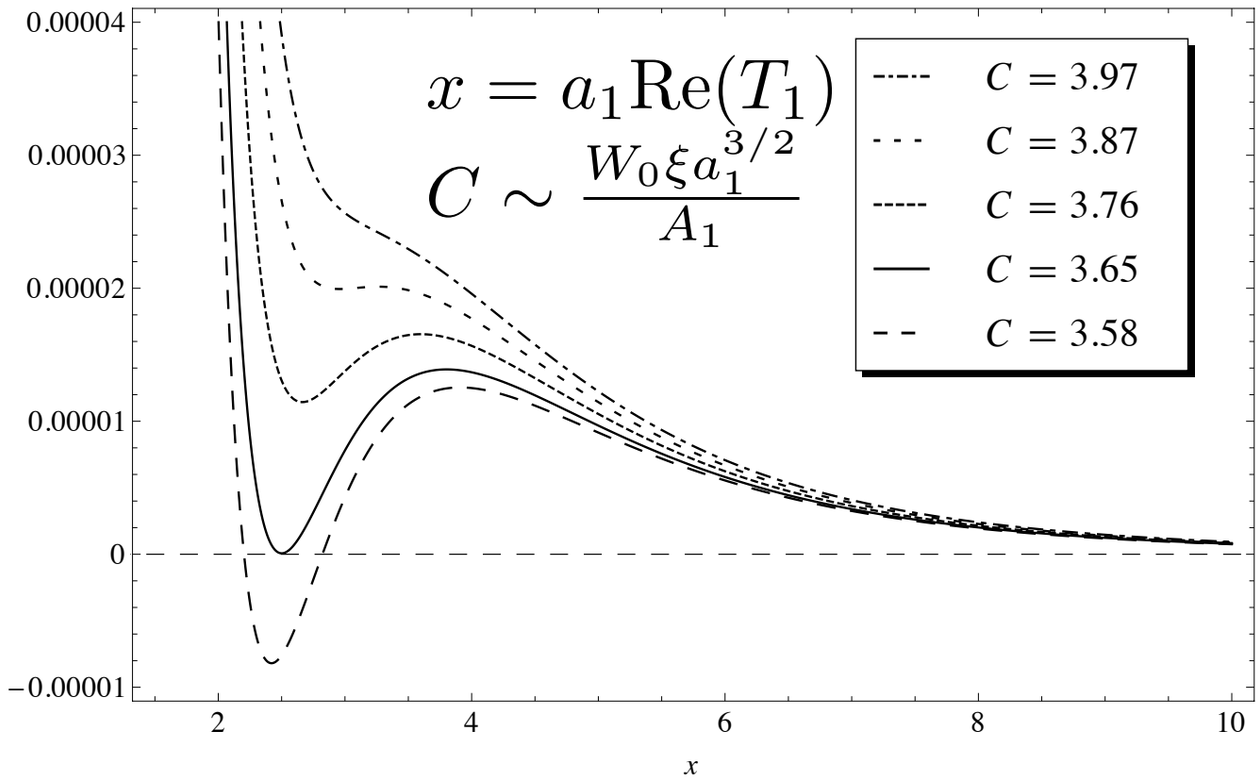
$$\Rightarrow V_{up} \sim \frac{e^{-2b\langle s \rangle}}{\mathcal{V}}$$

Kähler Uplifting

[Balasubramanian, Berglund 04], [Westphal 06], [MR, Westphal, 11], [de Alwis, Givens 11]

$$K = -\ln\left(\mathcal{V} + \frac{\xi}{2}\right), \quad W = W_0 + A_1 e^{-a_1 T_1} + \dots$$

- same setup as Large Volume scenario but different region in parameter space
- de Sitter directly from V_F
- Upper bound on $a_1 \mathcal{V}^{2/3}{}^{V(x)}$
  $\Rightarrow$ Make a_1 small or
- Racetrack Kähler Uplift
  $W = W_0 + A_1 e^{-a_1 T_1} + B_1 e^{-b_1 T_1}$ [Sumitomo, Tye, Wong, 13]
  $\Rightarrow$No upper bound



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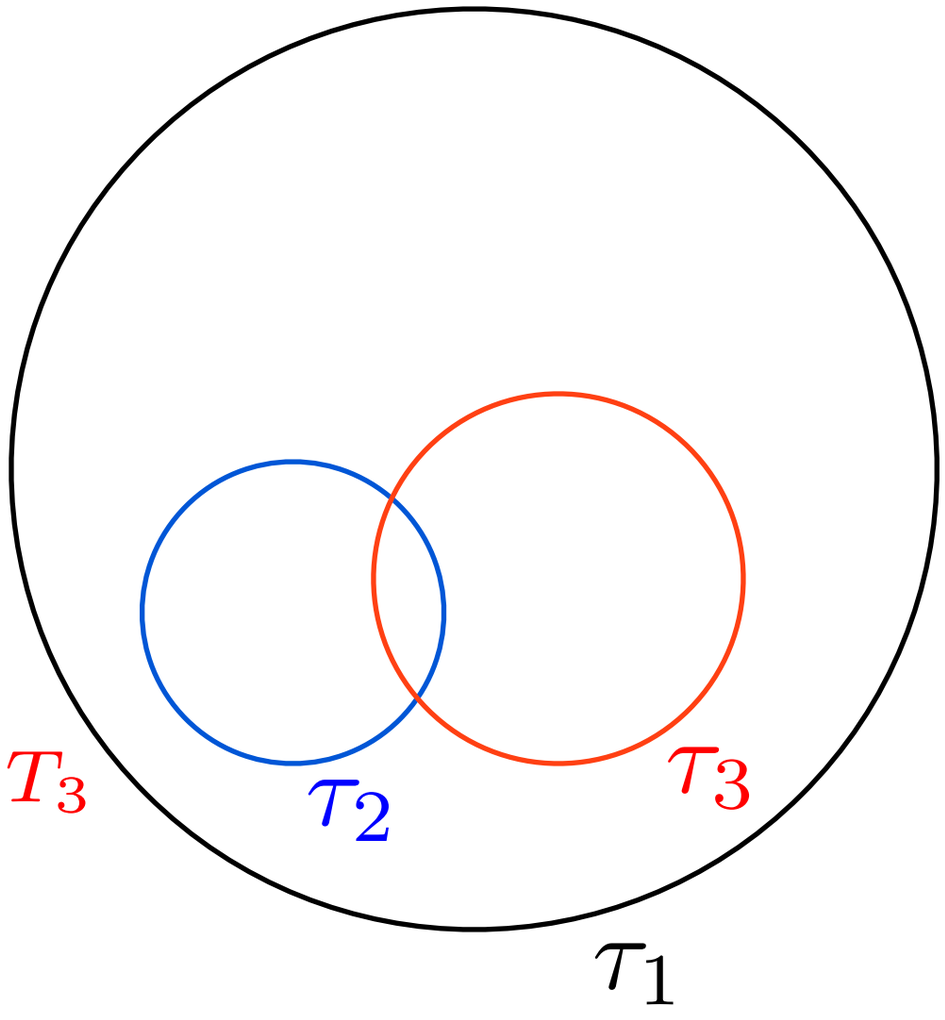
D-term Racetrack uplift

[MR, Sumitomo 14]

- $K = -2\ln\left(\mathcal{V} + \frac{\xi}{2}\right)$,

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



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

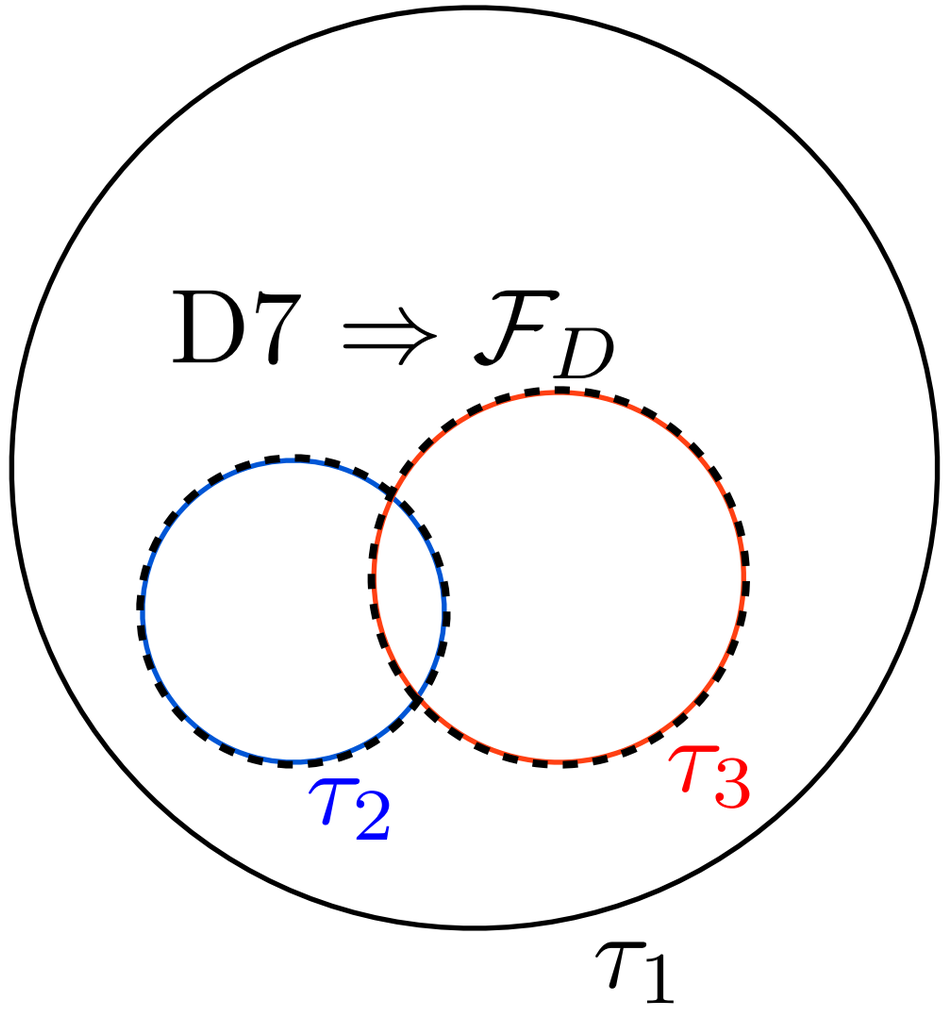
LVS region $\Rightarrow \frac{V_F}{W_0^2} \sim \frac{3\xi}{4\mathcal{V}^3} + \mathcal{O}\left(\frac{e^{-a_i\tau_i}}{\mathcal{V}^2}\right) + \mathcal{O}\left(\frac{e^{-2a_i\tau_i}}{\mathcal{V}}\right) \sim \mathcal{O}\left(\frac{1}{\mathcal{V}^3}\right)$

D-term Racetrack uplift

- Wrap divisor $T_D = T_2 + T_3$ with D7 branes
- $\Rightarrow$ D-term potential

$$V_D \sim \left(\sum_j \varphi_j - \xi_D \right)^2$$

- with matter fields φ_j and



$\xi_D = \frac{1}{\mathcal{V}} \int D_D \wedge J \wedge \mathcal{F}_D \sim \sqrt{\tau_2} - \sqrt{\tau_3}$ (gauge Flux $\mathcal{F}_D$)

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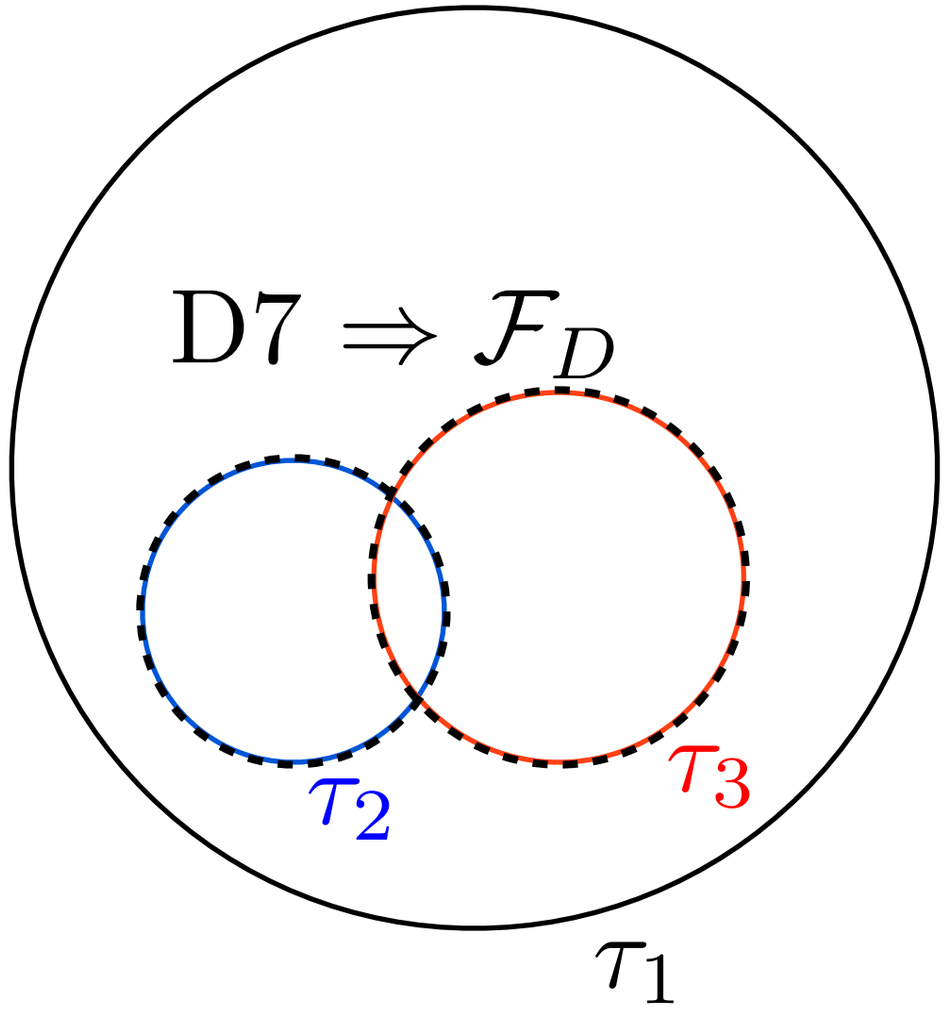

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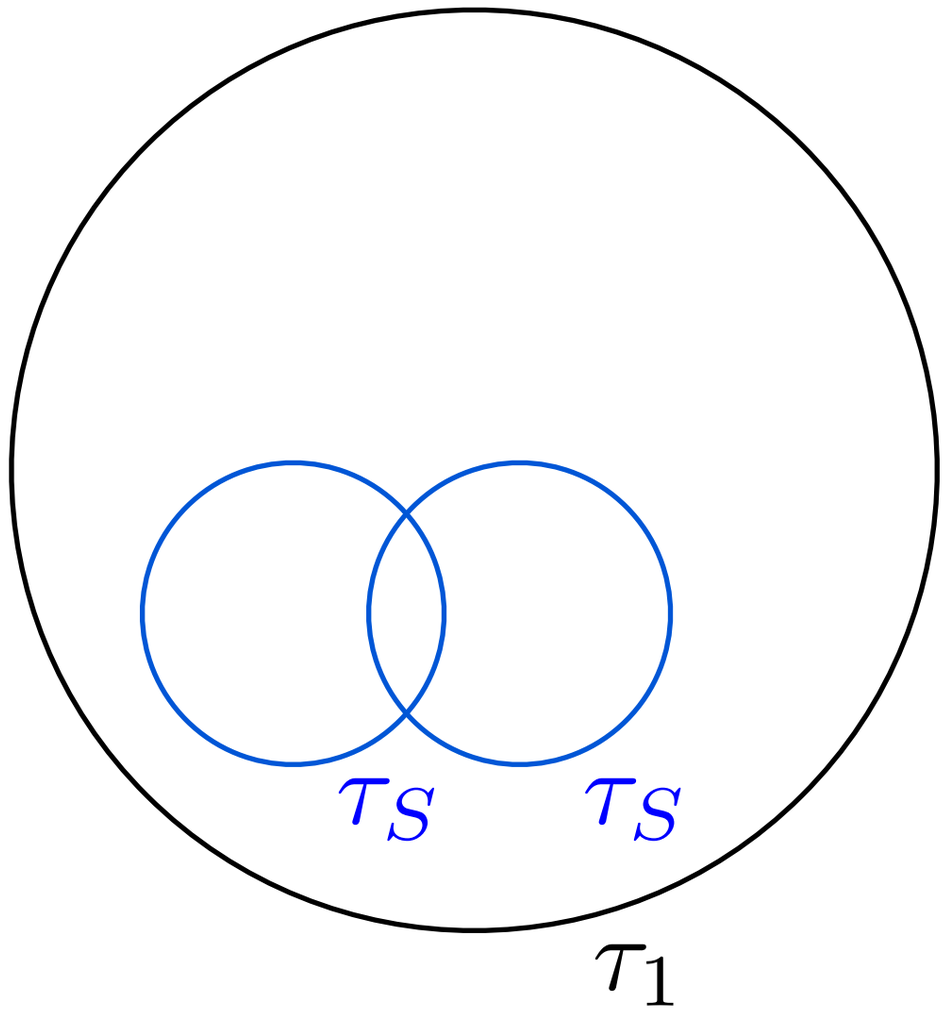
$$V_D = 0 \Rightarrow \tau_2 = \tau_3 \quad \text{(for } \varphi_j = 0 \text{)}$$

D-term Racetrack uplift

Resultant F-Term potential for $\mathcal{V} \sim \tau_1^{3/2}$ and $\tau_S = \tau_2 = \tau_3$:

$$\frac{V_F}{W_0^2} \sim \frac{\xi}{\mathcal{V}^3} + \frac{c_2 e^{-a_2 \tau_s}}{\mathcal{V}^2} + \frac{c_2^2 e^{-2a_2 \tau_s}}{\mathcal{V}} + \frac{c_3 e^{-a_3 \tau_s}}{\mathcal{V}^2} + \dots$$

with $c_i = \frac{A_i}{W_0}$



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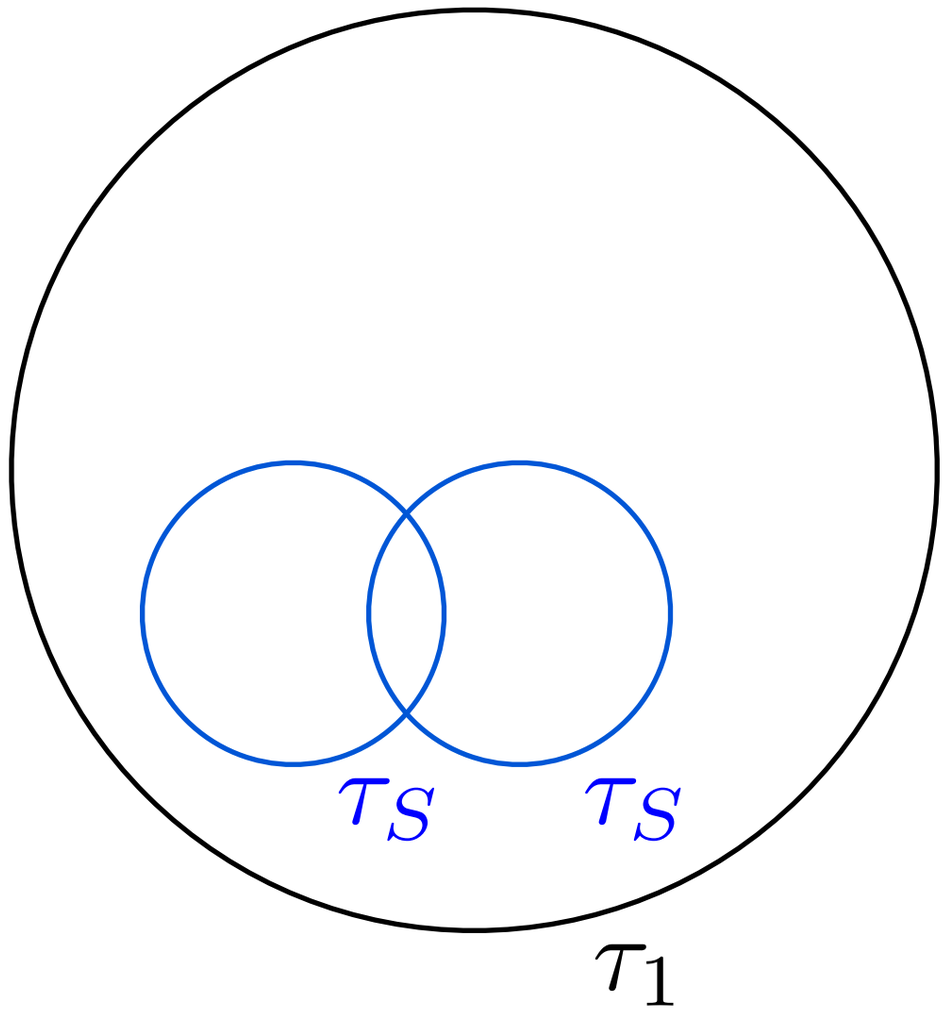
Allows de Sitter for

$$c_2/c_3 < 0,\ a_3/a_2 < 1/2\,!$$



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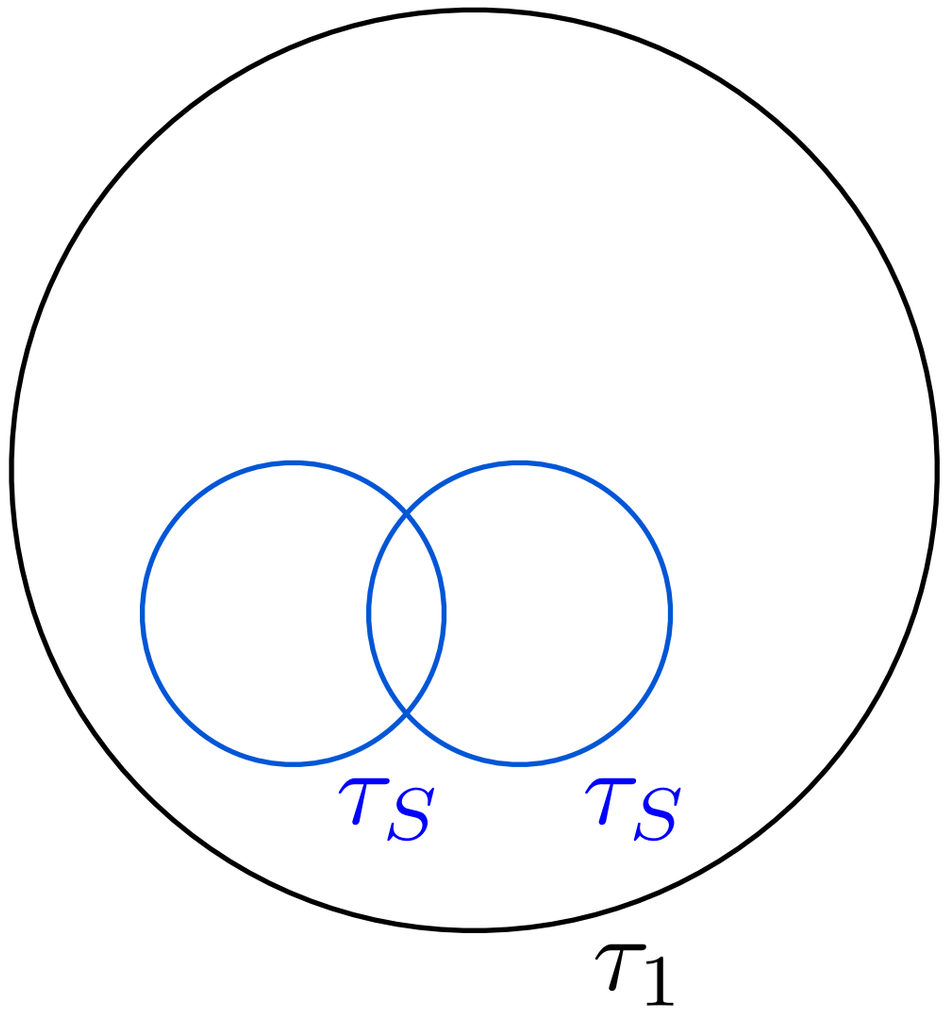
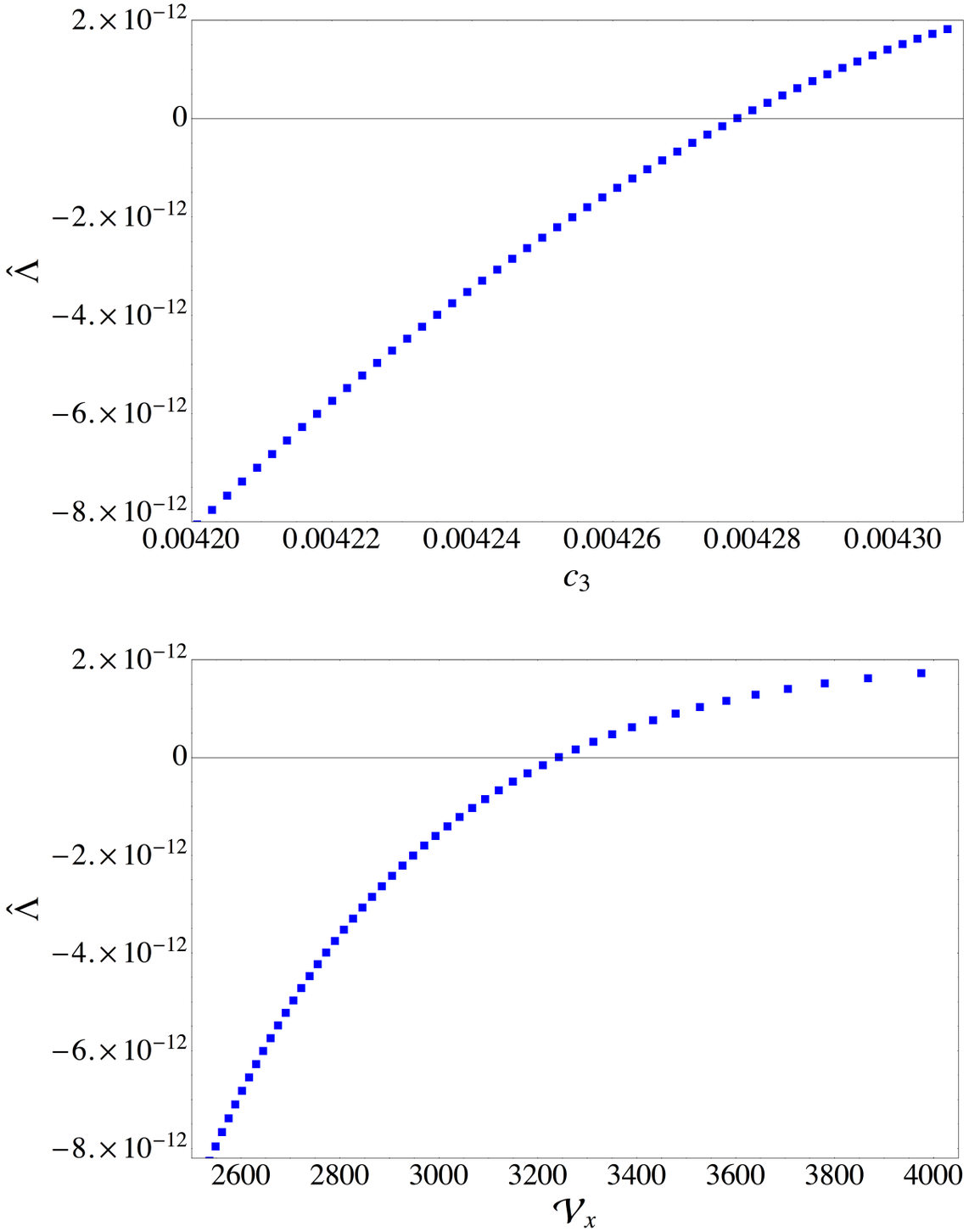
Allows de Sitter for
$c_2/c_3 < 0,\ a_3/a_2 < 1/2$ **!**

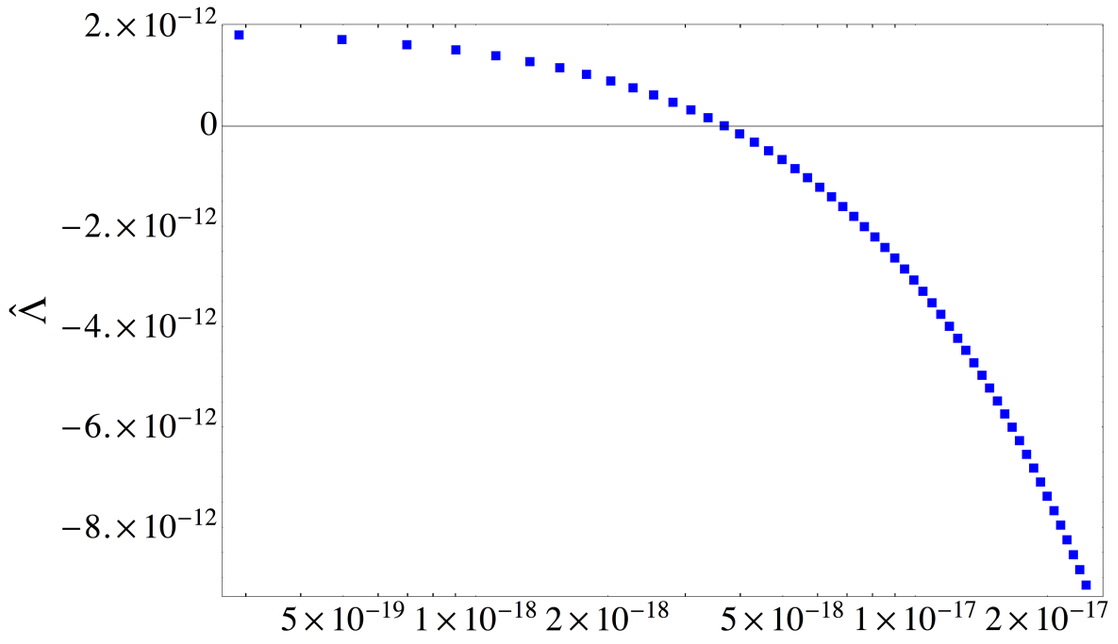
Different from simple racetrack
$W = W_0 + A_2 e^{a_2 T_S} + A_3 e^{a_3 T_S}$

(cross terms in c_2, c_3 different)



Numerical example





$$c_2 = -0.01,\ \xi = 5,$$
$$a_3/a_2 = 5/12,$$
$$c_3 = 0.004$$

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Conclusions

- De Sitter model building in String Theory is important since dark energy is consistent with small cc
- D-term generated racetrack is Large Volume Scenario with uplifting completely within Kähler sector
- Less (additional) tuning than other mechanisms since $V_{up}, V_F \sim \mathcal{O}(\mathcal{V}^{-3})$
- Price: additional cycle with NP effect + D-term
- Volume grows as uplift term is increased

Outlook: Explicit Examples

Explicit Examples exist for D-term LVS and Kähler Uplifting [Cicoli,Krippendorf,Mayrhofer,Quevedo,Valandro 12],[Louis,MR,Valandro,Westphal 12]

$\Rightarrow$ Construct explicit models!

Constraints:

- Tension between $\mathcal{F}_D \neq 0$ and $A_2, A_3 \neq 0$ [Blumenhagen, Moster, Plauschinn 07]
- Stabilization inside Kähler Cone
- D7 and D3 Tadpole
- Freed-Witten Anomalies [Minasian, Moore 97], [Freed, Witten 99]

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Thank you for your attention!