De Sitter Vacua from a D-term Generated Racetrack Uplift

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with Yoske Sumitomo
+ work in progress with Andreas Braun, Roberto Valandro and Yoske Sumitomo

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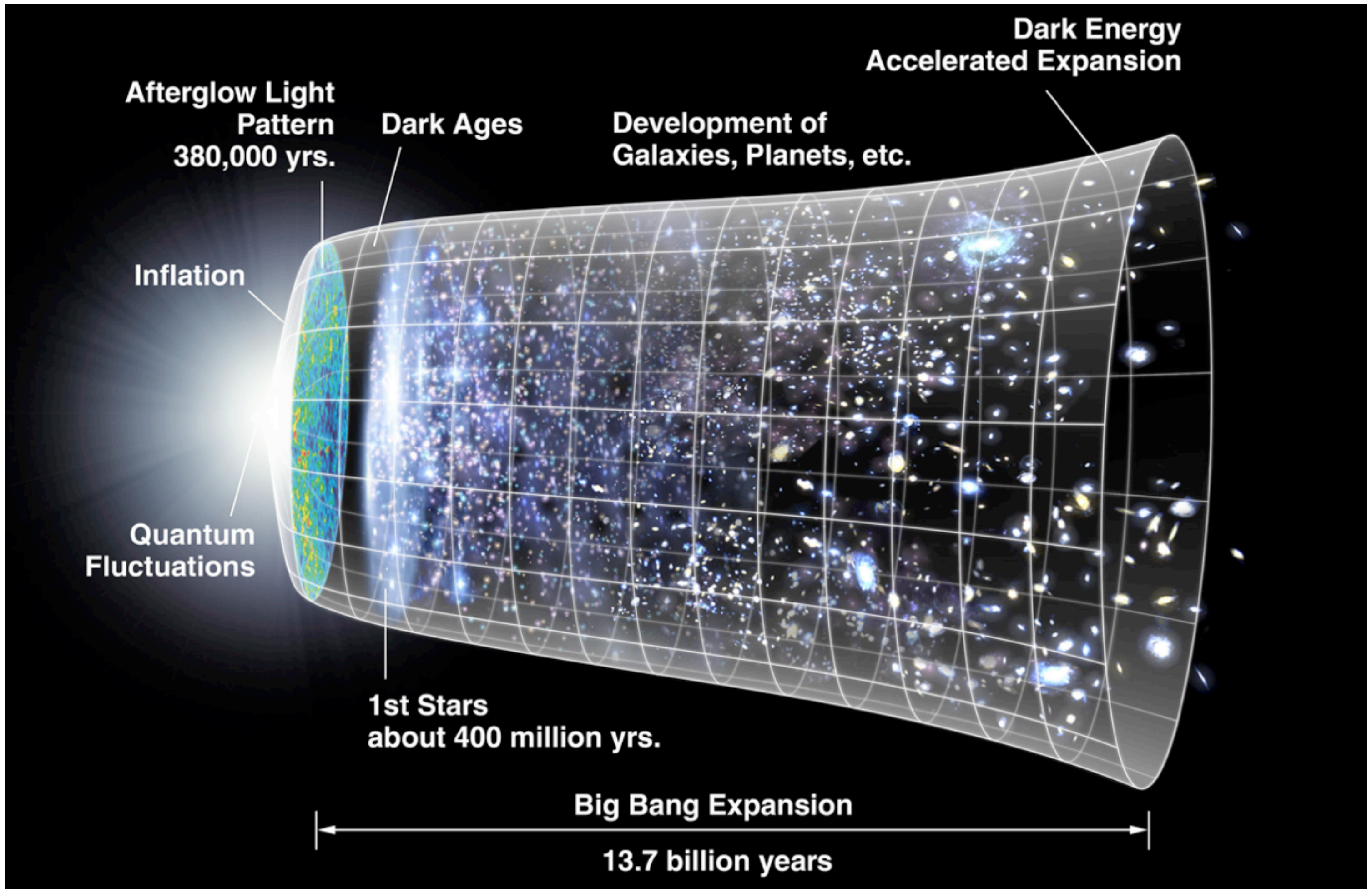
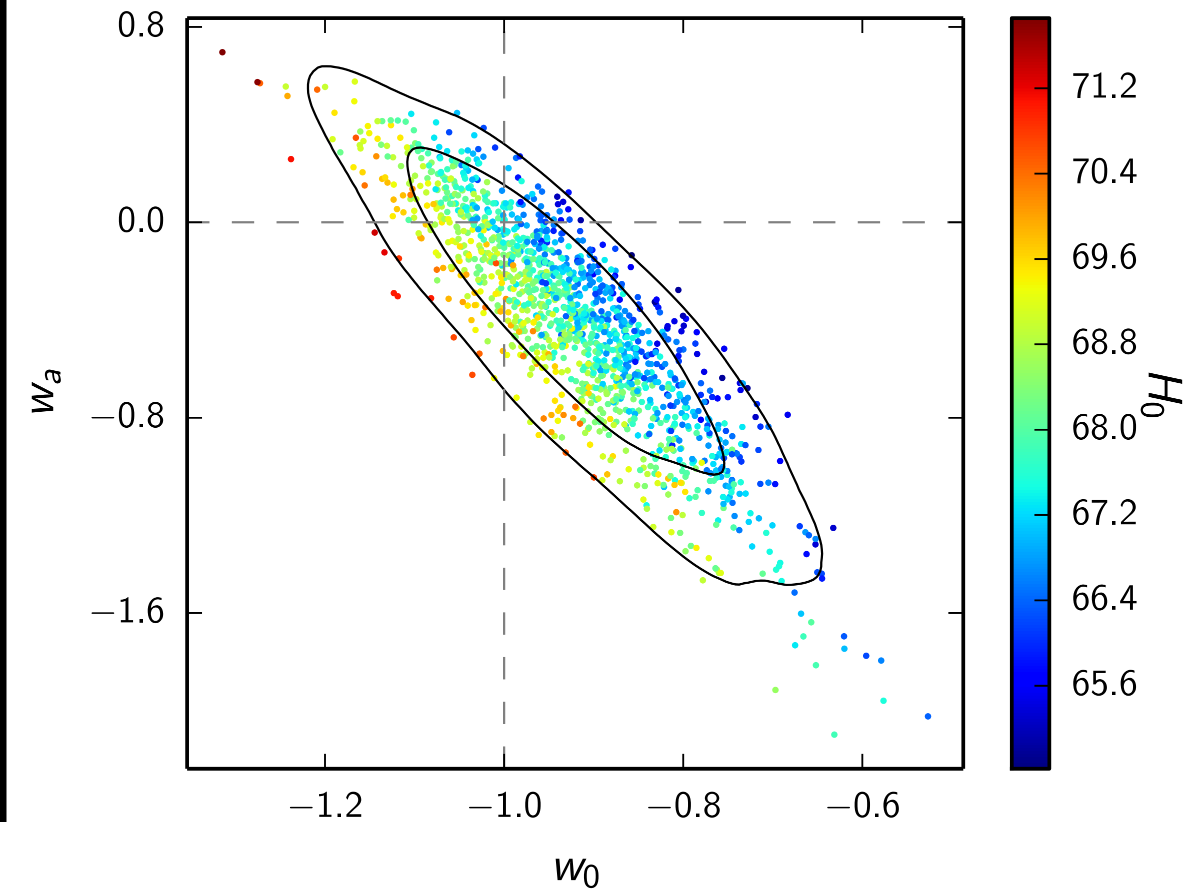
Bad Honnef 2015, 17/03/2015

Dark Energy



After Planck:



$$w = -1.023^{+0.091}_{-0.096} \quad \textit{Planck}\ \mathrm{TT{+}lowP{+}ext}\ (\mathrm{BAO,\ JLA\ and}\ H_0)$$

[Planck 15]

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 [see Palti's talk]
- CC is very small $\langle V \rangle \sim \Lambda \sim 10^{-120}\mathrm{M}_\mathrm{P}^4$
  $\Rightarrow$ 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]

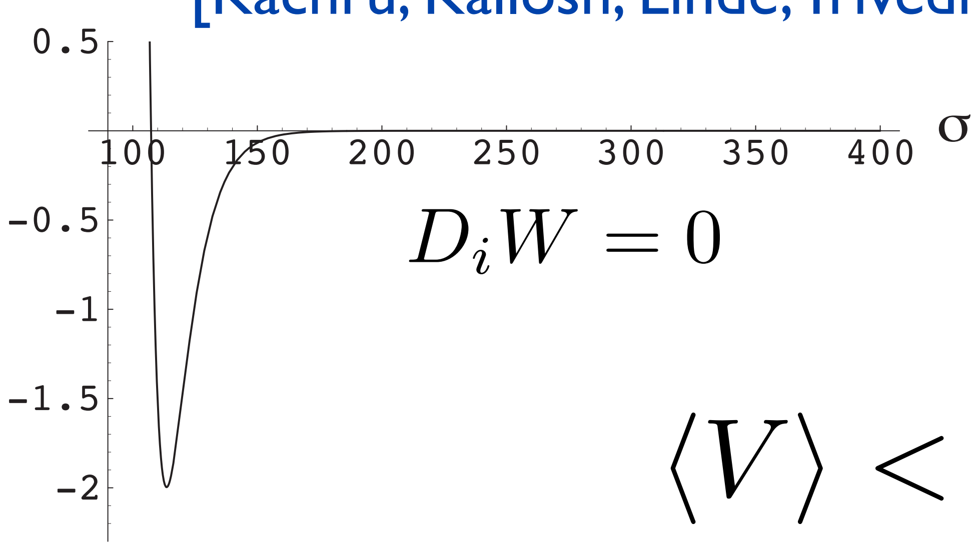
$$V = e^k \left(K^{a\bar{b}} D_a W \, \overline{D_b W} - 3W^2 \right) = \underbrace{V_{\text{Flux}}}_{\mathcal{O}(\mathcal{V}^{-2})} + \underbrace{V_{\text{NP}} + V_{\alpha'}}_{\mathcal{O}(\mathcal{V}^{-3})}$$

and V_{Flux} positive semi-definite

$\Rightarrow$ Flux stabilized moduli can be integrated out

KKLT:

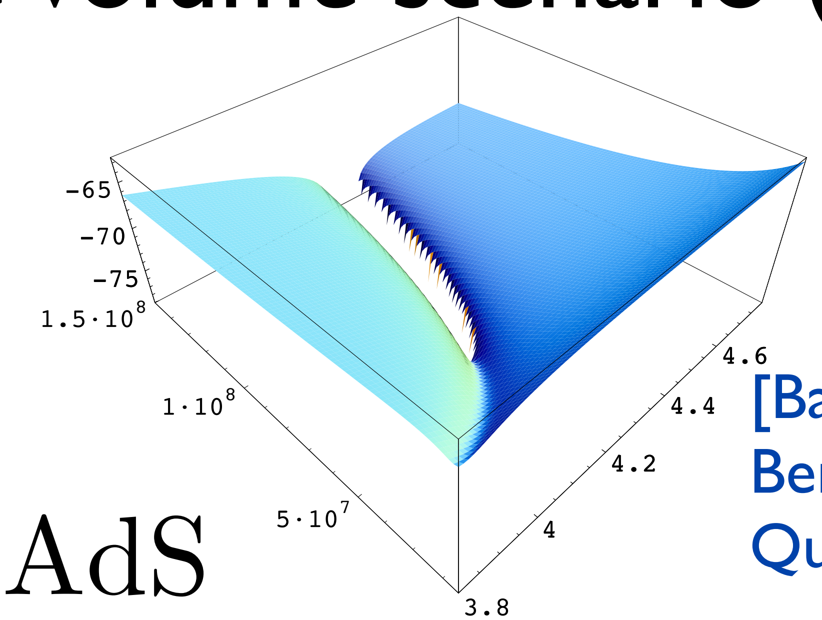
[Kachru, Kallosh, Linde, Trivedi 03]



$D_i W = 0$

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

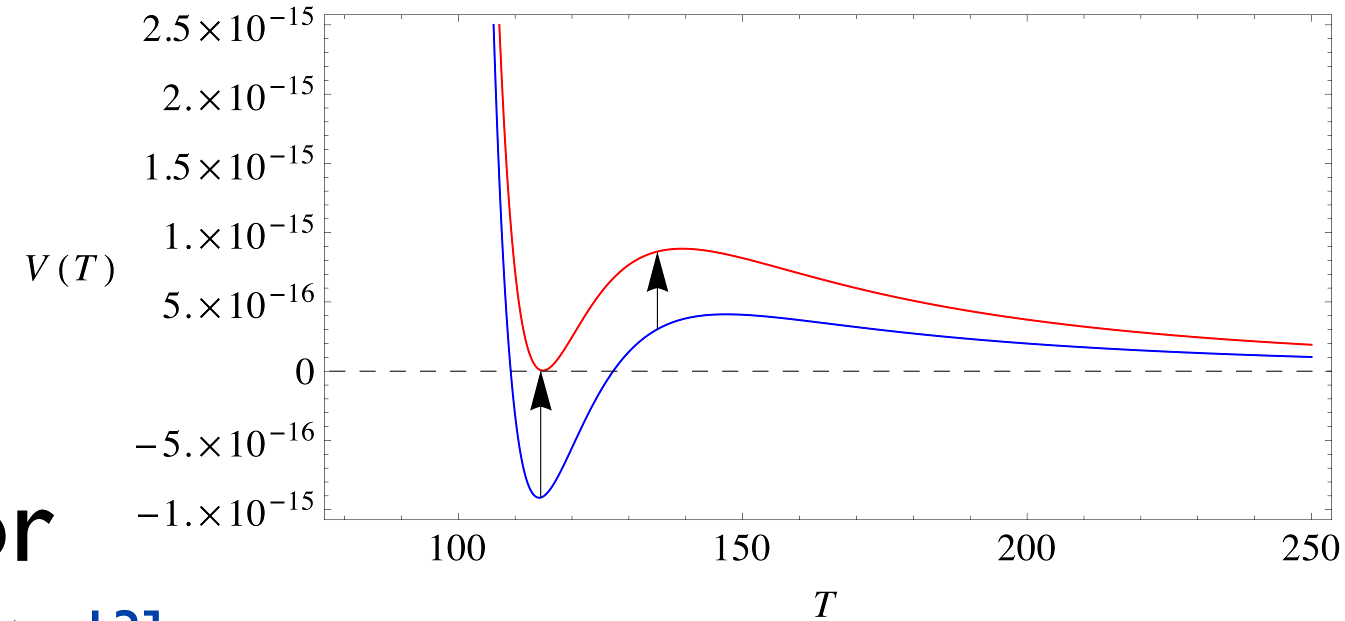
Large Volume scenario (LVS):



$\partial_i V = 0$

[Balasubramanian, Berglund, Conlon, Quevedo 05]

De Sitter uplifting



- Anti D3 branes

  [Kachru, Pearson, Verlinde 01],
  [Kachru, Kallosh, Linde, Trivedi 03],
  [Talks by Gautason and Junghans]

- Complex structure sector

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

- negative curvature of manifold [Silverstein 07]

- D-terms via magnetic flux on D7 branes

  [Burgess, Kallosh, Quevedo 03], [Cremades, Garcia del Moral, Quevedo 07],
  [Krippendorf, Quevedo 09]

- non-perturbative dilaton effects

  [Cicoli, Maharana, Quevedo, Burgess 12]

Kähler Uplifting

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

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

- same setup as Large Volume scenario but different region in parameter space
- de Sitter directly from V_F but upper bound on $\mathcal{V}$
- Racetrack Kähler Uplift [Sumitomo, Tye, Wong, 13]

  $$W = W_0 + A_1 e^{-a_1 T_1} + B_1 e^{-b_1 T_1}$$

  $\Rightarrow$ No upper bound

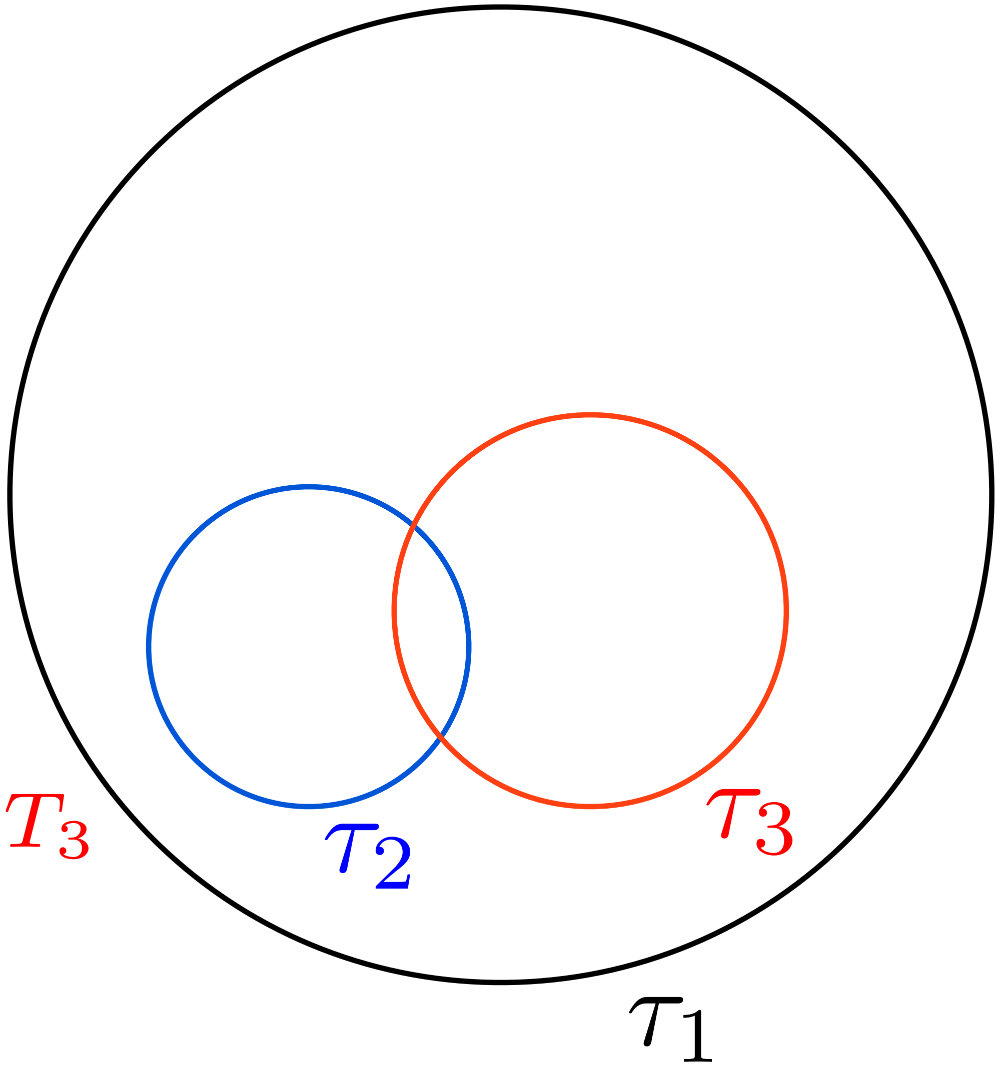
D-term Racetrack uplift

[MR, Sumitomo 14]

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

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

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



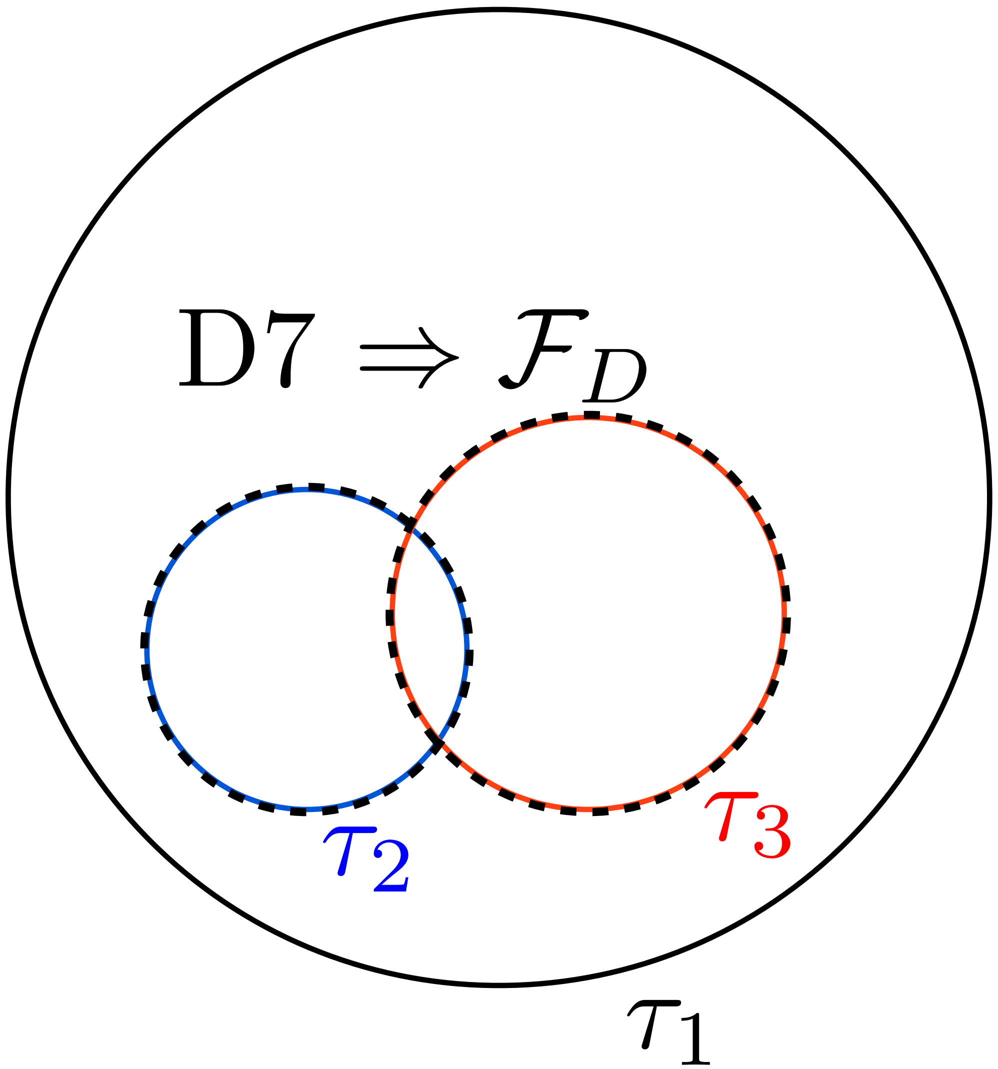
LVS region
$$\Rightarrow \frac{V_F}{W_0^2} \sim \frac{3\xi}{4\mathcal{V}^3} + \mathcal{O}\left(\frac{e^{-a_i\tau_i}}{\mathcal{V}^2}\right) + \mathcal{O}\left(\frac{e^{-2a_i\tau_i}}{\mathcal{V}}\right) \sim \mathcal{O}\left(\frac{1}{\mathcal{V}^3}\right)$$

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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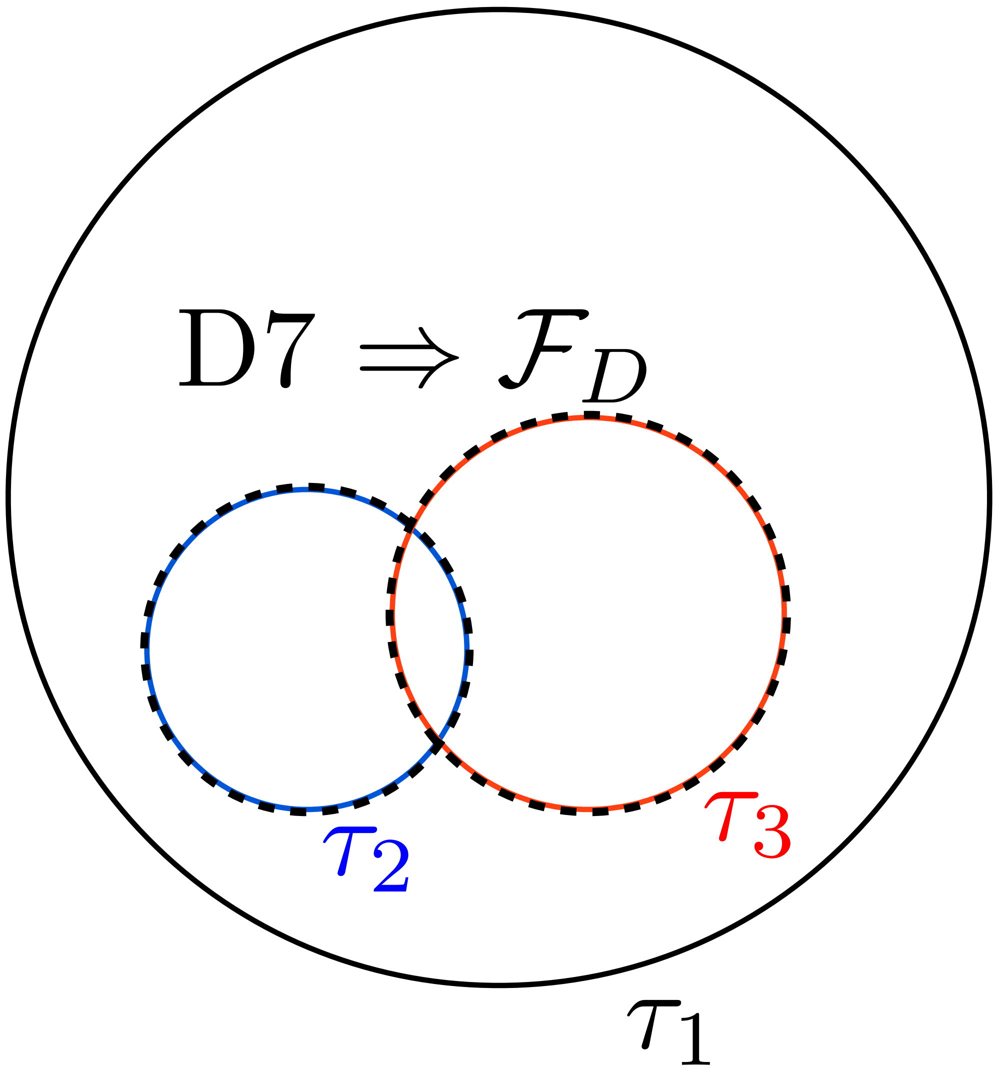

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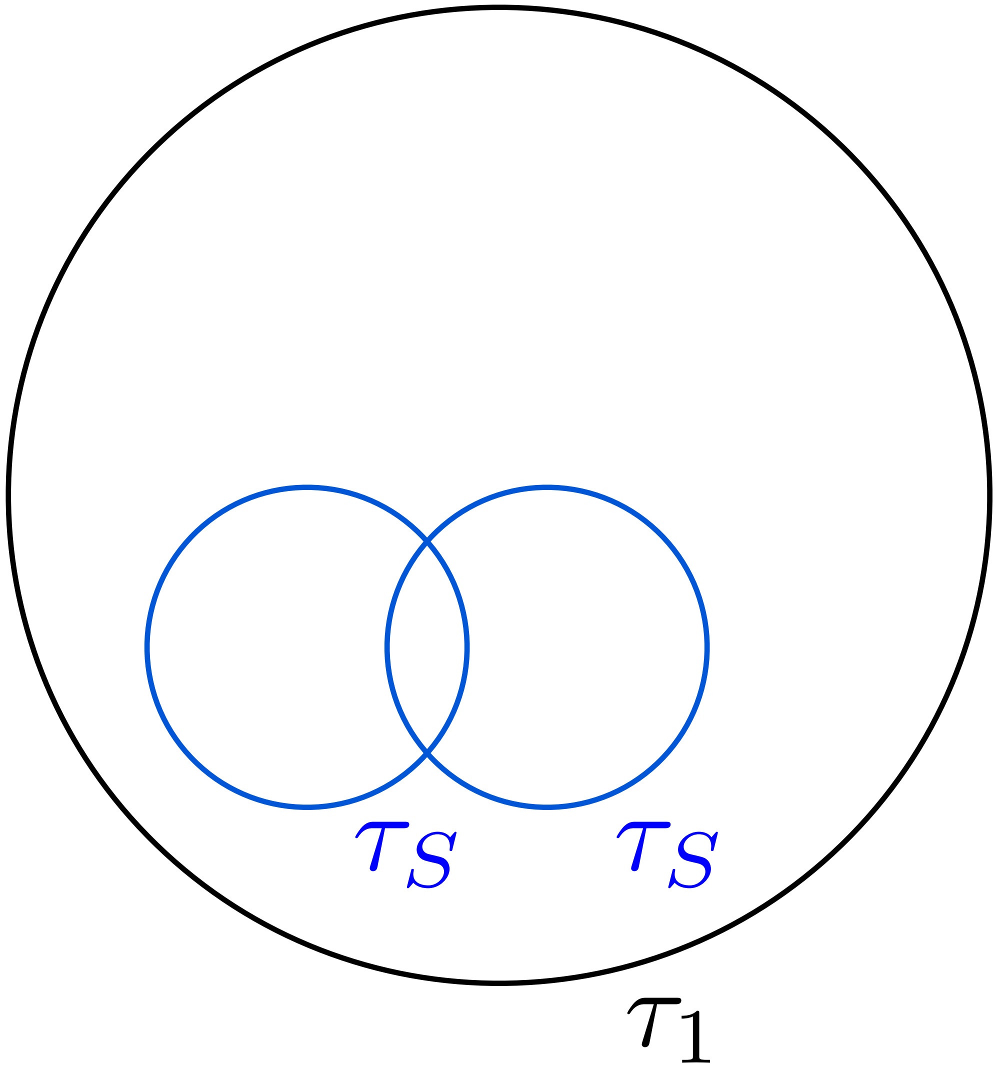
$$\boxed{\xi_D = 0 \Rightarrow \tau_2 = \tau_3}$$

D-term Racetrack uplift

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

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

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



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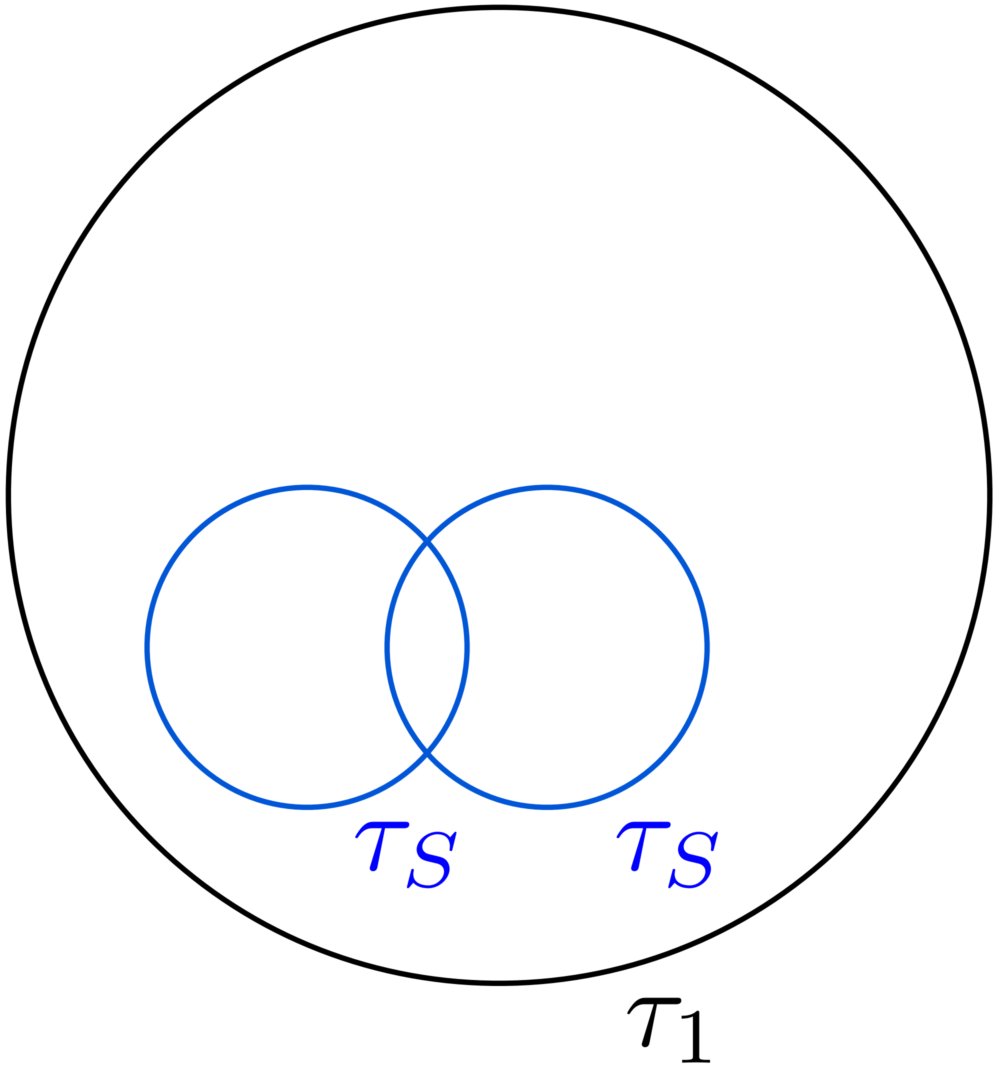
Allows de Sitter for

$$\boldsymbol{c_2/c_3 < 0,\ a_3/a_2 < 1\ !}$$



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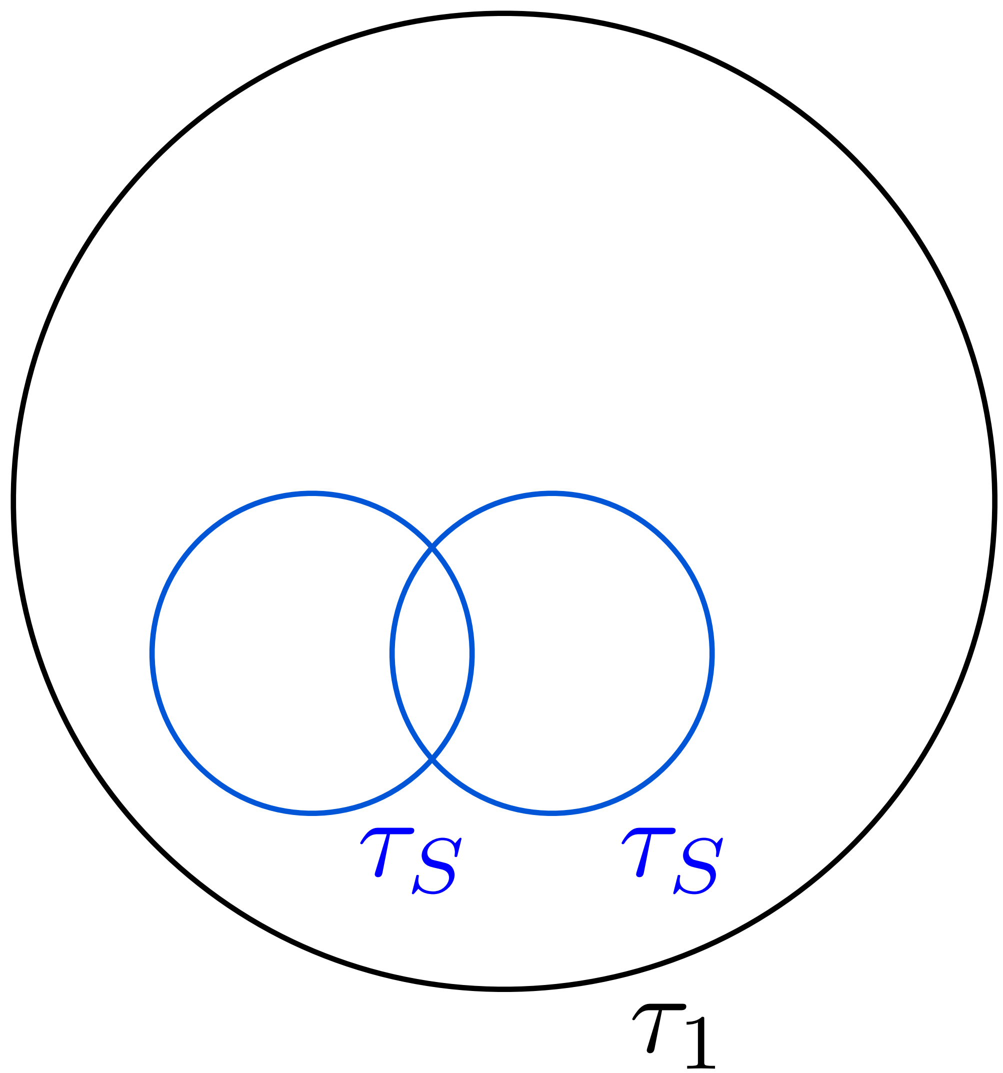
Allows de Sitter for
$\boldsymbol{c_2/c_3 < 0,\ a_3/a_2 < 1}$ **!**

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)



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:

- Matter field stabilization and $\xi_D = 0$
- 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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$\Rightarrow$ **Scan toric Calabi-Yaus!** [Kreuzer, Skarke 00], [Altman, Gray, He, Jejjala, Nelson 14]

Matter field stabilization

- In general $\mathcal{F}_D \neq 0$ leads to hidden sector matter fields living on D_2 , D_3 and $D_2 \cap D_3$

$$V = V_D + V_{matter}$$
$$= \frac{1}{\mathcal{V}^\alpha}\left(\sum_i^N q_i|\phi_i|^2 - \frac{\tilde{\xi}}{\mathcal{V}}\right)^2 + \frac{1}{\mathcal{V}^\beta}\sum_i^N a_i|\phi_i|^2 + \frac{1}{\mathcal{V}^\gamma}\sum_i^N c_i|\phi_i|^4 + \dots$$

- For certain parameters, in particular tachyonic soft masses $a_i < 0$, minima with

$$\langle|\phi_i|\rangle \neq 0 \ (\Rightarrow A_2, A_3 \neq 0)\,, \ \ \textstyle\sum_i^N q_i\langle|\phi_i|^2\rangle = 0 \ (\Rightarrow \xi_D = 0)$$

Scanning for explicit examples

Checklist for simplest realization of D-term generated racetrack:

- Two rigid, only self-intersecting, small divisors D_2, D_3 leading to two ED3 instantons, avoids Freed-Witten anomalies, inside Kähler cone
- Irreducible divisor D_D intersecting D_2, D_3 generates $\xi_D = 0$ via $\mathcal{F}_\mathcal{D} = f_2 D_2 + f_3 D_3$ via 8 D7 branes on D_D, $O_7 : z_D \mapsto -z_D$
- $Q_{D3} \sim \int F_3 \wedge H_3 - \frac{\chi(D_D)}{2} - \int \mathcal{F}_D \wedge \mathcal{F}_D$

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PRELIMINARY

An explicit example

rigid

$$\mathcal{V} = \tau_b^{3/2} - \tau_2^{3/2} - \tau_3^{3/2} \qquad D_D = 4D_b - 2D_2 - 2D_3$$

PRELIMINARY

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- $\mathcal{F}_D \Rightarrow \tau_2 = \frac{9}{16}\tau_3 \qquad Q_{D3} = \int F_3 \wedge H_3 - 20 \quad \chi(D_D) = 240$

PRELIMINARY

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rigid (→ τ_2, τ_3)

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- AdS LVS solution: $A_2 = -0.1,\ A_3 = 0$

$$\langle \mathcal{V} \rangle = 3.7 \cdot 10^5\,, \qquad \langle \tau_s \rangle = 2.13\,, \qquad \langle V \rangle = -1.1 \cdot 10^{-18}$$

An explicit example

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- D-term racetrack **dS**: $A_2 = -0.1,\ A_3 = 2 \cdot 10^{-5}$

$$\langle \mathcal{V} \rangle = 5.2 \cdot 10^5\,, \qquad \langle \tau_s \rangle = 2.20\,, \qquad \langle V \rangle = 2.3 \cdot 10^{-19}$$

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
- Price: additional cycle with NP effect + D-term
- Search for examples can be highly automated using toric geometry
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Thank you for your attention!