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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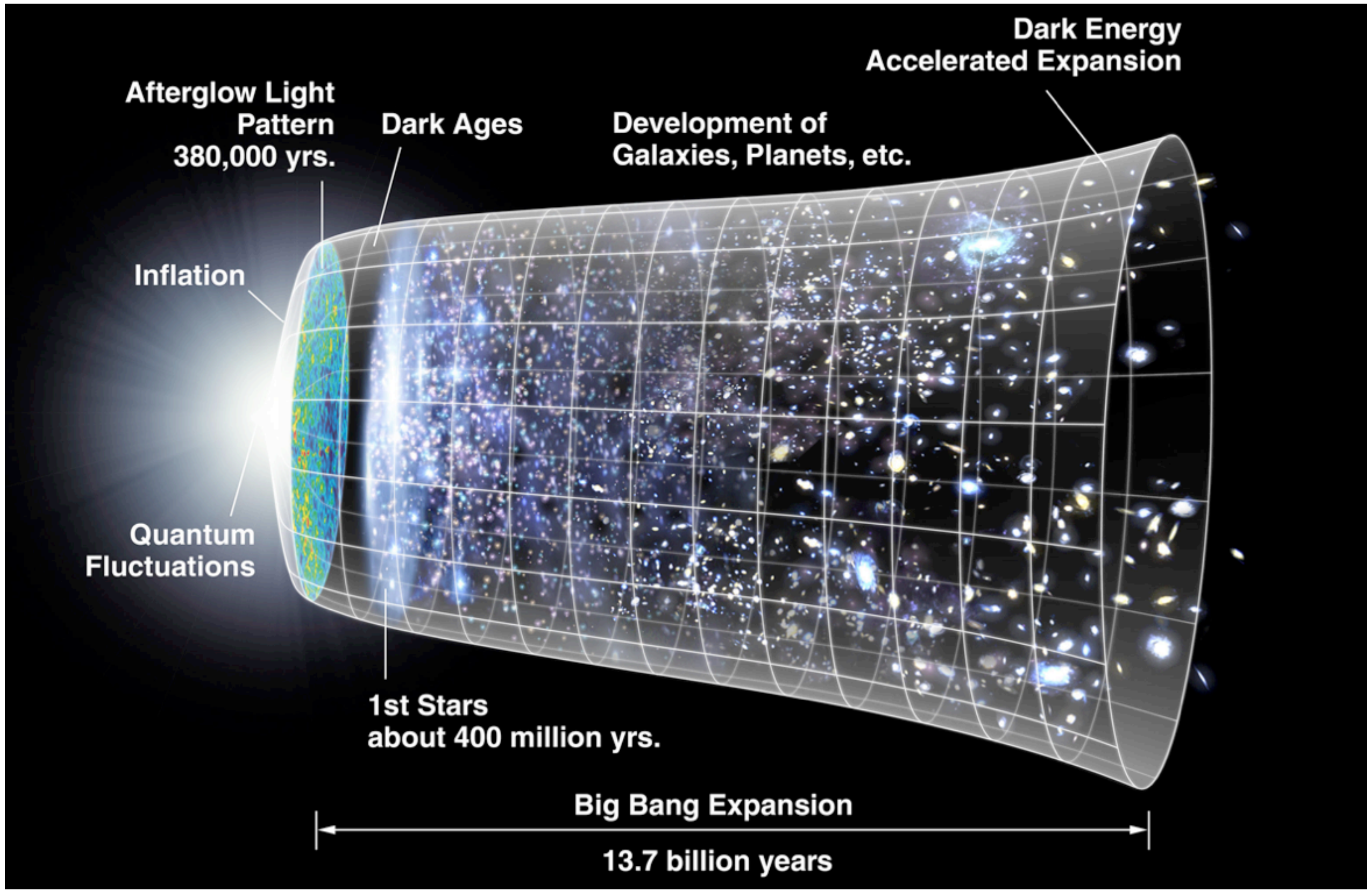
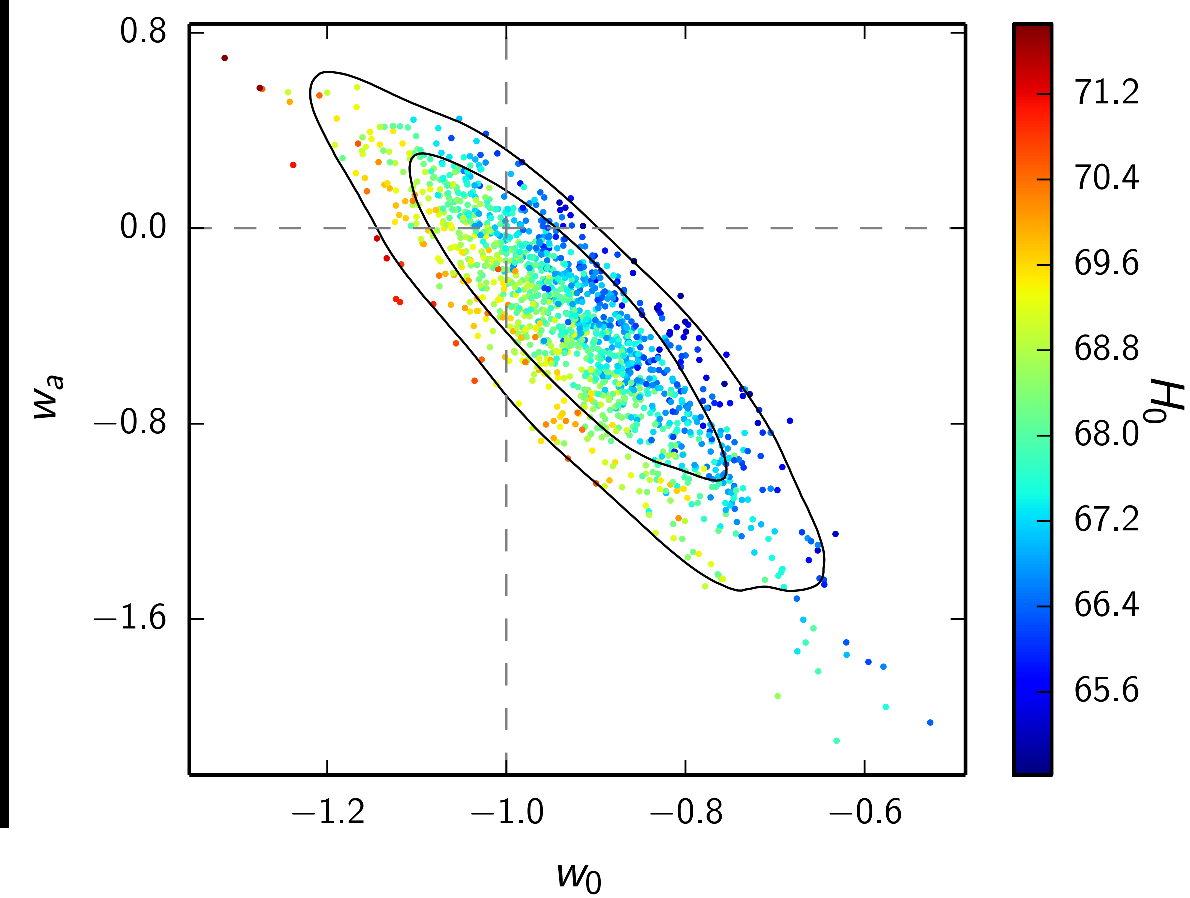
String Pheno Madrid 2015, 09/06/2015

UNIVERSITY OF OXFORD

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: $m_{\phi_a} \gtrsim 30 \text{ TeV} \Rightarrow$ Stabilization required
- 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]

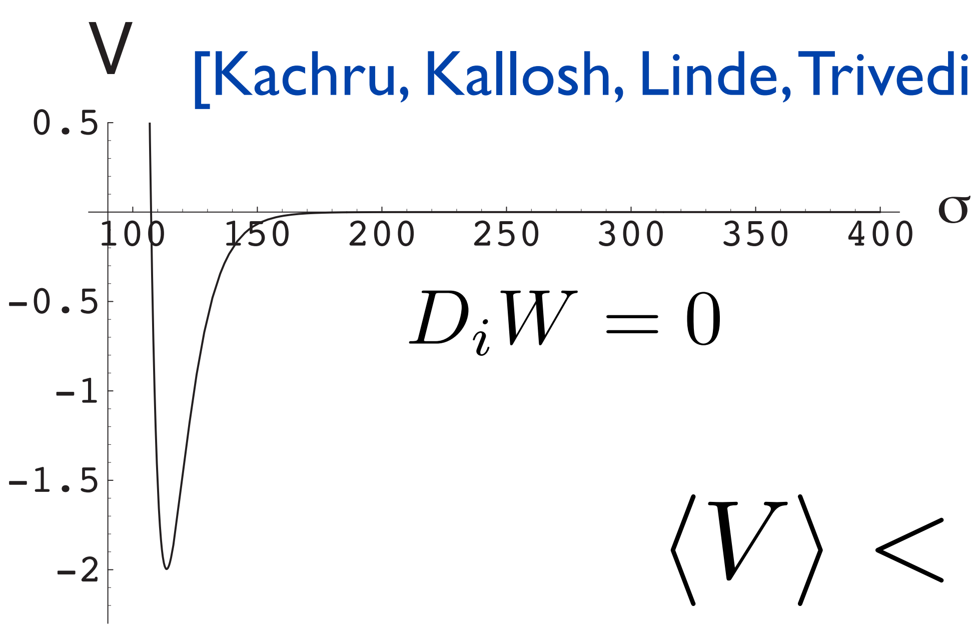
$$V = e^k \left(K^{a\bar{b}} D_a W \, \overline{D_b W} - 3W^2 \right) = \underbrace{V_{\text{Flux}}}_{\mathcal{O}(\mathcal{V}^{-2})} + \underbrace{V_{\text{NP}} + V_{\alpha'}}_{\mathcal{O}(\mathcal{V}^{-3})}$$

and V_{Flux} positive semi-definite

$\Rightarrow$ Flux stabilized moduli can be integrated out

KKLT:

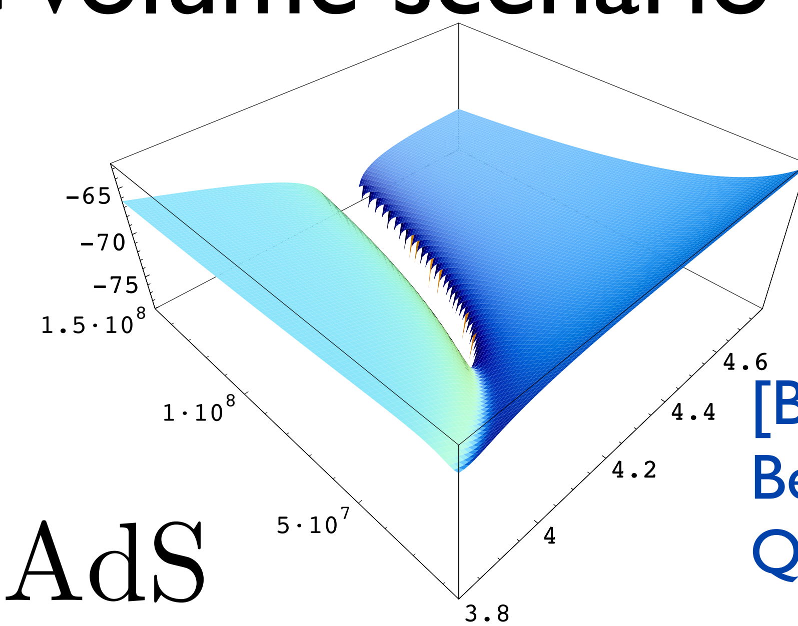
[Kachru, Kallosh, Linde, Trivedi 03]



$D_i W = 0$

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

Large Volume scenario (LVS):



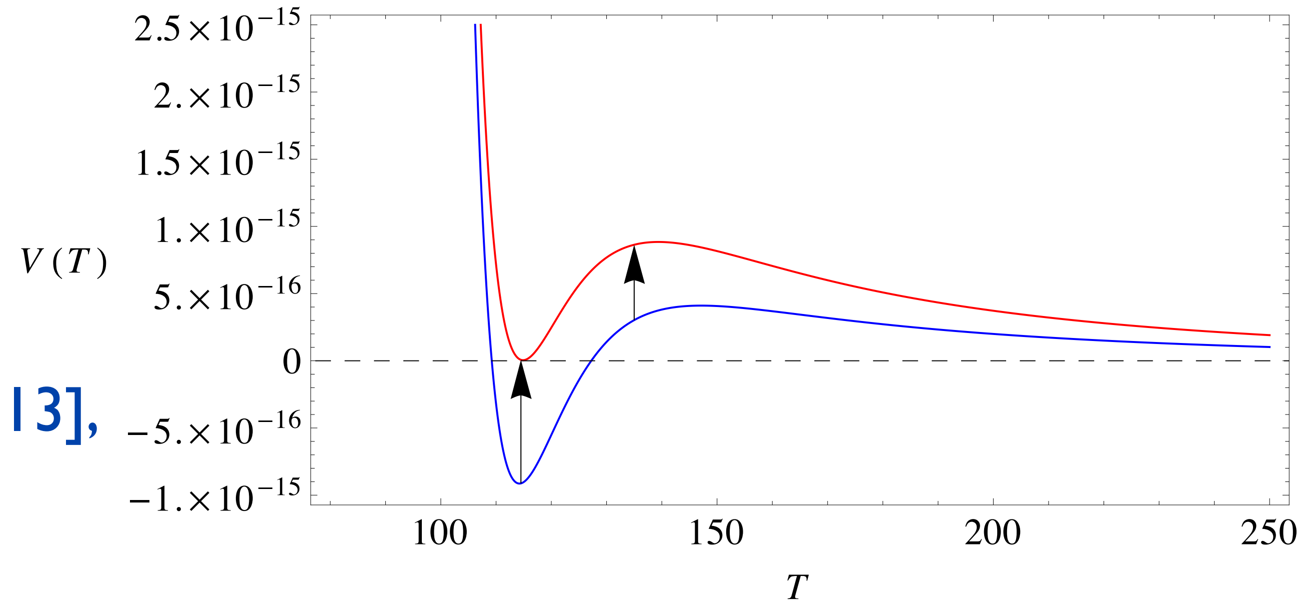
$\partial_i V = 0$

[Balasubramanian, Berglund, Conlon, Quevedo 05]

De Sitter uplifting

- Anti D3 branes

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



- 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]

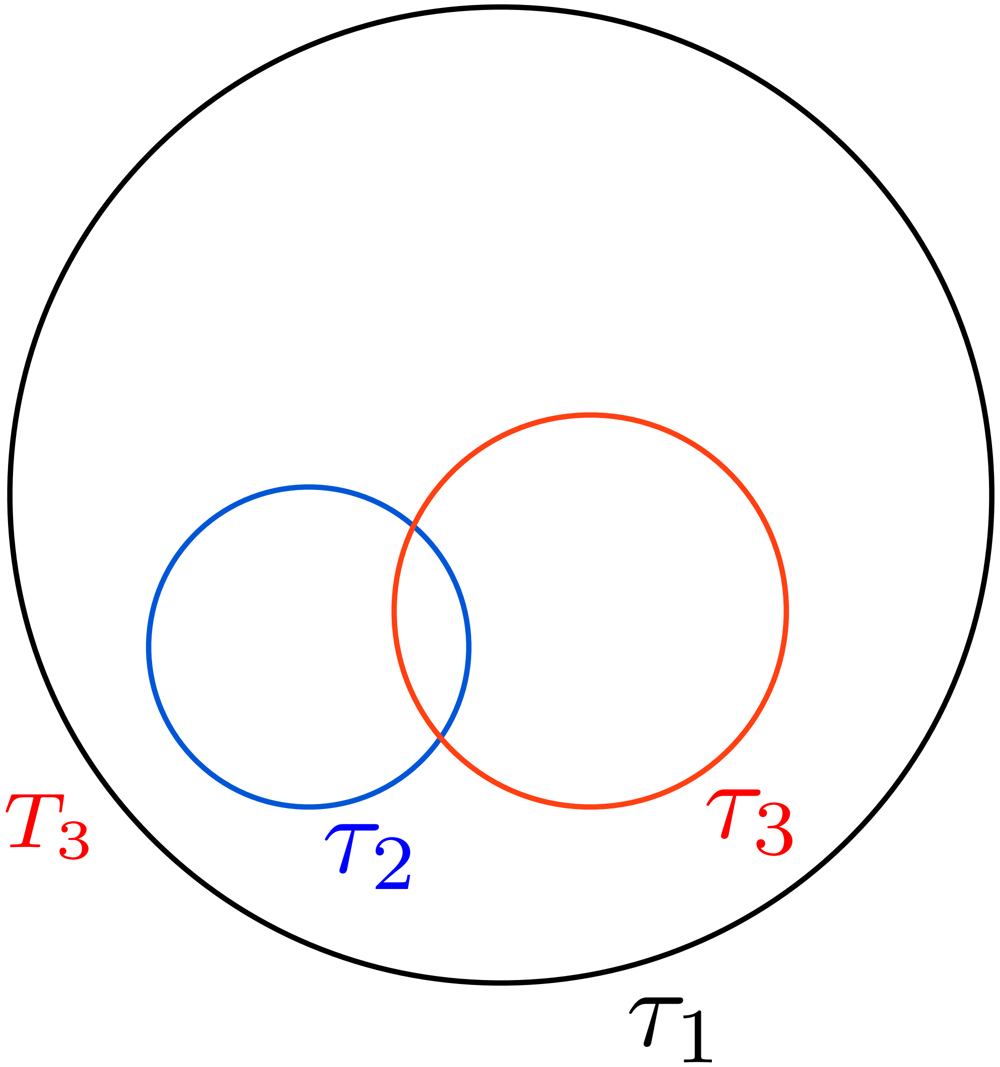
- non-perturbative dilaton effects

  [Cicoli, Maharana, Quevedo, Burgess 12]

- Kähler uplifting [Balasubramanian, Berglund 04], [Westphal 06], [MR, Westphal, 11], [de Alwis, Givens 11], [Sumitomo, Tye, Wong 13]

D-term Racetrack uplift

[MR, Sumitomo 14]



- $K = -2\ln\left(\mathcal{V} + \frac{\xi}{2}\right)$,
  $\mathcal{V} = \tau_1^{3/2} - \tau_2^{3/2} - \tau_3^{3/2}$

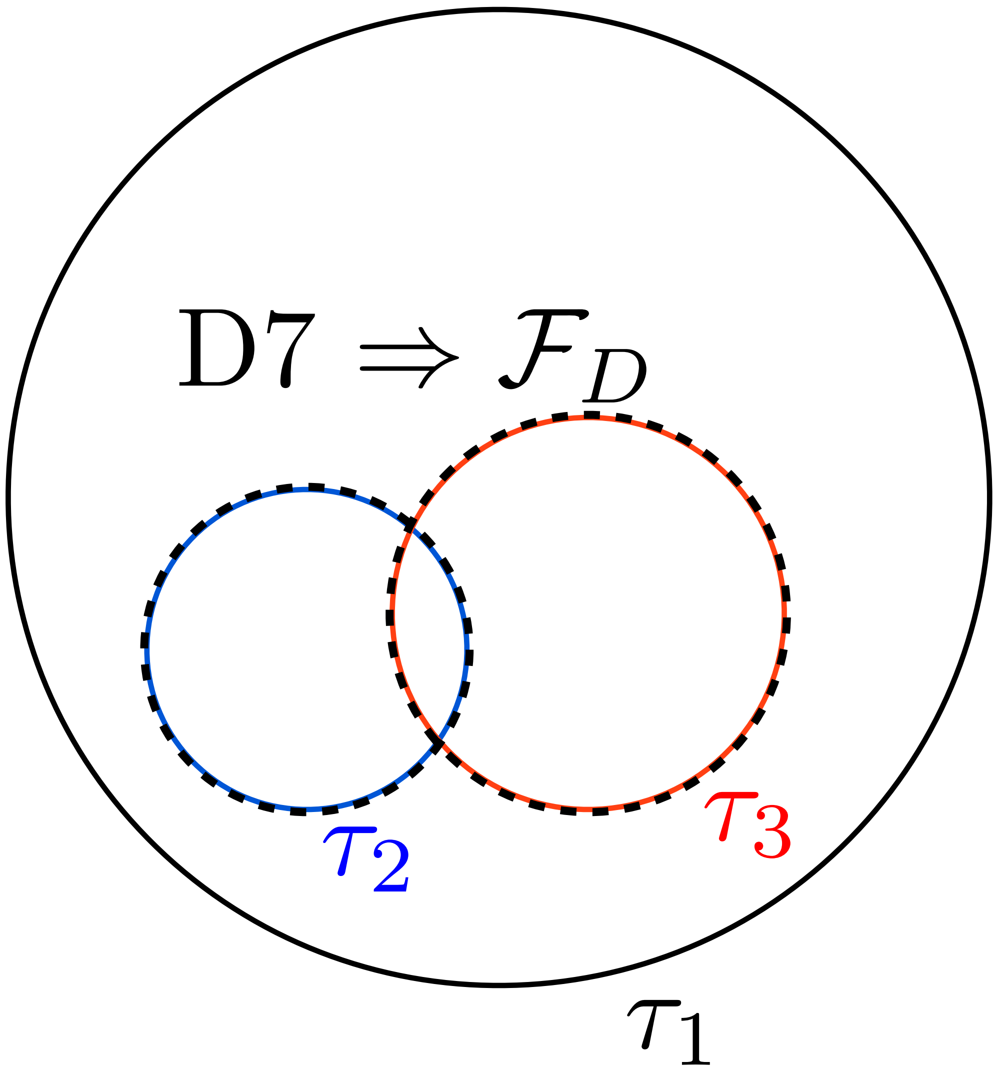
- $W = W_0 + A_2 e^{-a_2 T_2} + A_3 e^{-a_3 T_3}$

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 $D_D \supset D_2, D_3$ 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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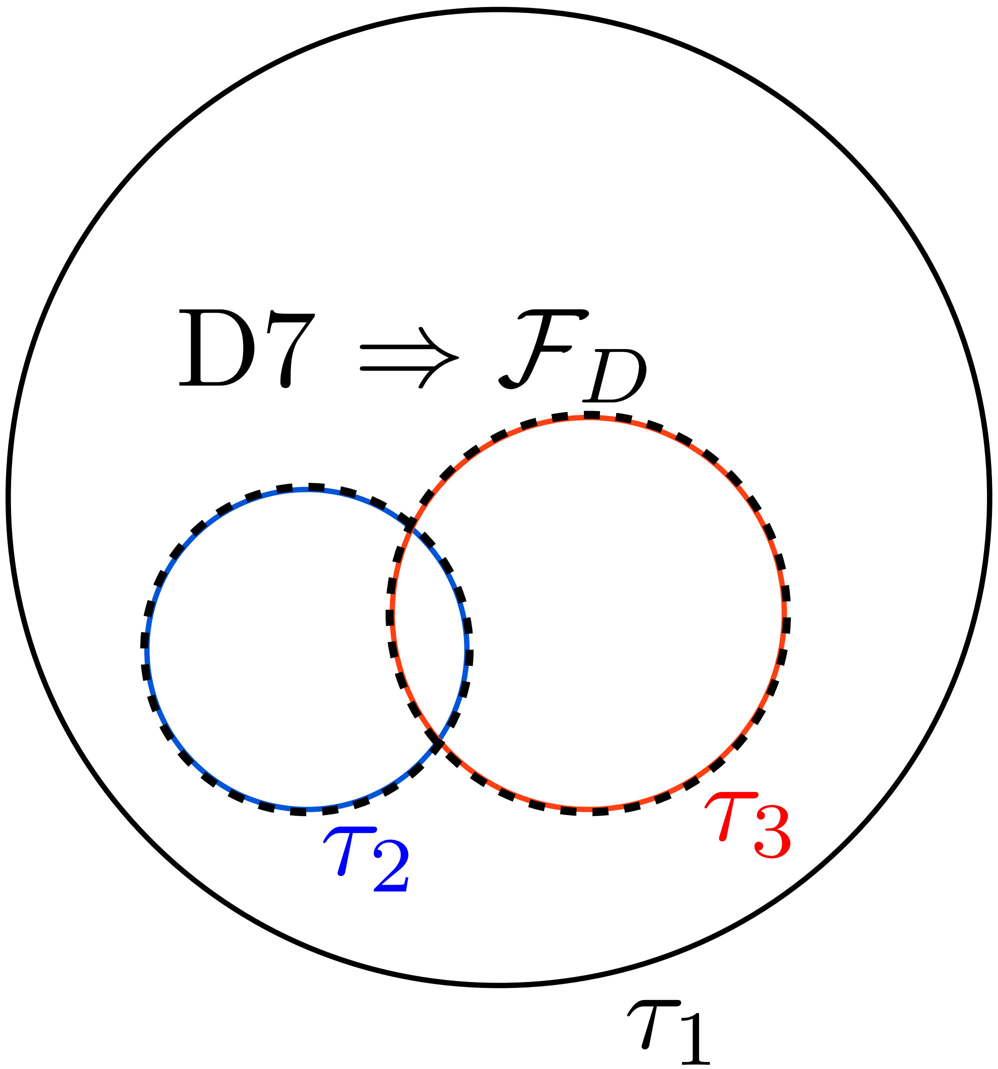

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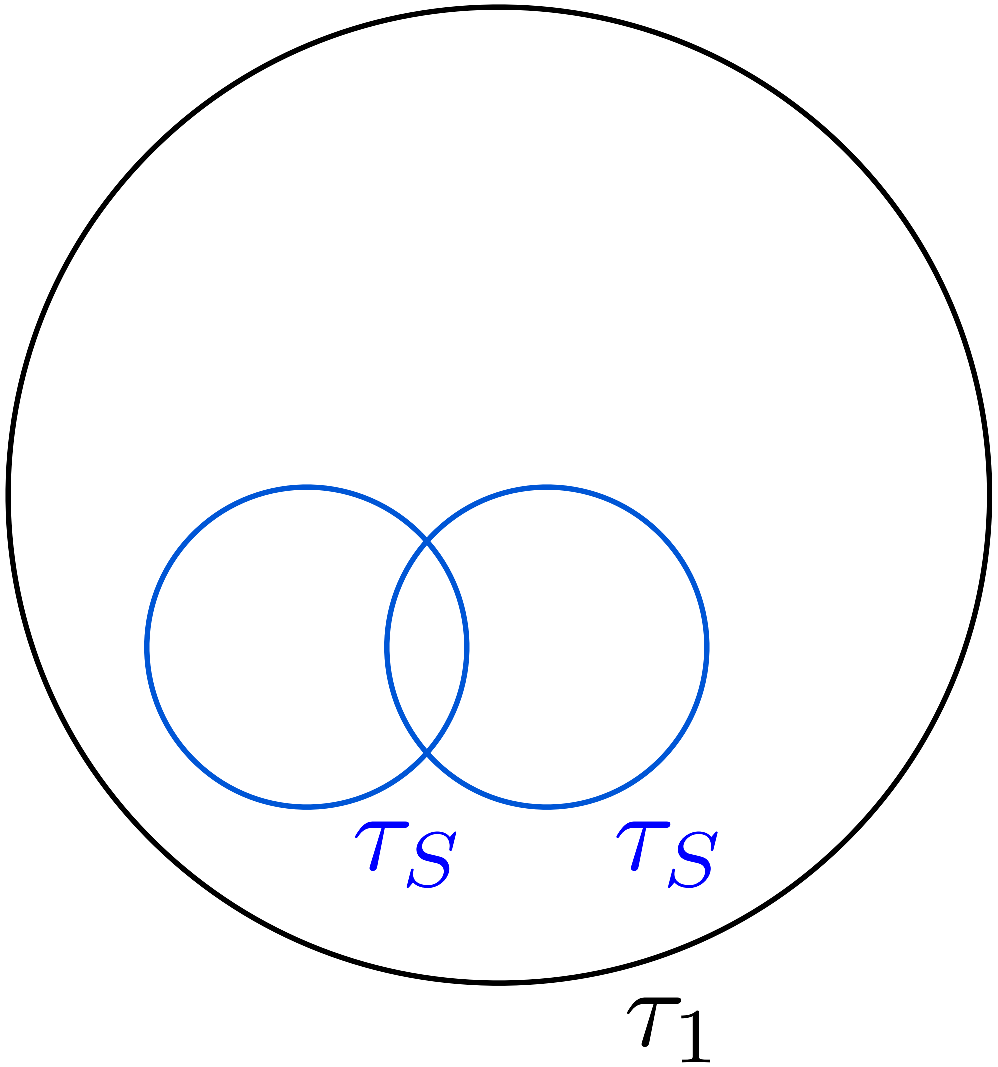
$$\boxed{\xi_D = 0 \Rightarrow \tau_2 = \tau_3}$$

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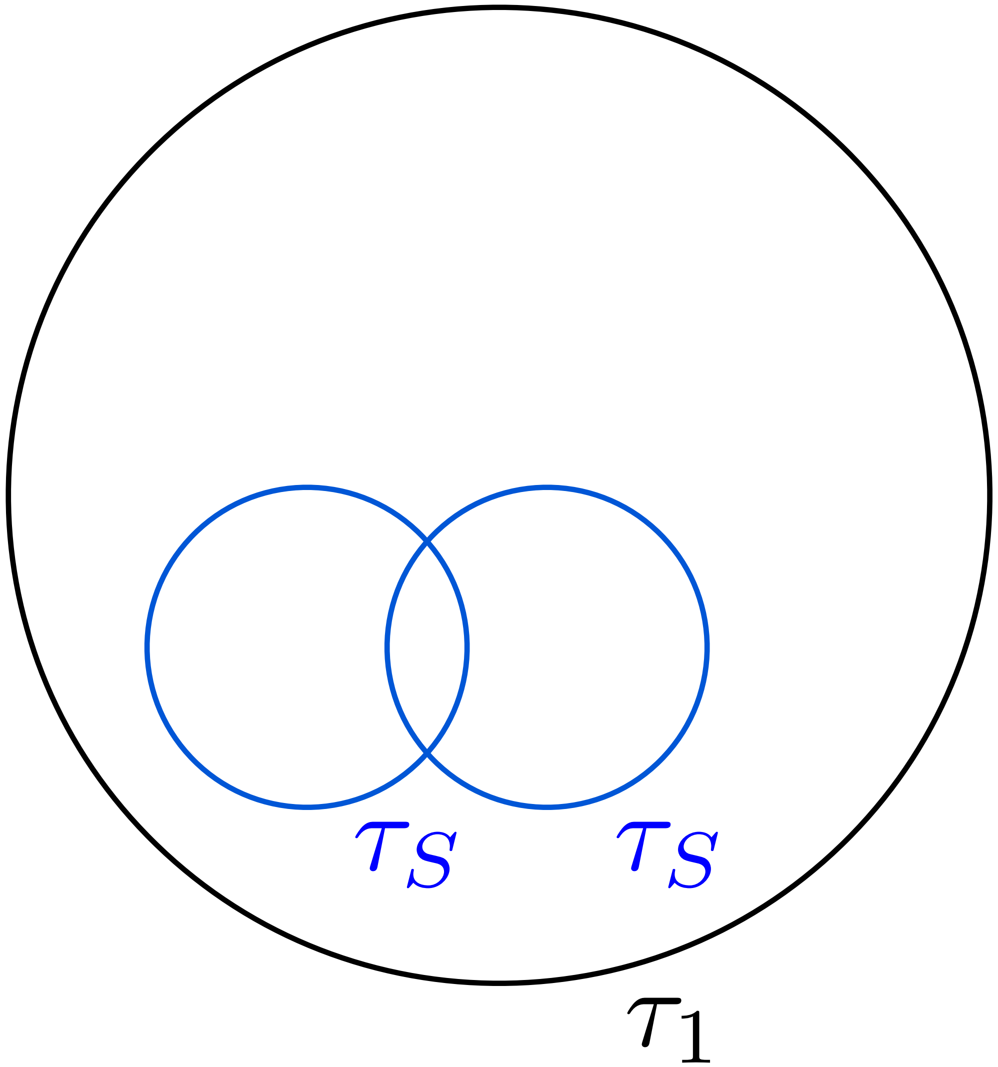
Allows de Sitter for
$c_2/c_3 < 0,\ a_3/a_2 < 1$!



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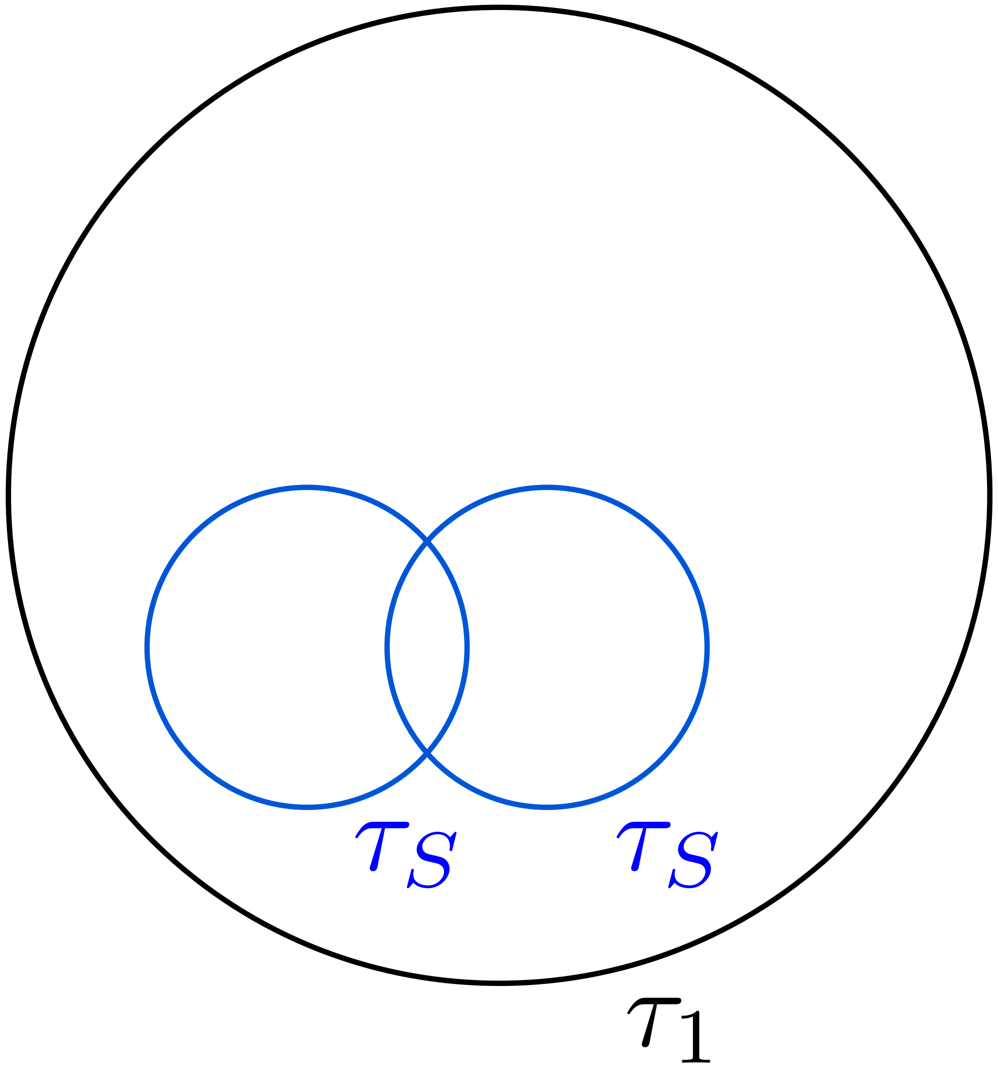
with $c_i = \frac{A_i}{W_0}$

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 because they are rare!

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]

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 via $F_i \supset c_1(D_i)/2$, 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, $O_7 : z_D \mapsto -z_D$
- $Q_{D3} \sim \int F_3 \wedge H_3 - \boxed{\frac{\chi(D_D)}{2}} - \int \mathcal{F}_D \wedge \boxed{\mathcal{F}_D} - \boxed{\frac{\#O3s}{2}}$

An explicit example

Model 257, triangulation 1 of database [Altman, Gray, He, Jejjala, Nelson 14]

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$$h^{1,1} = 3\,, \;\; h^{2,1} = 103$$

rigid

$$\mathcal{V} = \frac{1}{3}\tau_b^{3/2} - \frac{1}{3}\tau_2^{3/2} - \frac{\sqrt{2}}{3}\tau_3^{3/2} \qquad D_D = 4D_b - 2D_2 - 3D_3$$

An explicit example

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$$\mathcal{F}_{2,3} = 0$$

$$B = \frac{D_2}{2} + \frac{D_3}{2} + \sum_{i\neq 2,3} \frac{B_i}{2} D_i = \frac{D_2}{2} + \frac{D_3}{2} \qquad \Rightarrow \boxed{\tau_2 = \tfrac{1}{2}\tau_3}$$

$$\mathcal{F}_D = \sum_{i=1}^{h^{1,1}} F_i^D D_i^{\text{int}} + \frac{D_D}{2} - B = -\tfrac{3}{2}D_2 + D_3$$

An explicit example

Model 257, triangulation 1 of database [Altman, Gray, He, Jejjala, Nelson 14]

$h^{1,1} = 3\,,\ \ h^{2,1} = 103$

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$$\mathcal{F}_D = \sum_{i=1}^{h^{1,1}} F_i^D D_i^{\rm int} + \frac{D_D}{2} - B = -\tfrac{3}{2} D_2 + D_3$$

$$Q_{D3} = \int F_3 \wedge H_3 - 60$$

using $Q_{D3}^{(\mathcal{F}_D)} = -48 \qquad Q_{D3}^{(O7)} = 215/2 \qquad Q_{D3}^{(O3)} = 1/2$

An explicit example

- $\#\text{chiral matter fields} = 9$

  $\#\text{(anti)-symmetric matter fields} = 6$

- Choose parameters $W_0 = 1\,, \qquad \hat{\xi} = 2.5$

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

  $$\langle \mathcal{V} \rangle = 3.3 \cdot 10^6\,, \qquad \langle \tau_s \rangle = 2.47\,, \qquad \langle V \rangle = -1.8 \cdot 10^{-21}$$

- D-term racetrack **dS**: $A_2 = -0.1,\ A_3 = 5 \cdot 10^{-6}$

  $$\langle \mathcal{V} \rangle = 6.0 \cdot 10^6\,, \qquad \langle \tau_s \rangle = 2.57\,, \qquad \boxed{\langle V \rangle = 7.2 \cdot 10^{-22}}$$

... more examples, statistics to come...

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
- Search for explicit examples promising!

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Thank you for your attention!

Backup: 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

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

Backup: Gauge flux

- Flux in a toric basis

$$\mathcal{F}_D = \left(-\tilde{F}_1^D + \tilde{F}_2^D - \frac{3}{2}\right) D_1 + \left(-\tilde{F}_1^D + \tilde{F}_3^D - 2\right) D_2 + \left(\tilde{F}_1^D + 2\right) D_b$$