de Sitter vacua from non-perturbative flux compactifications

Ivonne Zavala
CTN, Groningen

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Based on 1312.5328 (PRD)
w/ Johan Blåbäck & Diederik Roest

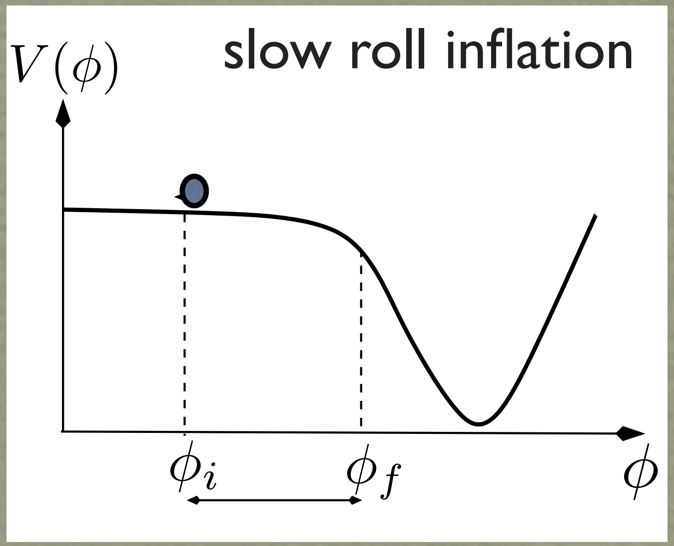
OUTLINE

- Introductory words
- Flux compactifications and de Sitter vacua: KKLT and beyond
- A single step F-term dS stabilisation: the model, tools, solutions, constraints
- Summary and outlook

INTRODUCTORY WORDS

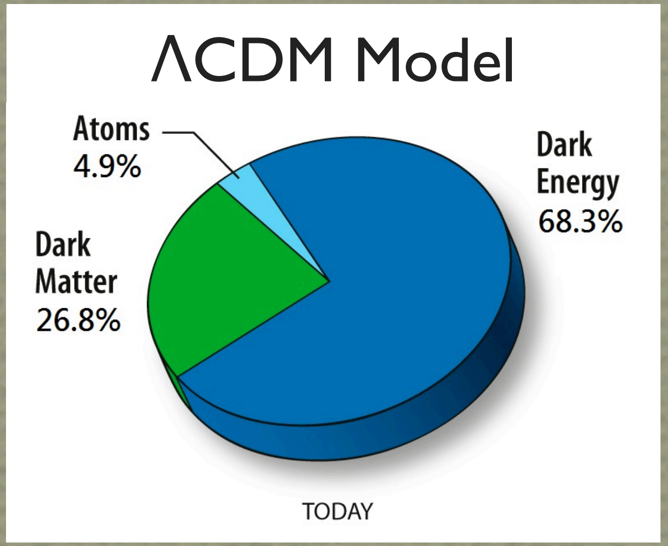
Cosmic acceleration came to stay:

Early Universe: **Inflation**



Late Universe: **Dark Energy**

(~68% energy density content made of Dark Energy)



Cosmological Constant, Λ>0, consistent with data

- Crucial to make further progress in understanding the origin of de Sitter (dS) vacua in string theory

- If amount of dS vacua is huge, string theory landscape may explain the tiny value of the CC today $\Lambda \sim 10^{-120}$ (if responsible for present day acceleration!)

- In any case important to understand dS vacua in ST/SUGRA. Find systematic ways to generate stable dS vacua

FLUX COMPACTIFICATIONS AND DE SITTER

Flux compactification in type IIB: N=1 sugra

[Giddings-Kachru-Polchiski, '01]

1. Fluxes generate a potential for dilaton S and complex structure moduli, Ui. Kähler moduli T remain as flat direction

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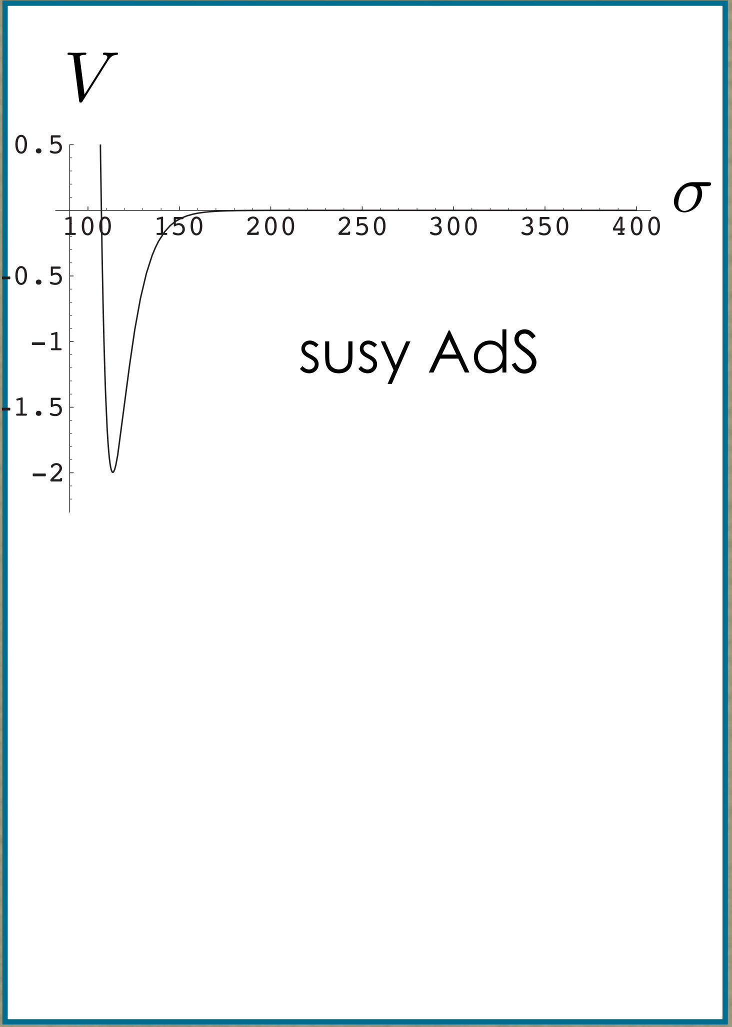

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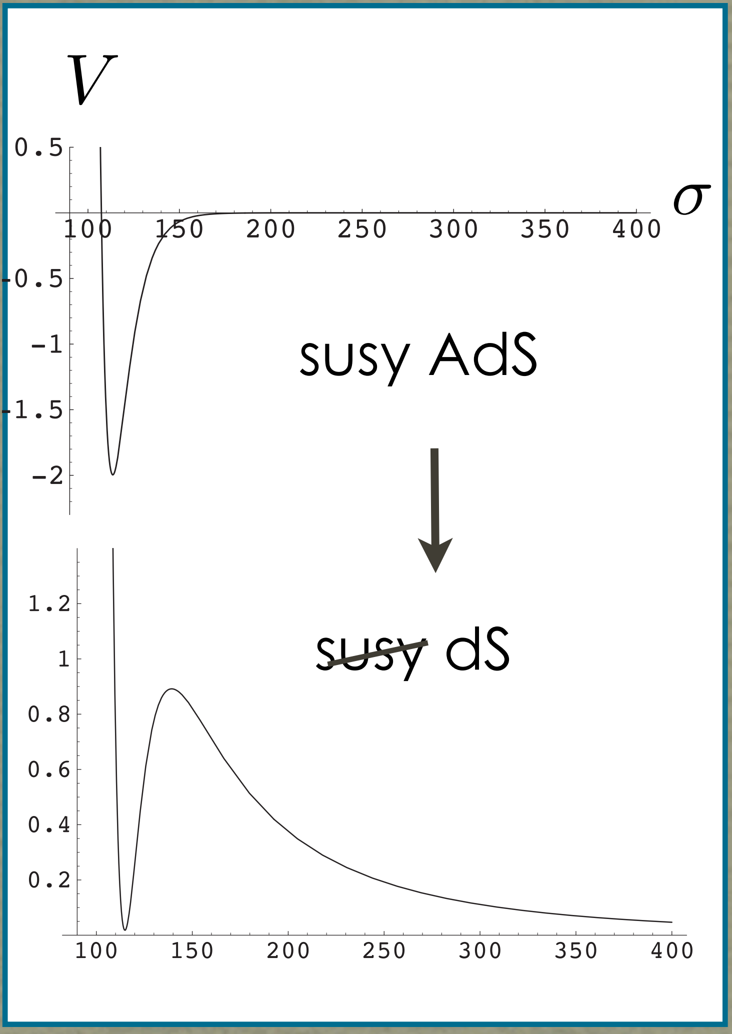

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3. Uplift the minimum to a dS, positive vacuum energy by adding an anti-D-brane

$$V_{tot} = V_{AdS} + V_{uplift}$$

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In type IIA, D-term uplift, F-term uplift, large volume scenario, heterotic (CY&orbifolds), M-theory . . .

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In type IIA, D-term uplift, F-term uplift, large volume scenario, heterotic (CY&orbifolds), M-theory . . .

In 4D N=1, via *duality*, *non-geometric* fluxes were found and *stable dS vacua* have been found in *STU models* with isotropic and non-isotropic fluxes.

[Shelton-Taylor-Wecht, ’05]
[de Carlos-Guarino-Moreno, ’09]
[Damian-Diaz-Loaiza-Sabido, ’13]
[Blåbäck-Danielsson-Dibitetto, ’13]

WIDENING THE DS LANDSCAPE

[Blåbäck-Roest-IZ, '13]*

Consider IIB $T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$ orbifold compactification with (isotropic) fluxes $H_3\,, F_3$ $(S, T_i = T, U_i = U)$

In this case, the Kähler potential is

$$K = -\log[-i(S+\bar{S})] - 3\log[-i(T+\bar{T})] - 3\log[-i(U+\bar{U})]$$

*[Simultaneously with Danielsson-Dibitetto, '13 in IIA]

We consider the tree-level flux superpotential plus a *moduli dependent non-perturbative* term

$$W = P(a_i, U) - SP(b_i, U)$$

$$P(f_i, U) = f_0 - 3f_1 U + 3f_2 U^2 - f_3 U^3$$

$$a_i = \mathrm{RR\ flux}\,,\ \ b_i = \mathrm{NSNS\ flux}$$

$$\tilde{a}_i, \tilde{b}_i = \text{“non-perturbative flux”}$$

$$x = 2\pi/K\,,\ \ \mathrm{for\ gaugino\ condensation}$$

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- *duality covariance* in non-geometric fluxes and heterotic orbifolds*

HETEROTIC ORBIFOLDS

Heterotic $T^6/\mathbb{Z}_N$ orbifolds fertile arena for (semi-)realistic particle physics model building. Free CFT, can compute LEEFT, N=1 sugra.

LEEFT inherits modular symmetry: W, K are modular covariant. In particular (STU) *moduli dependent non-perturbative* terms can be computed:

$$W_{NP} = A_3 e^{-aS} \eta^{\alpha}(T_i, U_j) + A_4 e^{-bS} \eta^{\beta}(T_i, U_j)$$

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We found dS vacua with tachyons. Can we use Johan's et al. approach to include moduli dependent NP terms?

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Form of WNP motivated by

- duality covariance in non-geometric fluxes and heterotic orbifolds*
- fluxed instanton effects [Uranga, '09]
- expansion in small U

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We look for dS vacua in a ***single step stabilisation of all moduli, avoiding SUSY adS stage, direct dS stable vacua***: all moduli contribute to SUSY breaking, lifting the potential

$$V = e^K \left(|DW|^2 - 3|W|^2\right)$$

$$D_i W = \partial_i W + \partial_i K\, W$$

SEARCH FOR SOLUTIONS

We want to find stable dS solutions in an effective way

$$D_I V = 0$$

$$V_0 > 0$$

$$\left(m^2\right)^I_{\ J} = \frac{K^{IJ} D_K D_J V}{V} > 0$$

to solve (numerically) this system we use various techniques

THE ORIGIN

Any solution to the equations of motion can be represented by a solution in the origin of moduli space:

[Dibitetto-Guarino-Roest,'11]

$$S = T = U = i$$

The solution can be move to any point using symmetries of the potential, preserving the solution

The equations reduce to quadratic equations in the fluxes!

$$D_I V = \sum (\text{fluxes})^2 (\text{scalars})^{(\text{mixed powers})}$$

For the non perturbative term, $f(U,S)e^{-ixT}$ at the origin we also take

$$x = 1$$

~~SUSY~~ Ansatz

[Danielsson-Dibitetto, '12]

Equations of motion are implied by SUSY

$$D_I W \equiv A_I + i B_I = 0 \quad \Rightarrow \quad D_I V = 0$$

these ~~SUSY~~ parameters A_I, B_I are linear combinations of fluxes. Split these into SUSY and ~~SUSY~~ combinations.

When written in terms of the ~~SUSY~~ parameters, the eom`s take schematic form:

$$D_I V = \sum (\cancel{\mathrm{SUSY}})^2 + \sum (\cancel{\mathrm{SUSY}})(\mathrm{SUSY})$$

In other words, they become linear in the fluxes (SUSY combi)

For this to work, one needs at least as many SUSY & ~~SUSY~~ parameters (2N) as real fields (N=real fields):

- ➡ Specify the ~~SUSY~~ parameters
- ➡ Solve the N linear SUSY equations for N of the fluxes
- ➡ Solve the N linear eom wrt the other N fluxes
- ➡ Look for stable dS

With this approach, all fields take part in ~~SUSY~~

- We have 6 real fields STU: need 12 fluxes.

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- We add 4 more non-perturbative fluxes $\tilde{a}_i$

$$W = P(a_i, U) - SP(b_i, U) + P(\tilde{a}_i, U)\, e^{ixT}$$

GENETIC ALGORITHM

[Blåbäck-Danielsson-Dibitetto, '13]
[Damian-Diaz-Loaiza-Sabido, '13]

1. Select a population at random (vectors of ~~SUSY~~)
2. Calculate all desired quantities ($V, m^I_J \ldots$)
3. Mutate (perturb some parts of ~~SUSY~~ vectors)
4. Calculate properties for children
5. Select best solutions using fitness function
6. Repeat 3-6 until termination

Solutions: abundant!

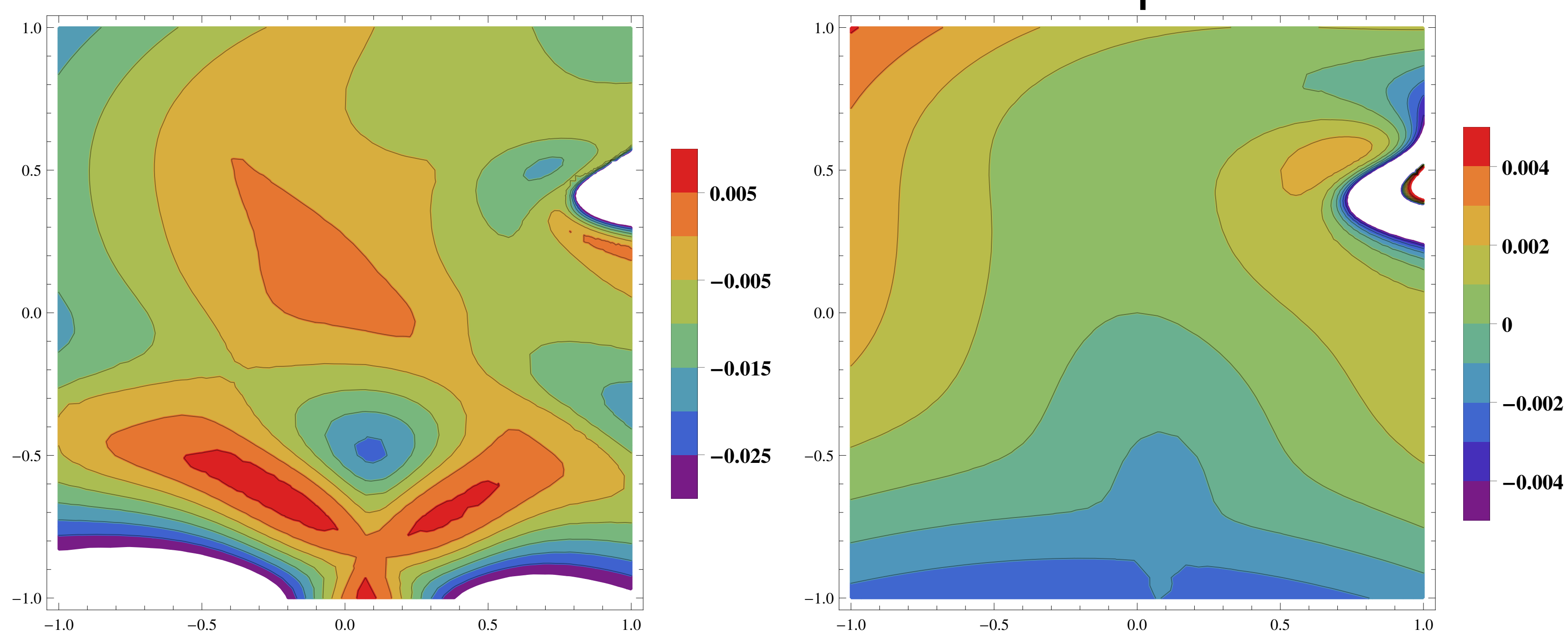
	Sol. 1	Sol. 2	Sol. 3	Sol. 4	Sol. 5
V_0	0.00113	2.23×10^{-12}	0.0000251	0.0000234	8.61×10^{-12}
$\tilde{\gamma} - 1$	0.0256	5.11×10^{-11}	0.00248	0.0160	6.05×10^{-10}
$\frac{\lvert b_i \rvert}{\lvert a_i \rvert}$	0.298	0.599	1.32	0.208	0.997
$\frac{\lvert \tilde{a}_i \rvert}{\lvert a_i \rvert}$	0.611	0.274	0.528	0.621	0.000227
Masses	39.0	2.11×10^{10}	1140.	76.2	2.20×10^{9}
	19.7	8.71×10^{9}	387.	36.0	9.80×10^{8}
	12.4	7.00×10^{9}	106.	19.6	2.45×10^{8}
	9.74	3.41×10^{9}	18.4	11.4	490000.
	0.00236	1.26×10^{9}	6.16	0.774	101000.
	0.0000747	6.01×10^{8}	0.0000612	0.000252	100000.

	Sol. 1	Sol. 2	Sol. 3	Sol. 4	Sol. 5
A_1	−0.147286	−0.0859982	0.0590861	−0.0115235	0.000516097
A_2	0.449418	−1.58993	−0.483429	0.165447	1.15243
A_3	−0.907814	0.4631	−0.131249	−0.144582	−0.000587804
B_1	0.377918	−0.236806	0.0870739	0.0793589	0.00319387
B_2	1.6678	−1.12127	0.826607	0.259372	−0.196848
B_3	0.173821	−0.047207	−0.0614712	0.0902761	−0.00969035

$$\tilde{\gamma} = \frac{|DW|^2}{3|W|^2}$$

Stability/dS overlap very large (c.t. non-geo solutions)

solution 2 landscape



stability

dS

Constraints

Can get a reliable N=1 sugra solution

- Large Volume $\mathcal{V} \sim r^6 \gg 1$ $\quad$ $\mathrm{Im}\, T = \mathcal{V}^{2/3}$
- Small string coupling $g_s^{-1} \gg 1$ $\quad$ $(\mathrm{Im}\, S)^{-1} = g_s$
- Flux quantisation

by rescaling of the fluxes and $x = 2\pi/K$

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Rescaled Solution 5

$$\{a_0, a_1, a_2, a_3, b_0, b_1, b_2, b_3, K\} = \{-1, 4, 1, -12, 4, 0, -1, 0, 67\}$$

$$\Downarrow$$

$$\{\tilde{a}_0, \tilde{a}_1, \tilde{a}_2, \tilde{a}_3\} \approx \{0.180917, -0.0186322, 0.0494774, 0.0191168\}$$

$$V_0 \sim 1.3 \times 10^{-7}$$

$$m_i \sim \{70027.5, 29274.4, 6043.98, 338.867, 16.0712, 7.88339\}$$

$$\mathcal{V} \sim 50\,, \qquad g_s \sim 0.2$$

SUMMARY/OUTLOOK

- Extended the dS landscape in type IIB flux compactifications
- One step (F-term) dS moduli stabilisation using moduli dependence of non-perturbative terms.
- Our work has motivated recent work on analytic method to construct abundant of dS vacua!

[Kallosh-Linde-Vernocke-Wrasse,’14]

- Of course need to extend to more realistic STiUi case, compute NP term, relax of ~~susy~~ Ansatz, etc

GRAZIE