Mass Production of Stable de Sitter Vacua

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de Sitter Constructions in String theory

December 2019, Saclay

Based on recent series of papers with A. Linde, T. Wrase, N. Cribiori, C. Roupec

1808.09427, 1909.08629

In this talk: 1910.08217, 1912.00027, 1912.02791

The main result:

In M-theory/string theory inspired d=4 N=1 supergravity including a nilpotent multiplet (representing **pseudo-calibrated anti-Dp-branes**) we found a **relatively simple regular procedure** to construct **stable de Sitter minima** in theories with many moduli and many different Kahler potentials and superpotentials associated with **M-theory**, **type IIA** and **type IIB string** theory.

The necessary conditions are:

1) The model requires a **progenitor**: a **supersymmetric Minkowski minimum without flat directions**. This happens if $\partial_i W = 0$ and $W = 0$ at a finite point (or a series of disconnected points) in the moduli space, **W** being the superpotential of the model.

2) The progenitor model has to be deformed: first, a downshift to a supersymmetric AdS minimum, via a **parametrically small deformation** of W. This can be achieved by adding a small constant (or a small function) ΔW to **W** .

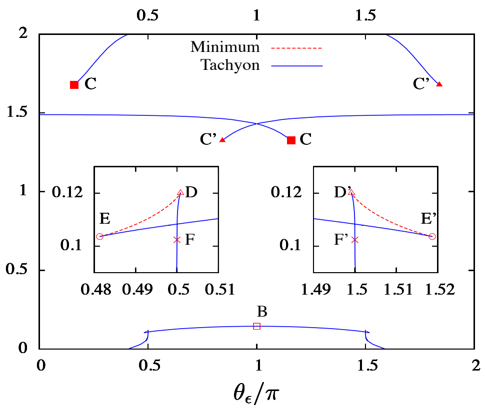
3) A **nilpotent chiral multiplet** has to be added to the original model to uplift AdS to a **dS minimum**. If the **supersymmetry breaking scale is parametrically small**, then the resulting potential inherits the shape of the original potential in the vicinity of the Minkowski minimum, i.e. **the final dS state is also a minimum**.

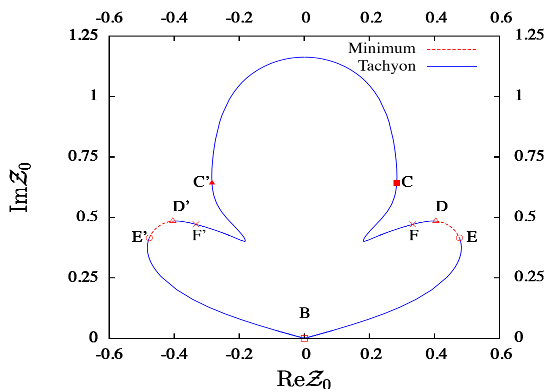
The main **difference** with many recent attempts to find dS minima in 4d $\mathcal{N}$=1 string theory motivated supergravity: We are not randomly scanning around for dS solutions, but we simply construct them via the mass production mechanism, with the guaranteed outcome

example

de Carlosa, Guarino, Moreno, 0911.2876

Danielsson, Van Riet 1804.01120





Susy breaking Minkowski vacua in 3-moduli isotropic STU geometric flux models, mostly tachyons

With geometric fluxes, with an increased number of free parameters, it turns out to be possible to find metastable dS-vacua. They are scarce, but they exist.

Typically the dS vacua hide in very small corners in the landscape of allowed fluxes

Damian et al. 2013

In all our new models we start with Minkowski susy minima, there are no tachyons! Flat directions (might lead to instability after the uplift) are easy to avoid. All our new **7-moduli** non-isotropic S T_I U_K models originating from type IIA, type IIB string theory start with Minkowski susy minima without flat directions and lead to dS minima, as predicted, no fine tunig required!

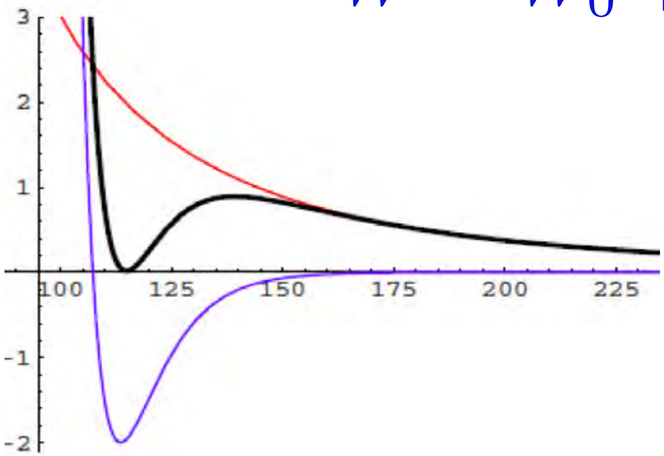
We also found dS minima in 4d, N=1, 7-moduli supergravity directly originating from M-theory

KKLT 2003, 2014

$$K = -3\ln\left(-i(T-\bar{T})\right) + X\bar{X}$$

or $$K = -3\ln\left(-i(T-\bar{T}) - X\bar{X}\right)$$

$$W = W_0 + Ae^{iaT} + \mu^2 X$$



KKLT anti-D3-uplift of AdS generates **dS** minimum

Only **after I have run a Mathematica nb**, I saw the minimum in AdS and in dS after uplifting

It was not predicted, but was one of our many attempts to find a relevant **K** and **W**. It gave us a dS minimum in 4d supergravity.

It was our first attempt to address the observational fact that 4d General Relativity with a **positive extremely small CC fits the data**.

Not much new (KL, LVC, …) till very recently 2018-2019:
mass production of dS vacua in type IIA and type IIB

dS minima in multiple moduli models are **predicted analytically**,
for specific choices of **K** and **W,** in a 3 step procedure.

The goal of Mathematica nb's is to check and illustrate the predictions.

My favorite example:

Maximal supersymmetry spontaneously broken to the minimal supersymmetry

$$\boxed{\textbf{Seven-moduli } [SL(2,\mathbb{R})]^7 \textbf{ model}}$$

M-theory (11d supergravity with local sources), string theory (10d supergravity with local sources), $\mathcal{N}$=8 supergravity with duality symmetry

$$E_{7(7)}(\mathbb{R}) \supset [SL(2,\mathbb{R})]^7$$

Perturbative UV finiteness?

7 benchmarks for future primordial gravitational wave detection, LiteBIRD

4d Mass Production of dS vacua

$$V^{dS} = e^{K^{dS}}(|D_I W^{dS}|^2 - 3|W^{dS}|^2) \qquad \Phi^I = \{\Phi^i, X\}$$

$$K^{dS} = K(\Phi,\bar\Phi) + K_{X,\bar X}(\Phi,\bar\Phi)X\bar X\ , \qquad W^{dS} = W(\Phi) + \mu^2 X \qquad X^2 = 0$$

Second derivative of the potential

$$\mathcal{M}^2 = \begin{pmatrix} V_{i\bar j} & V_{ij} \\ V_{\bar i\bar j} & V_{\bar i j}\end{pmatrix} \qquad \partial_i V = 0,$$

In our examples this matrix is block-diagonal in the real basis

$$\Phi^i = \phi^i + i\theta^i$$

$$\left.\begin{pmatrix} V_{\phi^i\phi^j} & V_{\phi^i\theta^j} \\ V_{\theta^i\phi^j} & V_{\theta^i\theta^j}\end{pmatrix}\right|_{dS} = \begin{pmatrix} V^{Mink}_{\phi^i\phi^j} + \Delta_{\phi^i\phi^j} + \tilde\Delta_{\phi^i\phi^j} & 0 \\ 0 & V^{Mink}_{\theta^i\theta^j} + \Delta_{\theta^i\theta^j} + \tilde\Delta_{\theta^i\theta^j}\end{pmatrix}$$

1) **Progenitor** model $\quad V^{Mink}_{\phi^i\phi^j} = V^{Mink}_{\theta^i\theta^j} > 0$

2) Corrections are parametrically **small** (downshift to supersymmetric AdS) $\quad \Delta_{\phi^i\phi^j} \neq \Delta_{\theta^i\theta^j}$

3) Corrections are parametrically **small** (uplift to dS) $\quad \tilde\Delta_{\phi^i\phi^j} \neq \tilde\Delta_{\theta^i\theta^j}$

$$V^{dS}_{i\bar j} \approx m_{ij} g^{j\bar k}\, \bar m_{\bar k\,\bar j} > 0$$

Prediction

Type IIA motivated

4d Seven-moduli $[SL(2,\mathbb{R})]^7$ model

$$\Phi^i = \{S,\, T_1,\, T_2,\, T_3,\, U_1,\, U_2,\, U_3\}$$

$$K = -\sum_i^7 \log\left(-\mathrm{i}(\Phi^i - \bar{\Phi}^{\bar{i}})\right)$$

$$W = f_6 + \sum_i^7 (A_i e^{\mathrm{i}a_i\Phi^i} - B_i e^{\mathrm{i}b_i\Phi^i})$$

6-flux and KL Double exp W

Free parameters

$A_S = 1$	$A_{T_1} = 3.1$	$A_{T_2} = 3.2$	$A_{T_3} = 3.3$	$A_{U_1} = 11$	$A_{U_2} = 12$	$A_{U_3} = 13$
$a_S = 2$	$a_{T_1} = 2.1$	$a_{T_2} = 2.2$	$a_{T_3} = 2.3$	$a_{U_1} = 0.41$	$a_{U_2} = 0.42$	$a_{U_3} = 0.43$
$b_S = 3$	$b_{T_1} = 3.1$	$b_{T_2} = 3.2$	$b_{T_3} = 3.3$	$b_{U_1} = 1.1$	$b_{U_2} = 1.2$	$b_{U_3} = 1.3$
$S_0 = 1$	$T_{1,0} = 1.1$	$T_{2,0} = 1.2$	$T_{3,0} = 1.3$	$U_{1,0} = 5.1$	$U_{2,0} = 5.2$	$U_{3,0} = 5.3$

7 B_i

f_6

solve 7+1 eqs. **$\partial_i W = 0$** and **$W = 0$**

Stage 1, Minkowski, done

$$\Delta f_6 = -10^{-5}$$

Stage 2, AdS, done

$$V^{uplift}_{\overline{D6}} = \frac{\mu_1^4}{\mathrm{Im}(T_1)\mathrm{Im}(T_2)\mathrm{Im}(T_3)} + \frac{\mu_2^4}{\mathrm{Im}(S)\mathrm{Im}(T_2)\mathrm{Im}(T_3)} + \frac{\mu_3^4}{\mathrm{Im}(S)\mathrm{Im}(T_1)\mathrm{Im}(T_3)} + \frac{\mu_4^4}{\mathrm{Im}(S)\mathrm{Im}(T_1)\mathrm{Im}(T_2)}.$$

Anti-D6 wrapped on various 3-cycles

$$\mu_1^4 = \mu_2^4 = \mu_3^4 = \mu_4^4 = 5.49028 \cdot 10^{-15}$$

A contribution from the nilpotent multiplet X

$$K + K_{X\bar{X}}(\Phi, \bar{\Phi})X\bar{X}$$

$$W + \mu^2 X$$

Stage 3, dS, done

7×7 mass matrix $V_{\phi^i \phi^j}$ in dS

$$\begin{pmatrix}
1.89809 \cdot 10^{-5} & -6.19837 \cdot 10^{-10} & -5.36624 \cdot 10^{-10} & -4.56280 \cdot 10^{-10} & -1.30375 \cdot 10^{-9} & -1.52470 \cdot 10^{-9} & -1.74268 \cdot 10^{-9} \\
-6.19837 \cdot 10^{-10} & 1.30911 \cdot 10^{-4} & -7.38721 \cdot 10^{-10} & -6.46383 \cdot 10^{-10} & -1.24516 \cdot 10^{-9} & -1.44398 \cdot 10^{-9} & -1.64104 \cdot 10^{-9} \\
-5.36624 \cdot 10^{-10} & -7.38721 \cdot 10^{-10} & 9.41667 \cdot 10^{-5} & -5.68241 \cdot 10^{-10} & -1.13520 \cdot 10^{-9} & -1.31758 \cdot 10^{-9} & -1.49834 \cdot 10^{-9} \\
-4.56280 \cdot 10^{-10} & -6.46383 \cdot 10^{-10} & -5.68241 \cdot 10^{-10} & 6.37888 \cdot 10^{-5} & -1.04022 \cdot 10^{-9} & -1.20871 \cdot 10^{-9} & -1.37571 \cdot 10^{-9} \\
-1.30475 \cdot 10^{-9} & -1.24516 \cdot 10^{-9} & -1.13520 \cdot 10^{-9} & -1.04022 \cdot 10^{-9} & 9.96472 \cdot 10^{-4} & -5.36645 \cdot 10^{-10} & -5.74900 \cdot 10^{-10} \\
-1.52470 \cdot 10^{-9} & -1.44398 \cdot 10^{-9} & -1.31758 \cdot 10^{-9} & -1.20871 \cdot 10^{-9} & -5.36646 \cdot 10^{-10} & 1.37262 \cdot 10^{-3} & -6.10079 \cdot 10^{-10} \\
-1.74268 \cdot 10^{-9} & -1.64104 \cdot 10^{-9} & -1.49834 \cdot 10^{-9} & -1.37571 \cdot 10^{-9} & -5.74900 \cdot 10^{-10} & -6.10079 \cdot 10^{-10} & 1.80465 \cdot 10^{-3}
\end{pmatrix}$$

The diagonal values are very close to the ones in Minkowski and in AdS minima, with values of order 10^{-3}- 10^{-5}. All of the off-diagonal terms are many orders smaller, ranging from 10^{-9} to 10^{-10}.

It is therefore not surprising that all mass square eigenvalues in dS are positive, as predicted!

$$\boxed{V^{dS}_{i\bar{\jmath}} \approx m_{ij}\, g^{j\bar{k}}\, \bar{m}_{\bar{k}\,\bar{\jmath}} > 0}$$

	Mink	dS
m_1^2	$1.80473 \cdot 10^{-3}$	$1.80465 \cdot 10^{-3}$
m_2^2	$1.80473 \cdot 10^{-3}$	$1.80465 \cdot 10^{-3}$
m_3^2	$1.37269 \cdot 10^{-3}$	$1.37262 \cdot 10^{-3}$
m_4^2	$1.37269 \cdot 10^{-3}$	$1.37262 \cdot 10^{-3}$
m_5^2	$9.96519 \cdot 10^{-4}$	$9.96472 \cdot 10^{-4}$
m_6^2	$9.96519 \cdot 10^{-4}$	$9.96471 \cdot 10^{-4}$
m_7^2	$1.30924 \cdot 10^{-4}$	$1.30911 \cdot 10^{-4}$
m_8^2	$1.30924 \cdot 10^{-4}$	$1.30911 \cdot 10^{-4}$
m_9^2	$9.41773 \cdot 10^{-5}$	$9.41667 \cdot 10^{-5}$
m_{10}^2	$9.41773 \cdot 10^{-5}$	$9.41660 \cdot 10^{-5}$
m_{11}^2	$6.37973 \cdot 10^{-5}$	$6.37888 \cdot 10^{-5}$
m_{12}^2	$6.37973 \cdot 10^{-5}$	$6.37883 \cdot 10^{-5}$
m_{13}^2	$1.89843 \cdot 10^{-5}$	$1.89809 \cdot 10^{-5}$
m_{14}^2	$1.89843 \cdot 10^{-5}$	$1.89806 \cdot 10^{-5}$

The 2d and 3d plots of the potentials at all 3 stages and in all possible slices in multimodule space we have in the Notebooks. We show them in a simper case of the STU model.

The eigenvalues of the mass matrix for the seven-moduli type example. The mass shift is small, but noticeable, when going from Minkowski to dS. One can also notice, as predicted by the mass production procedure, that in dS the masses of scalars and pseudoscalars are not exactly equal anymore, as was the case in Minkowski.

Type IIB models with KL double exponents in W

$$K = -\log\left(\mathrm{i}\int \Omega\wedge\bar{\Omega}\right) - \log\left(-\mathrm{i}(\tau-\bar{\tau})\right) - 2\log\left(\mathcal{V}_6\right),$$

$$W = \int G_3\wedge\Omega.$$

volumes of the two-cycles

$$\mathcal{V}_6 = \frac{1}{3!}\int J\wedge J\wedge J = \frac{1}{3!}d_{ijk}t_i t_j t_k,$$

complexified Kahler moduli space

$$T_i = \tau_i + i\chi_i,$$

$$\tau_i = \frac{\partial\mathcal{V}_6}{\partial t_i}$$

volumes of the four-cycles

We study stabilization of the Kahler moduli with 2- 3-moduli examples

$$K = -2\log\left(\mathcal{V}_6(\tau_i)\right)$$

$$\mathcal{V}_6(\tau_i) = \frac{1}{2}\sqrt{\tau_1}\left(\tau_2 - \frac{2}{3}\tau_1\right),$$

$$\mathcal{V}_6(\tau_i) = \alpha\left(\sqrt{\tau_1}\left(\tau_2-\beta\tau_1\right) - \gamma\tau_3^{3/2}\right),$$

$$\mathcal{V}_6(\tau_i) = \left(\frac{1}{108}\tau_1[6\tau_2-\tau_1][2\tau_3-\tau_1]\right)^{1/2},$$

$$\mathcal{V}_6(\tau_i) = \frac{1}{3\sqrt{2}}\left(2[\tau_1+\tau_2+2\tau_3]^{3/2} - [\tau_2+2\tau_3]^{3/2} - \tau_2^{3/2}\right)$$

K3 fibration models, a CICY model, multi-hole Swiss cheese mode

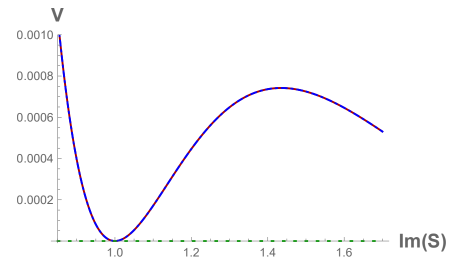
$$W = W_0 + \sum_{\Phi=S,T,U} A_\Phi e^{ia_\Phi\Phi} - B_\Phi e^{ib_\Phi\Phi}$$

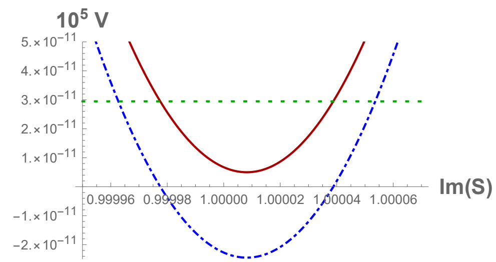
$$\tau_1 = -\mathrm{i}(S-\bar{S}), \qquad \tau_2 = -\mathrm{i}(T-\bar{T}), \qquad \tau_3 = -\mathrm{i}(U-\bar{U})$$

K3-fibration with two moduli

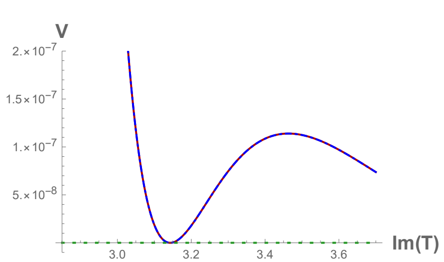
$$\mathcal{V}_6(\tau_i) = \alpha\left[\sqrt{\tau_1}\,\tau_2 - \gamma\tau_3^{3/2}\right]$$

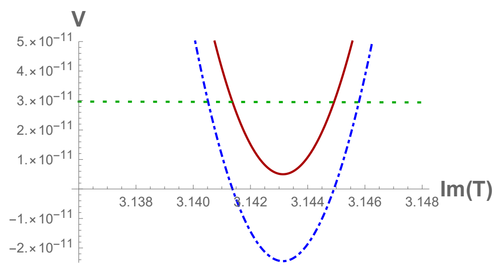
Stage 1,2,3





	Mink	dS
m_1^2	$5.22564\cdot 10^{-2}$	$5.21884\cdot 10^{-2}$
m_2^2	$5.22564\cdot 10^{-2}$	$5.21875\cdot 10^{-2}$
m_3^2	$1.38346\cdot 10^{-5}$	$1.36014\cdot 10^{-5}$
m_4^2	$1.38346\cdot 10^{-5}$	$1.35926\cdot 10^{-5}$



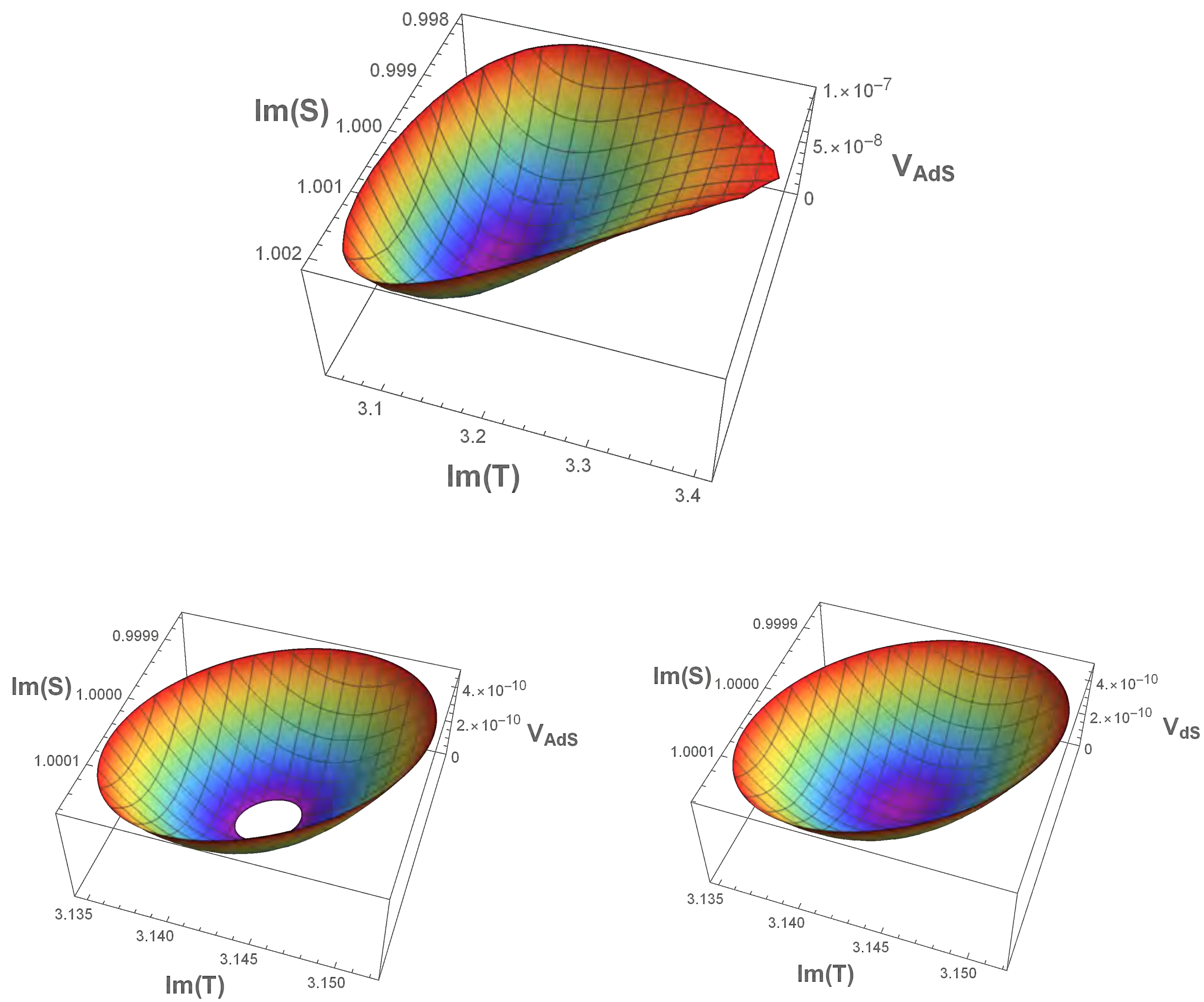


Eigenvalues of the mass matrices in Minkowski and dS. In this model and for our choice of the parameters, the mass splitting between the fields and their axionic partners is clearly visible, after moving away from Minkowski space.

$$M_{K3fib,\,Mink} = \begin{pmatrix} 5.22544\cdot 10^{-2} & 3.23902\cdot 10^{-4} & 0 & 0 \\ 3.23902\cdot 10^{-4} & 1.58428\cdot 10^{-2} & 0 & 0 \\ 0 & 0 & 5.22544\cdot 10^{-2} & 3.23902\cdot 10^{-4} \\ 0 & 0 & 3.23902\cdot 10^{-4} & 1.58428\cdot 10^{-2} \end{pmatrix}$$

$$M_{K3fib,\,dS} = \begin{pmatrix} 5.21864\cdot 10^{-2} & 3.20421\cdot 10^{-4} & 0 & 0 \\ 3.20421\cdot 10^{-4} & 1.5569\cdot 10^{-2} & 0 & 0 \\ 0 & 0 & 5.2155\cdot 10^{-2} & 3.20421\cdot 10^{-4} \\ 0 & 0 & 3.20421\cdot 10^{-4} & 1.55606\cdot 10^{-2} \end{pmatrix}$$

Amazing agreement between theoretical predictions and Mathematica examples!

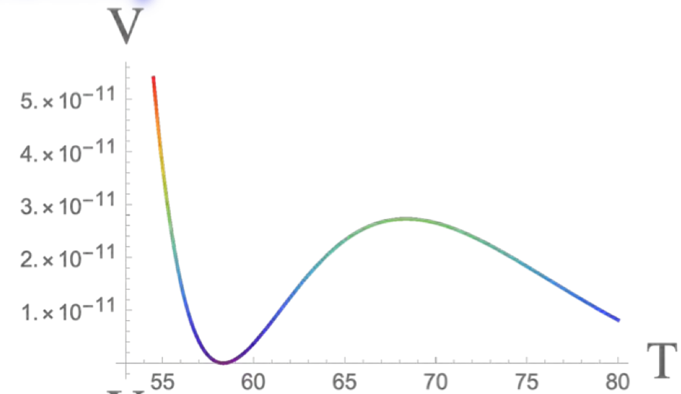


A complete set of 3D plots of the scalar potential for the K3 fibration on $\mathbb{C}P^4_{[1,1,2,2,6]}$
On top we show the overall shape of the potential, and below a close-up of the minimum in AdS and dS case.

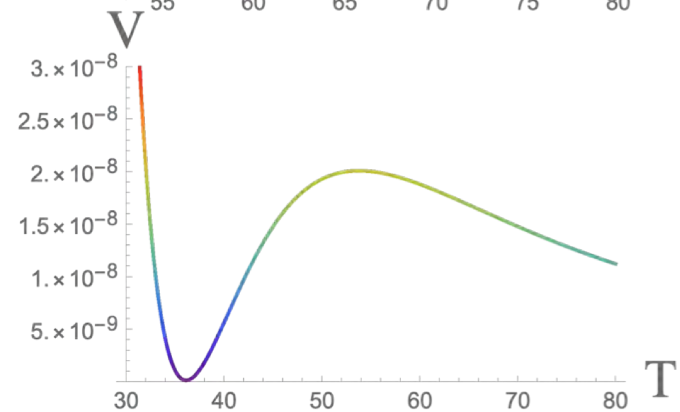
In some cases large downshift and uplift may strengthen stability

Example 1: A single field KL model

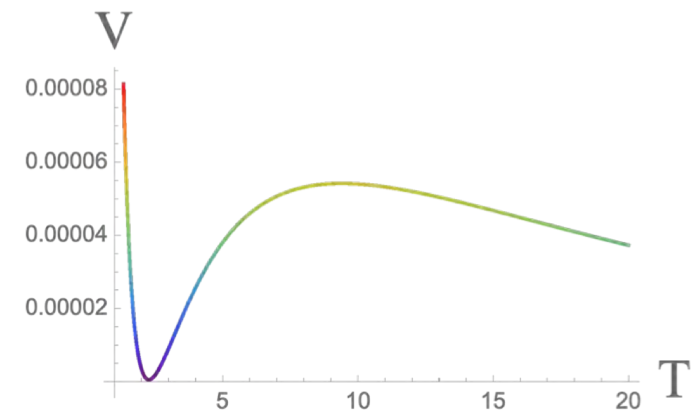
Original supersymmetric Minkowski vacuum



After a very large downshift and uplift, the barrier is 3 orders of magnitude higher, SUSY is strongly broken, but dS is stable

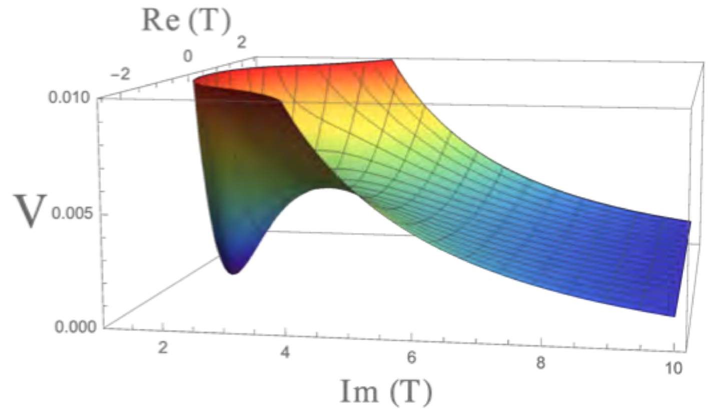


After an extremely large downshift and uplift, the minimum is strongly shifted, SUSY is very strongly broken, but the barrier is even higher, and dS remains stable

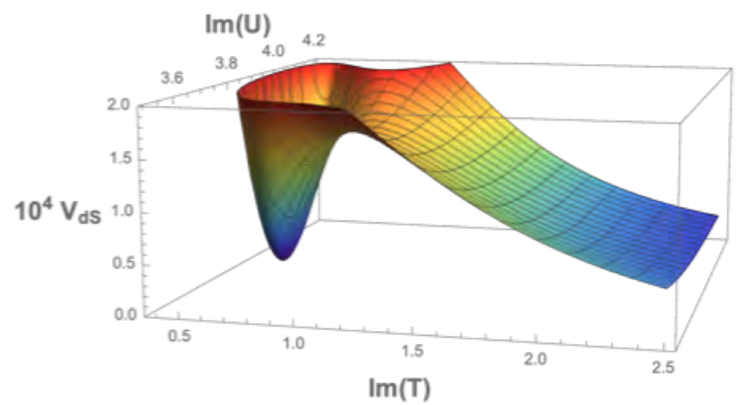


Example 2: KL model and STU model

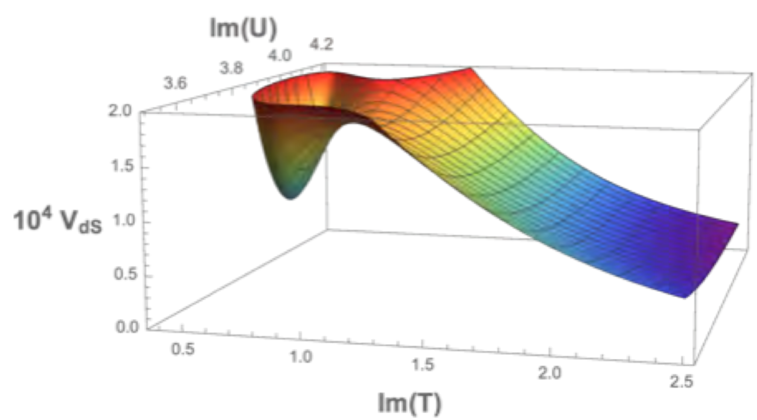
KL model after a very large downshift and uplift



STU model after a very large downshift and uplift



STU model after an additional large uplift



De Sitter Minima from M-theory and String Theory

We study M-theory compactification on a generalized twisted 7-torus

complex scalars, are coordinates of the coset space $\left[\frac{SL(2,\mathbb{R})}{SO(2)}\right]^7$

$$X_7 = \frac{\mathbb{T}^7}{\mathbb{Z}_2 \times \mathbb{Z}_2 \times \mathbb{Z}_2}$$

Betti numbers

$$(b_0, b_1, b_2, b_3) = (1, 0, 0, 7)$$

in the presence of a 7-flux, metric fluxes, local sources, like branes and O-planes, and KK6 monopoles, KKO6-planes and M-anti-M-branes. The effective four-dimensional supergravity has **7 chiral multiplets** whose couplings are specified by the **G_2-structure** of the internal manifold.

The effective **K**, **W** was obtained by Dall'Agata, Prezas, 2005, using the **'democratic form' of 11d supergravity** pseudo-action where the potentials and the dual curvatures both appear.

$$K = -\sum_{k=1}^{7} \log\left(-i(\Phi^k - \overline{\Phi}^{\bar{k}})\right) \qquad W = g_7 + G_i \Phi^i + \frac{1}{2} M_{ij} \Phi^i \Phi^j$$

M-theory, simple and elegant

7 elements

21 elements

$$M_{ii} = 0, \ \forall i$$

Related model of **IIA, IIB supergravity** with local sources on

$$X_6 = \frac{\mathbb{T}^6}{\mathbb{Z}_2 \times \mathbb{Z}_2}$$

Derendinger, Adolfo Guarino, 2014 Rederived and generalized Dall'Agata, Prezas, 2005

M-theory beyond twisted with KK6 monopoles (KKO6-planes)

Effective M-theory interpretation for non-geometric type IIA flux vacua

$$\Phi^i = \{S,\, T_I,\, U_J\}, \qquad I, J = 1, 2, 3.$$

$$W_M = W_{IIA}|_{m_R=0} + c^I \frac{T_1 T_2 T_3}{T_I} + S\, T_K d^K$$

In type IIA $\omega\,\omega \neq 0 \;\Rightarrow\;$ Net charge of KK5 (KKO5) sources

In M-theory $\omega\,\omega \neq 0 \;\Rightarrow\;$ Net charge of KK6 (KKO6) sources

Scherk-Schwarz metric ω-flux along the seven-dimensional internal space X_7

$$\left.\begin{aligned} W_{\text{M-theory}} \;=\;& a_0 - b_0\, S + \sum_{K=1}^{3} c_0^{(K)} T_K - \sum_{K=1}^{3} a_1^{(K)}\, U_K \\ &+ \sum_{K=1}^{3} a_2^{(K)} \frac{U_1 U_2 U_3}{U_K} + \sum_{I,J=1}^{3} U_I\, \mathcal{C}_1^{(IJ)}\, T_J + S \sum_{K=1}^{3} b_1^{(K)}\, U_K \\ &- \sum_{K=1}^{3} c_3'^{(K)} \frac{T_1 T_2 T_3}{T_K} - S \sum_{K=1}^{3} d_0^{(K)}\, T_K \end{aligned}\right\}\; 21$$

In our M-theory examples we use only terms even in moduli, but we add a non-perturbative exp

$$\sum_{i=k}^{7} A_k e^{i a_k \Phi^k}$$

M-theory, fluxes and KKLT

$$K = -\sum_{i=1}^{7} \log\left(-\mathrm{i}(\Phi^i - \overline{\Phi}^i)\right)$$

$$W = g_7 + \frac{1}{2} M_{ij}\Phi^i\Phi^j + \sum_{i=1}^{7} A_i e^{\mathrm{i}a_i\Phi^i}$$

$$\Phi^i = \{S,\, T_I,\, U_J\}, \qquad I, J = 1, 2, 3$$

To find a supersymmetric Minkowski minimum we must have W = 0 and W' = 0. The first condition can be satisfied by a proper choice of g_7. The condition W' = 0 reads

$$-\,\mathrm{i}a_i A_i e^{\mathrm{i}a_i\Phi_i} = M_{ij}\Phi^j$$

The solution is
$$A_i = \mathrm{i}a_i^{-1} e^{-\mathrm{i}a_i\Phi_i} M_{ij}\Phi^j$$

If we want to have a susy Minkowski minimum at Φ^j_0 we just use the parameters A_i given by this equation. The only problem is to avoid flat directions. In the previous method (double exponents for each moduli) there were no flat directions by construction. In the new setting one should check it, and we did it.

Model 1

$$W_1 = g_7 + b^K S U_K + C^{IJ} U_I T_J$$

$$+ A_S e^{\mathrm{i} a_S S} + \sum_I A_{T_I} e^{\mathrm{i} a_{T_I} T_I} + \sum_I A_{U_I} e^{\mathrm{i} a_{U_I} T_I}$$

parameters

S_0	1.0	a_S	1.0	C^{11}	0.11	C^{32}	0.32
$T_{1,0}$	1.1	a_{T_1}	1.1	C^{12}	0.12	C^{33}	0.33
$T_{2,0}$	1.2	a_{T_2}	1.1	C^{13}	0.13	b^1	0.55
$T_{3,0}$	1.3	a_{T_3}	1.1	C^{21}	0.21	b^2	0.60
$U_{1,0}$	5.1	a_{U_1}	0.51	C^{22}	0.22	b^3	0.65
$U_{2,0}$	5.2	a_{U_2}	0.52	C^{23}	0.23	Δg_7	$5 \cdot 10^{-3}$
$U_{3,0}$	5.3	a_{U_3}	0.53	C^{31}	0.31	μ^4	$9 \cdot 10^{-9}$

Masses of all 7 moduli before and after a small uplift

(omitting the axion masses, which are similar)

	m_1	m_2	m_3	m_4	m_5	m_6	m_7
Mk	0.6421	0.4700	0.3216	0.1757	0.1406	0.1129	0.08219
dS	0.6427	0.4705	0.3218	0.1758	0.1407	0.1130	0.08227

Model 1 and tadpole conditions:

$$b^I C^{IJ} + b^J C^{II} = 0$$
$$C^{IJ} C^{JK} + C^{IK} C^{JJ} = 0$$

One can satisfy these conditions by taking into account sources, such as KK monopoles, but one can also satisfy these condition by making a slight modification of the previous choice of parameters C^{IJ} with $I \neq J$ and C^{11}, keeping all other parameters intact.

This changes the masses in our table, but the susy Minkowski stays at the same values of the moduli, and the mass matrix remains positively definite.

	m_1	m_2	m_3	m_4	m_5	m_6	m_7
Mk	0.3006	0.1641	0.1179	0.07467	0.06229	0.03988	0.02517
dS	0.2997	0.1637	0.1176	0.07449	0.06227	0.03976	0.02513

Model 2 without S exponent:

$$
\begin{aligned}
W_2 =& g_7 + b^K S U_K + C^{IJ} U_I T_J \\
&+ \sum_I A_{T_I} e^{\mathrm{i} a_{T_I} T_I} + \sum_I A_{U_I} e^{\mathrm{i} a_{U_I} U_I}
\end{aligned}
$$

Model 3 without U exponents:

$$
\begin{aligned}
W_3 =& g_7 + a^I \frac{U_1 U_2 U_3}{U_I} + b^K S U_K + C^{IJ} U_I T_J \\
&+ A_S e^{\mathrm{i} a_S S} + A_{T_I} e^{\mathrm{i} a_{T_I} T_I} \ .
\end{aligned}
$$

Model 4 without T and U exponents:

$$
\begin{aligned}
W_4 =& \ g_7 + a^I \frac{U_1 U_2 U_3}{U_I} + b^K S U_K + C^{IJ} U_I T_J \\
&+ c^I \frac{T_1 T_2 T_3}{T_I} + A_S e^{\mathrm{i} a_S S} \ ,
\end{aligned}
$$

Model 5 in type IIB theory without any exponents

$$
\begin{aligned}
W_5 = a_0 + a^I \frac{U_1 U_2 U_3}{U_I} \\
+ S\left(b^I U_I + b_3 U_1 U_2 U_3\right) \\
+ T_K\left(C^{IK} U_I - c^K U_1 U_2 U_3\right) \\
- S\, T_K\left(d^K - D^{IK}\frac{U_1 U_2 U_3}{U_I}\right)
\end{aligned}
$$

F

H

Q

P

Parameters: same as in Model 1, plus additional ones

b^1	0.55	C^{11}	-0.11	C^{21}	0.21	C^{31}	0.31	d^1	5.1
b^2	0.60	C^{12}	0.12	C^{22}	-0.22	C^{32}	0.32	d^2	-5.2
b^3	0.65	C^{13}	0.13	C^{23}	0.23	C^{33}	-0.33	d^3	5.3

Masses in Minkowski and in dS

	m_1	m_2	m_3	m_4	m_5	m_6	m_7
Mk	0.5392	0.4551	0.1037	0.06185	0.05355	0.02389	0.01263
dS	0.5391	0.4552	0.1036	0.06183	0.05357	0.02381	0.01260

Discussion

Non-geometric fluxes & tadpole conditions ???

Top-down/bottom-up ?

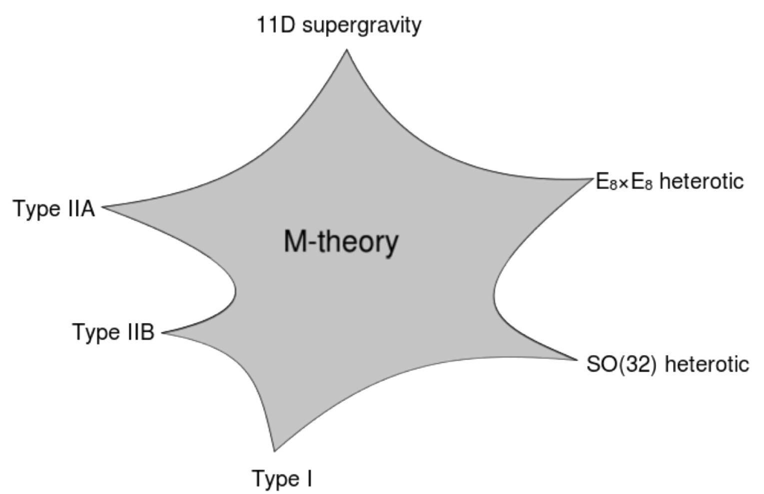


Figure showing the parameter space of **M-theory**. The different well-understood limits correspond to the 5 string theories and 11-dimensional supergravity.

Conclusions

We developed a simple procedure of constructing stable dS vacua with many moduli and many different Kahler potentials and superpotentials associated with **M-theory**, **type IIA** and **type IIB string** theory.

Instead of searching for AdS and checking dS stability with respect to all moduli after a large uplift, we find supersymmetric Minkowski vacua without flat directions. In that case, stability of dS vacua after a parametrically small uplift is guaranteed.

It is easy to find such vacua in many models with nonperturbative racetrack superpotentials with two or more exponents, independently of the choice of the Kahler potential. One can also find stable dS in models with flux superpotentials and a single KKLT-type exponent for some of the moduli. It works for a broad choice of parameters, no fine tuning is required.

In the theories with a sufficiently rich structure of flux superpotentials, as in one of our examples, we may be able to find stable dS even without using nonperturbative exponents.