Flux compactifications, dS vacua and the swampland

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Overview

Describing the vacuum state of the universe in a fundamental theory is one of the most daunting tasks in theoretical physics. This gets complicated by the fact that the universe is currently undergoing accelerated expansion. In order to achieve this goal it is necessary to find a quantum description of gravity. Currently the most promising candidate for such a formalism is string theory and its low energy effective theory supergravity. In this framework we can model the expansion of spacetime by a positive vacuum energy contribution from a scalar field.
In order to build a model from string theory it is necessary, among many other things, to compactify from ten dimensions to our familiar four. This can be achieved by so-called flux compactifications. There, fluxes on the internal six dimensions allow us to achieve physical properties we require in four dimensions. One of the best investigated model that achieves a de Sitter vacuum, describing our observed spacetime, is the KKLT scenario. There, in addition to fluxes, an anti-D3-brane is used to lift a stable anti-de Sitter vacuum to a positive vacuum energy.
Recently, the construction of de Sitter vacua has been brought into question as part of the swampland program. At its core the swampland program deals with inconsistencies between the full string theory and the effective supergravities. It is possible to have a consistent supergravity theory that cannot be lifted to string theory. The swampland program aims to find conditions that tell us which low energy effective theories are consistent and which are not. One particular claim is the no de Sitter conjecture, suggesting that no stable de Sitter vacua can arise from string theory. As an alternative quintessence models have been proposed, where instead of sitting at a stable point the field causing the accelerated expansion is rolling on a flat slope.
The goal of this thesis is to make progress in the aforementioned areas, several projects achieving this goal are presented here.

Uplifting anti-D6-brane in type IIA

The KKLT scenario is realized in type IIB string theory/supergravity utilizing an anti-D3-brane as a source of positive energy. A similar procedure was developed in type IIA theory [1].
The Kähler- and superpotential of the model before the uplift are:

$$K = -log(-\mathrm{i}(S-\bar{S})) - 3log(-\mathrm{i}(T-\bar{T})) - 3log(-\mathrm{i}(U-\bar{U}))\,,$$
$$W = f_6 + \sum_i A_i \mathrm{e}^{\mathrm{i}a_i\Phi_i} \qquad \Phi_i = \{S, T, U\}\,. \tag{1}$$

S, T, U are scalars and f_6 is a six flux. A_i and a_i are parameters.
The scalar potential for the moduli is given as:

$$V_0 = \mathrm{e}^K \left(K^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - 3 W \bar{W} \right) \tag{2}$$

The steps to achieve a stable de Sitter vacuum are:

- Stabilize the three moduli in AdS by solving $D_I W = 0$ in terms of the A_i.
- Use the position of the moduli and the parameters a_i in order to achieve weak coupling and large internal volume.
- Introduce an anti-D6-brane uplift via the effective contribution

$$V_{up} = +\frac{\mu_1^4}{Im(T)^3} + \frac{\mu_2^4}{Im(T)^2 Im(S)} \tag{3}$$

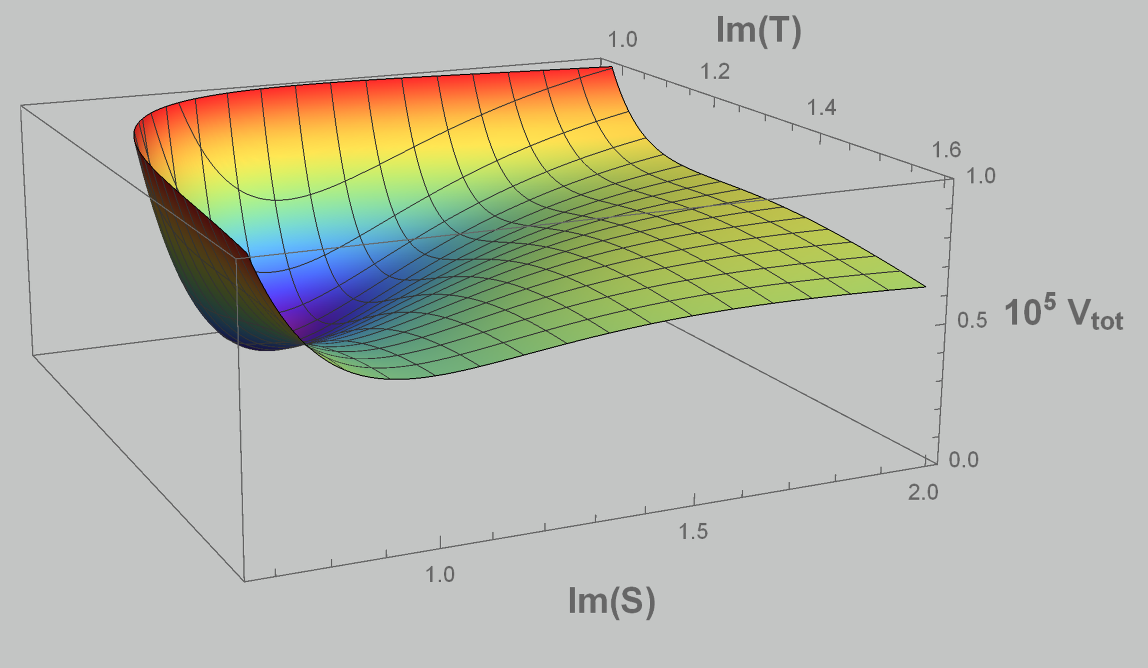

Figure: 3D plot in the S and T directions of the potential with the de Sitter point visible.

Non-linear supersymmetry

A useful tool in string model building is non-linear supersymmetry. If supersymmetry gets broken there are non-linear field transformations: $\delta\lambda^I = \epsilon^I + \sum_{J=1}^{3}(\bar{\lambda}^J\gamma^\mu\epsilon^J)\partial_\mu\lambda^I$. This can be used to describe the world volume fields of the anti-brane in the KKLT model [2] and to incorporate the uplifting anti-D6-brane into the Kähler- and superpotential [1]:

$$K = -\log\left(-\mathrm{i}(S-\bar{S})\right) - 3\log\left(-\mathrm{i}(T-\bar{T})\right) - \log\left(\left(-\mathrm{i}(U-\bar{U})\right)^3 - \frac{X\bar{X}}{e^{\mathcal{A}_1}N_{\overline{D6}_1}\left(-\mathrm{i}(S-\bar{S})\right) + e^{\mathcal{A}_2}N_{\overline{D6}_1}\left(-\mathrm{i}(T-\bar{T})\right)}\right)\,,$$
$$W = f_6 + A_S e^{\mathrm{i}a_S S} + A_T e^{\mathrm{i}a_T T} + A_U e^{\mathrm{i}a_U U} + \mu^2 X\,. \tag{4}$$

The field X is a nilpotent superfield satisfying $X^2 = 0$. It can be checked that this reduces to the scalar potential (2) + (3).

Mass production of de Sitter vacua

The uplift mechanism allows for the production of infinitely many de Sitter vacua provided one modifies the procedure above slightly [3]:

- Extend the superpotential to the Kallosh-Linde form:

$$W = f_6 + \sum_{\Phi^i} A_i \mathrm{e}^{\mathrm{i}a_i\Phi^i} - B_i \mathrm{e}^{\mathrm{i}b_i\Phi^i} \quad \text{where} \quad \Phi^i = \{S, T, U\}\,. \tag{5}$$

- Find a stable Minkowski point by solving $D_I W = 0$ and $W = 0$.
- We obtain an Anti-de Sitter vacuum by shifting $f_6 \to f_6 + \Delta f_6$.
- The uplift proceeds as before with anti-D6-branes.

It is possible to adjust the magnitude of the shift to anti-de Sitter and compensate with the uplift. This can avoid unreasonable fine tuning with the uplift parameter. Furthermore, every Minkowski point gives an infinite number of different uplift possibilities.

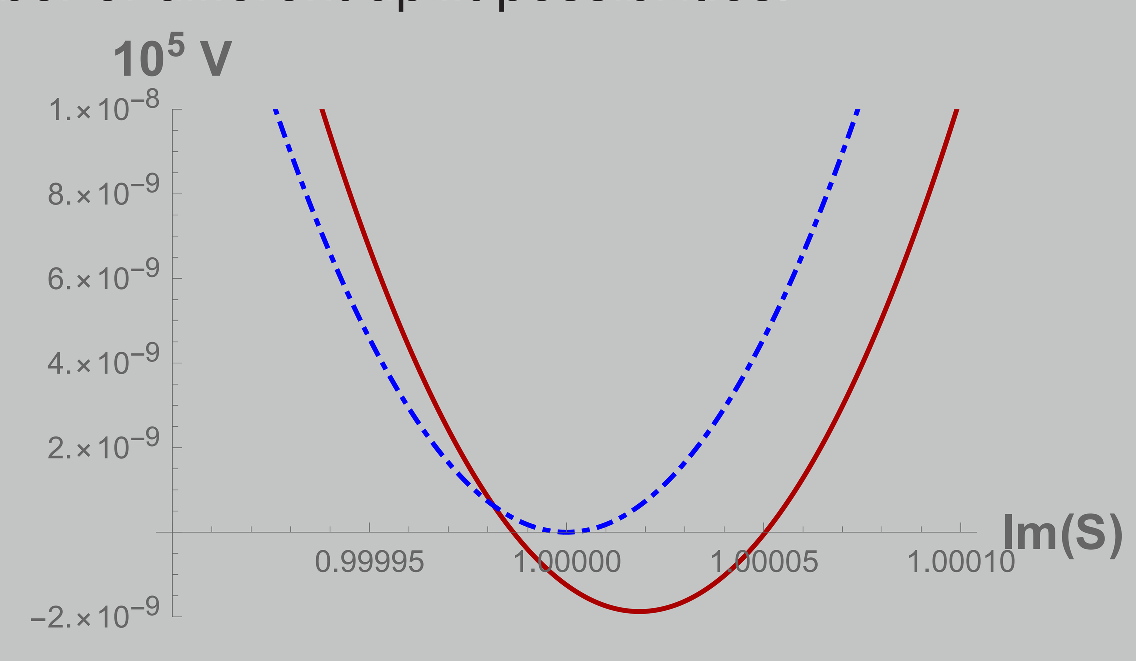

Figure: Scalar potential for the S modulus in Minkowski (blue) and in AdS (red).

De Sitter swampland conjecture

The original de Sitter conjecture states that all potentials should satisfy:

$$|\nabla V| \geq cV \quad \text{and} \quad \min(\nabla_i\nabla_j V) \leq c'V \quad \text{where} \quad c,\ c' \sim \mathcal{O}(1)\,. \tag{6}$$

This rules out stable de Sitter minima. We proposed an alternative condition, in terms of one inequality and with qualitative differences [4]:

$$\left(M_P\frac{|\nabla V|}{V}\right)^q - aM_P^2\frac{min(\nabla\partial V)}{V} \geq 1 - a \quad \text{where} \quad a > 0,\ q > 2\,. \tag{7}$$

Using numerical data from [5] it was possible to restrict the parameters to $a \geq 0.286$ and $2 < q \leq 3.03$.

References

[1] N. Cribiori, R. Kallosh, C. Roupec and T. Wrase, “Uplifting Anti-D6-brane,” JHEP **12** (2019), 171 doi:10.1007/JHEP12(2019)171 [arXiv:1909.08629 [hep-th]]
[2] N. Cribiori, C. Roupec, T. Wrase and Y. Yamada, “Supersymmetric anti-D3-brane action in the Kachru-Kallosh-Linde-Trivedi setup,” Phys. Rev. D **100** (2019) no.6, 066001 doi:10.1103/PhysRevD.100.066001 [arXiv:1906.07727 [hep-th]]
[3] N. Cribiori, R. Kallosh, A. Linde and C. Roupec, “Mass Production of IIA and IIB dS Vacua,” JHEP **02** (2020), 063 doi:10.1007/JHEP02(2020)063 [arXiv:1912.00027 [hep-th]]
[4] D. Andriot and C. Roupec, “Further refining the de Sitter swampland conjecture,” Fortsch. Phys. **67** (2019) no.1-2, 1800105 doi:10.1002/prop.201800105 [arXiv:1811.08889 [hep-th]]
[5] C. Roupec and T. Wrase, “de Sitter Extrema and the Swampland,” Fortsch. Phys. **67** (2019) no.1-2, 1800082 doi:10.1002/prop.201800082 [arXiv:1807.09538 [hep-th]]