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Effective upliftings in Large volume compactifications

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Abstract

After reviewing several mechanisms proposed to get a dS/Minkowski vacuum in moduli stabilization scenarios of type-IIB superstring orientifold compactifications we propose a criterium for characterizing those that may effectively lead to a positive small cosmological constant. We suggest that the variation in the expectation value of a good uplifting term, due to the shift in the minimum of the potential after uplifting, is much smaller than the original cosmological constant. This is studied with some detail in Large volume scenarios where the dependency on the volume direction is rather generic and easy to spot. Here we find that an uplifting term in the potential, with generic form $V_{up} \sim 1/\mathcal{V}^{\gamma}$, should be restricted to the one satisfying $\gamma \ll 12$. Such a bound might explain why in models previously studied no uplifting has been achieved, and gives motivations to study a novel proposal of dilaton dependent uplifting mechanism for which no numerical studies has been performed before. We find that in this case it is actually possible to get a dS vacuum, but still leave open the question of a more precise discrimination feature the good uplifting mechanisms should satisfy.

Keywords: String compactifications, dS vacua in string theory.

1. Introduction

In the LHC era superstring theory seems to be in good shape to accept the challenge: great deal of progress in recent years has shown that it is possible to reproduce the particle spectra of the Standard Model o well motivated extensions[1–5], as well scenarios with enough dynamics to stabilize all moduli with low energy Supersymmetry [6] leaving room for cosmological features like inflation [7]. In this context the so called Large volume scenarios (LVS) [8] present a kind of type-IIB vacua where both features has been shown to be present [9–11], thus, despite of being more rigid in implementation compared to models inspired by the seminal work of Kachru, Kallosh, Linde and Trivedi in [6], these a unique instance worth to be developed.

One of the features that moduli stabilization should give, if it is to help with the cosmological hierarchy problem, is the realization of a nearly vanishing positive value for the cosmological constant [12, 13]. Although the natural scenario for superstring vacua is a deep AdS, toy models have been proposed obtaining dS/Minkowski minima without the need of anti-D branes in the description [14–38]. For the LVS only a couple of works have done the honest work of a numerical computation of such vacua [26, 38, 39], while the rest remain relaying in parametrical indications which in any case do not guarantee the final implementation. Then, for instance, in a model proposed by Cremades et al. in [37], an F-term from a matter-like field serves as uplifting for the cosmological constant. However, later studies by the author showed that such model fails in getting an dS/Minkowski [39]. In other words the uplifting procedure does not achieve its target.

The intention of this letter is to give a first proposal for a characterization that identifies good uplifting mechanisms in the LVS. For this we concentrate on the uplift-

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ing term in the potential, which we define as one with the property of being positive definite and depending on parameters whose tuning allows, in principle, for a cancelation of the originally negative cosmological constant. We propose that an effective uplifting mechanism is one for which the difference between the Vacuum Expectation Value (VEV) of the uplifting term at the unperturbed minimum, when the uplifting is turned off, and its VEV in the perturbed one, when the uplifting is turned on, is much more smaller than the VEV of the potential without uplifting. In order to be more quantitative we use the fact that in general the uplifting part of the scalar potential comes as a negative power of the overall volumen, i.e., $V_{up} \sim \mathcal{V}^{-\gamma}$, for which we find, implementing the condition above, a bound given by $\gamma \ll 12$. Such a bound is latter on studied numerically. This results not only helps in understanding the failure of previous models but also as guidance for future constructions.
The letter is organized as follows: the next section reviews some standard mechanisms for generating an uplift. This is used in section 3 to presents and justify the requirement proposed in the paper, as well the explicit implementation in the case of the LVS. The last part of the letter discuses two uplifting scenarios, one for which a dS/Minkowski is not realized, something that is understood in the light of the requirement just presented. The last section serves as discussion on the results, which, however, are only a small part of broader and more systematic study left for a future report.

2. Uplifting terms

We work in the framework of $\mathcal{N} = 1$ Supergravity (SUGRA) as the low energy effective description of type-IIB superstring theory compactified on a Calabi-Yau 3-fold with an Orientifold plane. Then the different sources of uplifting come either from the F or D-term part of the scalar potential, or from stringy, Supersymmetry (SUSY) breaking, effects like anti-D branes.

2.1. Anti-brane potential

In some situations, in order to satisfy the tadpole condition which depend on the fluxes and the net D-brane number, a number of anti-D branes are included in the setup. In the probe approximation it is possible to get an expression for their contribution to the energy [40], proportional to the brane tension

$$V_{\overline{D}} = \frac{\nu}{\mathcal{V}^{\gamma}}\,, \tag{1}$$

with the parameter γ depending on the type of brane in the game and the amplitude ν going like a warping factor evaluated at the end of the throat, where the anti-brane is localized.
This uplifting mechanism is quite robust being completely independent of the scalar potential stabilizing the moduli, thus has been the main way used for justifying dS/Minkowski vacua. However, since it breaks explicitly SUSY its low energy SUGRA implementation seems sometimes obscure (see however [41]).

2.2. F-term uplifting

A more controlled way of introducing positive terms is adding new degrees of freedom that contribute to the F-term scalar potential,

$$V_F = e^K \left(\overline{D}_{\bar{J}}\overline{W} K^{\bar{J}I} D_I W - 3|W|^2\right), \tag{2}$$

in $M_{Planck} = 1$ units, with W and K the superpotential and Kähler potential respectively, $D_I W = \partial_I W + W\partial_I K$ the covariant derivative, the indices I and J running over the fields ϕ_I, and $K^{\bar{J}I}$ the inverse of the scalar manifold metric $K_{I\bar{J}}$. Indeed the diagonal terms, $K^{I\bar{I}}|D_I W|^2$, being positive definite might potentially uplift the vacuum.
An ubiquitous sector in string compactifications are matter like fields, for which the Kähler potential behaves like [42]

$$K_{matter} \sim \mathcal{V}^{-\eta}|\phi|^2\,. \tag{3}$$

Then regarding the moduli Kähler potential as $K_{mod} \supset -2ln\mathcal{V}$, a term of the form

$$V_{matter} \supset \frac{1}{\mathcal{V}^{2-\eta}}|D_\phi W|^2\,, \tag{4}$$

is induced in the scalar potential, which depends on the VEV for the matter field dictated by other dynamics, usually the D-term potential. The extra degrees of freedom can be as well other moduli that can be easily stabilized by other means, like in the model presented later on in sec.(4.2). This kind of uplifting as been exploited in several works so far [14–27].
Another possibility for this kind of uplifting is to consider perturbative corrections, α' or string loops, to the Kähler potential which might lead to important contributions potentially able to uplift the vacuum [33–35]. In this case a careful analysis on higher order corrections is compulsory as these might invalidate the initial first order implementation.
Contrary to the case of anti-D brane uplifting in here the moduli stabilization process should be, in principle, done simultaneously to uplifting, as the extra degrees of freedom or the quantum corrections might affect completely the way the moduli are stabilized. This is why

some authors prefers not to call this as uplifting. However, in almost all the cases it is possible to identify an uplifting term satisfying the definition above.

2.3. D-term uplifting

Once the dynamics includes gauge symmetries an extra contribution to the scalar potential appears. In general one can work in a mesonic SUSY preserving branch, such that the the only source of SUSY breaking and uplifting comes from $U(1)_X$ sectors, for which this contribution reads

$$V_D = \frac{1}{2Re(f_X)}(i\chi^I_X\partial_I K)^2\,, \tag{5}$$

with χ^I_X the Killing vectors of the symmetry and f_X is the field dependent gauge kinetic function corresponding to the gauge sector. Matter like fields transform linearly, $\chi^\phi_X = iq^\phi_X\phi$, proportional to the charge, while the moduli get charged non-linearly, i.e., $\chi^{\mathcal{M}}_X = i\delta^{\mathcal{M}}_X$ with $\delta^{\mathcal{M}}_X$ a constant, once magnetic fluxes are turned on in the D-branes supporting the matter fields and wrapped in the cycle parameterized by the moduli [43]. Once the VEV for this part of the potential is not vanishing it leads to a positive definite contribution that might uplift the vacuum.
Given the dependency of the Kähler potential on the volume, as well possible dependencies in the gauge kinetic function, the induced uplifting behaves like $V \sim 1/\mathcal{V}^\gamma$. Implementing this scenario, although not imposible [28–32], is in general more involved given dynamical constrains on the the D-term potential [44].

3. The requirement

The outshot of the previous section is the fact that the sources of uplifting in general generate uplifting terms that have a runaway behavior in the compact manifold volume direction, namely its perturbation on the vacuum goes in the de-compactification direction. Then, even if the uplifting at the end does not wipe out the vacuum the resulting potential is flatter (see figure 1), so that the masses for the moduli in general get lowered compared the ones obtained in the initial stabilization potentially facing the cosmological moduli problem.
One might still try to construct models with high SUSY breaking scale and testable signatures encoded in this light modulus direction, but a large perturbation on the vacuum position might invalidate the analysis and understanding of the stabilization process that is what allows the control for possible modifications in order to generated desirable physics.

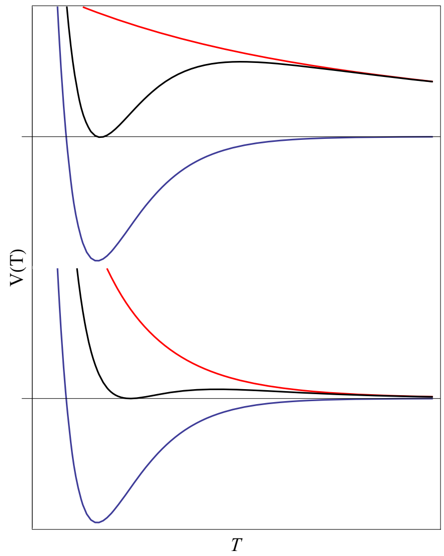

Figure 1: Single modulus case. The original potential (blue) is uplifted by $V_{up} \sim 1/T^n$ (red). Case on top with power $n = 2$, and bellow with $n = 11$. The total potential (black) is flatter for a steeper uplifting and the shift in the position of the minimum is larger.

Requiring a small perturbation is still not enough for a precise characterization of a good uplifting since this term should be relevant enough to do its job, namely, it should be comparable to the original potential so to cancel the cosmological constant. Let us illustrate the situation in the context of the numerical computation of the vacuum position and its properties; in here a tuning of some free parameters in the uplifting term allows, in principle, to get a vanishing cosmological constant. The value for these then is dictated by the value of the VEV of the original potential. However, due to the perturbation from the uplifting this VEV is shifted to larger values of the volume and the values for the parameters might not be the correct ones as the uplifting term is smaller the larger the volume. Changing the values for the parameters translates then in a larger shift in the vacuum that again might or might not be uplifted. The game then is iteratively done until, hopefully, a dS/Minkowski vacuum is obtained. In some cases at the end the perturbation is so large that the potential is flat enough that spotting the vacuum is quite hard or, in the worst case, its properties are changed completely.[1] Actually if the uplifting term decreases faster than the original potential the minimum will be always an AdS no matter how large is its constant amplitude modulated by the tuned parameters.

[1] For example by the collapse with neighbor solutions that might not be minima.

A good uplifting, then, avoids such problems by a "quick" uplift which, however, still can be thought as a small contribution in the stabilization process. This, we propose, is encoded in following condition

$$|\langle V_{up}\rangle_0 - \langle V_{up}\rangle| \ll |\langle V_0\rangle| \,, \tag{6}$$

where we denote by V_0 and V_{up} the original potential and the uplifting term respectively and $\langle\rangle_0$ the VEV evaluated at the unperturbed vacuum while the other VEV's are evaluated at the point resulting by introducing the uplifting with parameters that in principle lead to a cancelation of the cosmological constant. Condition (6) simply requires that the shrink on the uplifting, due to the shift, is small enough so that the uplifting indeed proceeds. This together with a precise knowledge of the stabilization procedure can help in establishing, a priori, if a possible uplifting will indeed do the job or not.

In general the situation can be complicated enough so that in any case such an analysis is not straightforward. We simplify the analysis by assuming the uplifting as a function of the volume alone. Although this is not exactly the case a justification for such an assumption is that in LVS the volume modulus is sightly lighter than the rest of directions, meaning that the dynamics responsible of stabilizing the other directions are parametrically larger and, therefore, the direction that is going to be more affected by the uplifting is precisely the volume one. Having said that and regarding a small shift we can quantitatively evaluate its value by expanding the equation of motion for $V = V_0 + V_{up}$ around the original minimum, given by $\partial_{\mathcal{V}} V_0 = 0$, leading to

$$\delta\mathcal{V} \approx \left\langle \frac{\partial_{\mathcal{V}} V_{up}}{\partial^2_{\mathcal{V}} V_0} \right\rangle_0 \,. \tag{7}$$

Here it is explicit that the steeper the uplifting the larger the shift is, and also the fact that it is inverse to the mass of the volume modulus (non canonical normalized), given by the second derivative of the potential.

4. Explicit scenario

Philosophically the proposed constrain (6) seems to be well motivated, but still we should do better in order to establish how good it is a as discrimination tool for an effective uplifting mechanism. Here we will do so using a single model of moduli stabilization and a couple of potential uplifting mechanisms. The first reason to chose this particular model is the fact that one of the uplifting mechanisms to be shown have been studied previously with the conclusion that it cannot lead to a Minkowski vacuum [39]. The second reason is that, so far, no explicit numerical dS/Minkoski vacuum appear to be reported in the literature and therefore we enjoy the opportunity to try to look for such using a new uplifting mechanism proposed in ref.[45].

In general the LVS leading potential results from an expansion in powers of the volume and exponentials from nonperturbative sources. Then, with a Kähler potential with a leading dependency of the form $K \sim -2Log(\mathcal{V})$, the potential scales with the volume as

$$V_0 \sim \mathcal{V}^{-3} \,. \tag{8}$$

More precisely α' corrections change the no-scale nature of the model inducing a positive term that exactly go with this power. The minimization process makes that all terms in the leading potential at the end scale in the same way. As shown in the previous section the behavior of the uplifting term is encoded in the following potential

$$V_{up} = \nu\mathcal{V}^{-\gamma} \,, \tag{9}$$

ν an amplitude modulated by tunable parameter or even VEV's of other moduli. Then, eq.(7) leads to the explicit expression,

$$\frac{\delta\mathcal{V}}{\mathcal{V}} \approx \frac{\gamma}{12} \,, \tag{10}$$

where we have used the requirement of a vanishing cosmological constant, i.e., $|\langle V_{up}\rangle| \approx |\langle V_0\rangle|$. After plugging this in the constrain (6), in an expansion in $\delta\mathcal{V}$ up to leading order, and regarding again a vanishing cosmological constant we have the following condition

$$\gamma^2 \ll 12 \,, \tag{11}$$

stating a limit on the possible dependency of the uplifting on the volume. Notice that this bound is stronger than the one that is obtained by simply requiring that the shift, eq.(10), be much more smaller than the volume it self.

To check this result let us take the model proposed by Cremades et al. in [37], regarding three D7-branes, two of them on top of each other, wrapped on a small 4-cycle in an orientifold compactification. On the brane left alone a magnetic flux is turned on generating a chiral spectrum with gauge group $SU(2) \times U(1)$, the $U(1)$ being pseudo-anomalous. More precisely strings stretching between the stack of branes and the single magnetized one generate φ fields transforming as $(\Box, 1)$, while the ones stretching between the orientifold image of the stack and the magnetized brane, fields $\tilde{\varphi}$, transform as $(\overline{\Box}, 1)$. The Kähler modulus, t, parametrizing the 4-cycle where the branes wrap gets a nonlinear $U(1)$ charge due to a Grenn-Schwarz mechanism for the cancelation of anomalies. Practically one can work in a SUSY preserving mesonic direction, canonically normalized $\phi = \sqrt{\varphi\tilde{\varphi}}$. Then normalizing the charges such that $q_\phi = -1$ and $\delta^t = 2/a$, a gauge invariant nonperturbative ADS superpotential can be generated

$$W = W_{SC} + A\frac{e^{-at}}{\phi^2} . \quad (12)$$

The W_{SC} part is a flux induced superpotential responsible for the stabilization of the dilaton and complex structure moduli, at SUSY preserving points, and the amplitude A might also depend in those fields. Regarding a Swiss-cheese like manifold with two 4-cycles: a large one, T, parametrizing the whole size of the manifold and a small one, t, parametrizing the small cycle where the branes are wrapped. The Kähler potential for the system is given by

$$K = -2log(\mathcal{V} + \hat{\xi}) + \frac{Z(t)}{\mathcal{V}^\eta}|\phi|^2 , \quad (13)$$

where $\mathcal{V} = T_r^{3/2} - t_r^{3/2}$, Z is a function of the complex structure and t, and $\hat{\xi}$ a α' correction that depends on the dilaton modulus. The subindex r denotes the real part but we omit hereafter such a notation as the solutions turn out to be real for the values chosen in the numerics. The gauge kinetic function for the $U(1)$ is given by $f_X = t$, disregarding irrelevant but possible dependencies on the dilaton induced by the magnetic flux. This leads to a D-term part of the scalar potential of the form, at leading order in an expansion in inverse powers of $T \approx \mathcal{V}^{2/3}$,

$$V_D \sim \frac{1}{t}\left(\frac{3}{2a}\frac{\sqrt{t}}{T^{3/2}} - \frac{Z(t)}{T^{3\eta/2}}|\phi|^2\right)^2 . \quad (14)$$

The approximate cancelation of this potential fixes the value of ϕ at $\langle|\phi|^2\rangle \approx \frac{3\sqrt{t_r}}{2aZ(t_r)T_r^{3/2(1-\eta)}}$. Plugging this value in the F-term part of the scalar potential, eq.(2), leads to a potential for the moduli with a LVS solution [37]

$$V_{mod} = \frac{8Z(t)^2a^4A^2e^{-2at}}{27\sqrt{t}T^{3\eta-3/2}} - \frac{2\sqrt{t}Z(t)a^2W_{SC}Ae^{-at}}{T^{3/2(1+\eta)}} + \frac{3W_{CS}^2\hat{\xi}}{2T^{9/2}} , \quad (15)$$

regarding real values for all quantities, and whose VEV is negative.

4.1. Uplifting proposal with extra matter

Actually strings stretching between the magnetized brane and its orientifold image generate fields ρ singlets of $SU(2)$ and doubly charged under $U(1)$, such that a coupling between this field and ϕ is possible,

$$W_{up} = \frac{1}{2}m\rho\phi^2 . \quad (16)$$

Now an extra term in the potential appears from the ρ F-term,

$$V_{up} \sim \frac{1}{4Z(t)T^{3(1-\eta/2)}}m^2|\phi|^4 \sim \frac{m^2}{\mathcal{V}^{4-3\eta}} . \quad (17)$$

Then by taking $m^2 \sim \mathcal{V}^{1-3\eta}$ this term might cancel the negative contribution from the moduli potential. However, a well motivated value for the modular weight is $\eta = 2/3$ that implies a dependency of the uplifting in the volume with $\gamma = 2$. Although it seem plausible that such value still satisfy the condition (11) by numerical computation, in a previous work [39], the author checked that in fact such uplifting, with this modular weight, is not able to generate Minkowski vacua.

4.2. Dilaton dependent uplifting proposal

An interesting possibility is one where the uplifting appears depending on the dilaton modulus [45]. This field is supposed to be already stabilized via fluxes at SUSY preserving points, so such a term should come necessarily suppressed compared to the flux induced potential [39, 46] as can be inferred also from the fact that it should be of the order of the potential for the Kähler moduli in order to cancel the cosmological constant. Such a term can be generated via gaugino condensation in a D3-brane and/or E(-1)-instantons at a singularity whose size is parametrized by a blow-up mode, Q. The presence of magnetic fluxes generates a shift in in the gauge kinetic function, given by the dilaton, and introduces a dependency on the blow-up mode in an ADS superpotential

$$W_{up} = A_{up}e^{-a_{up}(S+h_{up}Q)} . \quad (18)$$

The blow-up mode is stabilized at a nearly vanishing point by D-term dynamics, something that we do not discuss in detail here but simply introduce in the scalar potential as

$$V_{D,Q} = \frac{1}{8\pi(S_r + h_{up}Q_r)}\left(q_Q\frac{Q_r}{\mathcal{V}}\right)^2 , \quad (19)$$

where we regard a Káhler potential for Q of the form $(Q + \bar{Q})^2/\mathcal{V}$, q_Q the corresponding $U(1)$ charge for Q. The induced uplifting, coming from the Q F-term, then is [45].

$$V_{up} \approx (a_{up}h_{up}A_{up})^2\frac{e^{-2a_{up}S_r}}{\mathcal{V}} . \quad (20)$$

Thus in this case $\gamma = 1$ and the condition (11) is clearly satisfied.

5. Numerical results

The aim now is to check whether this uplifting indeed does the job or not. The study seems complicated due to the fact that the dilaton appears as an important dynamical factor in the game. However, regarding these moduli as stabilized at SUSY preserving point we can rely on the results given by a model where the dilaton and complex structure are just frozen [39, 46]. Also in order to clear up the ideas we suppose that there is no coupling with the field ρ, i.e, $m = 0$, for example due to some extra symmetry forbidding it. In this case $\langle\rho\rangle = 0$ with a non tachyonic mass, so we do not report any result from this sector being irrelevant for our study.
Under this setup we set the following parameters and functions:

W_{CS}	$\hat{\xi}$	a	$Z(t)$
10	2	3π	$\sqrt{t}$

For the dilaton we fix $S_o = 1$ and an extra contribution in the Kähler potential from the Dilaton and Complex Structure is fixed to be $K_{SC} = -2Ln(2)$, whose value is actually irrelevant here but is chosen having in mind a functional form like $K_{SC} = -Ln(S + \bar{S}) - Ln(U + \bar{U})$. The original vacuum is obtained by setting $A_{up} = 0$ in eq.(18) or simply ignoring the the Q sector, finding real valued solutions for the VEV's shown in table 1.

T	t	ϕ	V_0
2.39×10^6	3.26	1.09×10^{-2}	-9.44×10^{-29}

Table 1: VEV's at the original vacuum in natural units.

We report only the first two figure digits but the existence and localization of the reported minima have been checked up to the 30th decimal place. The canonical normalized masses at this point are given in table 2.

$m_{3/2}$	m_ϕ	m_t	m_T
3.25×10^6	1.44×10^{10}	2.0×10^8	85.7

Table 2: Canonical masses in TeV units at the original vacuum. $m_{3/2}$ the gravitino mass. For the t field both, real and imaginary, parts get roughly the same mass. The imaginary component for T is massless, expected to be stabilized by quantum correction, and the imaginary part of ϕ is the would-be Goldstone for the broken $U(1)$ symmetry.

Introducing the uplifting sector with parameters

A_{up}	a_{up}	h_{up}	q_Q
-3.954×10^{-5}	4π	1/2	1

showing in A_{up} up to the tuned decimal in order to get the tuning for the cosmological constant below. The value for A_{up} is sightly above to the one estimated by setting the term in eq.(20) to cancel the original cosmological constant mainly due to the shift in the position of the vacuum. We should mention that although a positive value for A_{up} seems to do also the uplifting, in practice the phase introduced induces a tachyonic mass for the Q with real valued VEV's. Having said that we find the new vacuum reported in table 3.

T	t	ϕ	Q
2.68×10^6	3.28	1.05×10^{-2}	6.27×10^{-7}

Table 3: VEV's at the uplifted vacuum in natural units.

The VEV for the potential is indeed uplifted to 3.42×10^{-32}, in natural units, with a tuning at the level of almost one part in ten thousand from a tuning in A_{up} in one part in five hundred. A better tuning would be justified by scanning the string landscape of fluxes, as the amplitude A_{up} in general depend on the complex structure and dilaton moduli.
The canonical masses are shown in table 4.

m_ϕ	m_Q	m_t	m_T
1.32×10^{10}	7.26×10^9	1.7×10^8	54.4

Table 4: Canonical masses in TeV units at the uplifted vacuum. $m_{3/2} = 2.75 \times 10^6 TeV$ the gravitino mass. For the t field both, real and imaginary, parts get roughly the same mass. The imaginary component for T is massless, expected to be stabilized by quantum correction, and the imaginary part of ϕ and Q are the would-be Goldstone for the broken $U(1)$ symmetries.

As advertised in the beginning the masses get lowered compared to the ones at original vacuum. The ϕ field, being stabilized by the D-term dynamics, has variation in the mass mainly due to the shift in the scale of gauge symmetry breaking dictated by the VEV of ϕ. For the Kähler moduli instead, getting the mass from the F-term part of the potential, this is due to two effects: one is the larger volume that lowers all the energy scales associated to the scalar potential, in particular the gravitino mass now with value $m_{3/2} = 2.75 \times 10^6 TeV$. More precisely the overall factor $e^K \sim \mathcal{V}^{-2}$ makes that a change $\Delta T = 2.9 \times 10^5$ would explain a decrement in the masses of the Kähler moduli of order 30%, as exactly happens in for the small t modulus. However, in the case of the large modulus T the variation is almost in 40% which is explained, instead, by the contributions from the uplifting that make flatter the potential in this direction.

6. Conclusions

With the intention of having a guide for possible superstring vacua realizing appealing phenomenological features we propose a criterium, eq.(6), the uplifting mechanism, if any, should satisfy in order to effectively generate a tiny dS cosmological constant. Given that the uplifting mechanisms in the market so far have a clear dependency on the compact manifold volume, namely a monomial with negative power, this bound can be explored with better detail in the case of LVS where also the scalar potential isolates the dependency in such direction, in the moduli space, in a rather universal way. This leads to a bound for the power in the uplifting term, eq.(11).

An attentive reader might already notice that this last bound should be taken with caution as the original LVS potential, see eq.(15), does not actually scales like the third power of the volume being in fact the combination of three terms scaling differently all of them. Indeed this constraint actually gives the less conservative possibility in the sense that the actual behavior of the potential is the competition of three term and therefore is sightly bellow the supposed third power that would lead to lower bound. The bound in any case gives an indication of the order for which one expects the uplifting term not to work. In particular seems to exclude powers larger than two, and leave two at the edge. This is actually the power found in the uplifting term proposed in [37] which have been studied numerically in the past with the outshot of the impossibility of finding Minkowski vacua.

A novel uplifting mechanism was proposed in ref.[45] where the power in the volume is one making it a potential option for doing the job. As a check for the bound found analytically we perform the numerical study of the uplifting finding for the first time a dS vacuum in a setup with a charged small Kähler modulus.

It is important, however, to leave clear that this results are far from being conclusive. Indeed, although the bound clearly excludes $\gamma = 3$ it is not obvious that the $\gamma = 2$ value, like in the first case showed in the letter, does not work. More precisely for values close to two we expect model dependent factors to be important. This actually is checked by studying the special case of uplifting with hypothetical modular weights zero and minus one, leading to uplifting terms scaling like $1/\mathcal{V}^2$ and $1/\mathcal{V}^3$ respectively. In the first case, contrary to the finding in [39], we are able to find a vacuum, although the volume modulus mass is almost 80% less than the original one. The later case, forbidden by the bound, indeed fails in getting a Minkowski vacuum, with a negative cosmological constant independently of the value for the amplitude.

As stated in the beginning, and also shown in the explicit example, the potential once is uplifted is flatter leading to a smaller mass in the volume direction. This gives the indication that a more precise, although possibly more complicated, way of discriminating good or bad uplifting mechanism is through their side effects on the masses (see for example [47, 48] for works in this direction). We hope to come to this point in a later and more extended study on the issue.

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