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An Effect of α' Corrections on Racetrack Inflation

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Abstract: We study the effects of α' corrections to the Kähler potential on volume stabilisation and racetrack inflation. In a region where classical supergravity analysis is justified, stringy corrections can nevertheless be relevant for correctly analyzing moduli stabilisation and the onset of inflation.

Keywords: Inflation, moduli stabilisation.

Contents

1. Introduction

Recent studies seeking to embed inflation in string theory in the context of Type IIB flux compactifications [1, 2, 3, 4, 5, 6, 7, 8, 9, 10] have revealed the importance and the delicate nature of moduli stabilisation: moduli need to be stabilised with a large enough mass to avoid Equivalence Principle violations while still allowing sufficient flat regions in the potential for the onset of inflation. This suggests the possibility that a successful realization of inflation in string theory might place interesting constraints on the moduli of the compact manifold. With the wealth of possible string compactifications, such potential phenomenological constraints on the parameter space are worthy of study; conversely with the wealth of proposals in the literature for instantiating inflation, any restrictions curtailing the possibilities similarly deserves attention.

In this note, we focus on the specific proposal of racetrack inflation in string theory [7], which has been studied in the large radius limit of Calabi-Yau compactifications. An interesting question is whether this approach to inflation can be realized as we move to smaller radii, or whether corrections that contribute away from large radius might significantly affect the analysis. Naively, one might anticipate that so

long as we remain at a radius large enough to justify perturbation theory, such corrections would have little relevance[1] . The requirement of successful inflation, however, is far more constraining than perturbative reliability and hence even at moderately large radii, perturbative corrections can be important to the cosmological analysis.

Specificially, we study the effect that the leading perturbative corrections to the Kähler potential have on cosmological studies using the supergravity scalar F-term potential. For the cases we study, such corrections can undermine the onset of inflation in a region of moduli space where classical supergravity analysis concludes inflation should occur. In some cases, it may be possible to choose a new set of parameters to yield inflationary dynamics; even so, the parameters would generally be unrelated to those studied in the literature, and additionally, the choice would depend on the specific Calabi-Yau on which one compactifies as well as the string coupling constant g_s. It would be interesting to include α' corrections at the outset in any search for inflationary potentials as this may provide a tighter handle on the available regions in parameter space in which one could stabilise the moduli and find inflation.

This note is organised as follows. In section 2 we quote the result for the corrected Kähler potential and illustrate that the supersymmetric minimum is insensitive to this correction. By using the corrected Kähler potential, in section 3, we show that the no-scale structure is broken and a potential for the volume modulus is generated. In order to be self-contained, section 4 is devoted to a brief review of the relevant results from racetrack inflation [7]. The slow roll parameters are computed for the case of interest. In section 5 we explore the effect of the corrections on volume stabilisation and on the conditions necessary for inflation. In addition, we choose specific compactifications to study and for each find the minimum value for the volume modulus that ensures α' corrections can be safely ignored. Our results indicate that such minima are generally deep in the perturbative domain and hence α' corrections can be relevant even at reasonably large volume.

2. The Corrected Kähler Potential

The leading perturbative corrections to the Kähler potential of the volume modulus have been computed in [11] using the results of [12, 13, 14, 15, 16]. With $2\pi\alpha' = 1$ [17], the Kähler potential including α' corrections is

$$K = -2\log(\hat{\mathcal{V}} + \frac{1}{2}\xi e^{-3/2\phi}), \tag{2.1}$$

[1] We thank P. Berglund for bringing to our attention [8] in which the authors find that stringy corrections are relevant even at large volumes in agreement with the results presented in this note.

where $\xi = -\frac{1}{2}\chi\zeta(3)$ and χ is the Euler number of the compactification manifold. To facilitate comparisons with earlier results, we work in the Einstein frame; this is the origin of the dilaton dependance of the correction. While the result holds for any number of Kähler moduli, we will restrict ourselves to a single Kähler modulus, T. As such the Calabi-Yau volume, $\hat{\mathcal{V}}$, is related to the volume modulus, T, by $\hat{\mathcal{V}} = (T + \overline{T})^{3/2}$. In keeping with [2] and [7], we treat the complex structure moduli and the dilaton as having been stabilized prior to the fixing of the volume modulus. It is clear from the above, however, that one should include stringy corrections prior to this fixing as all fields should be stabilized using the corrected Kähler potential. At the SUSY minimum

$$D_i W = \partial_i W + W \partial_i K = 0, \tag{2.2}$$

where i runs over the complex structure moduli and the dilaton. This should be contrasted with

$$D_i^{(0)} W = \partial_i W + W \partial_i K^{(0)} = 0, \tag{2.3}$$

where $K^{(0)}$ is the tree level Kähler potential. Fixing moduli using (2) rather than (1) is expected to change the specific values where the complex structure moduli and the dilaton are fixed but not the systematics. Hence the correction term can be treated as a constant for any specific Calabi-Yau. Henceforth, we set $L = -\frac{1}{4}\chi\zeta(3)e^{-3/2\phi} = -\frac{1}{4}\chi\zeta(3){g_s}^{-3/2}$.

At the SUSY minimum, the potential is insensitive to the α' corrections as one would expect from non-renormalisation theorem arguments [18]. It is instructive to see how this happens explicitly here. At the SUSY minimum

$$D_T W = 0 \rightarrow W = -\frac{\partial_T W}{\partial_T K} = -\frac{(\partial_T W)((T + \overline{T})^{3/2} + L)}{(-3(T + \overline{T})^{1/2})} \tag{2.4}$$

The scalar potential, $V = e^K (g^{T\overline{T}} D_T W \overline{D_T W} - 3|W|^2)$ at the minimum is

$$\begin{aligned} V_{SUSY} &= -3e^K |W|^2 \\ &= -3((T + \overline{T})^{3/2} + L)^{-2}((T + \overline{T})^{3/2} + L)^2 \Big(\frac{(\partial_T W)^2}{(9(T + \overline{T})}\Big) \\ &= -\frac{(\partial_T W)^2}{3(T + \overline{T})} \end{aligned} \tag{2.5}$$

We see from this how the correction term drops out in the final result. Of course, this will no longer be the case away from the SUSY minimum.

3. Breaking the No-scale Structure

The classical supergravity potential displays a no-scale structure which makes fixing the volume modulus more subtle. In [2] this fixing was achieved by including non-perturbative corrections to the superpotential that break the no-scale structure and generate a potential for T. One can, however, break the no-scale structure in other ways. In particular, α' corrections to the Kähler potential break this structure and generate a correction to the supergravity potential dependant on T and proportional to the Euler number of the internal manifold. With the corrected Kähler potential and its metric, $g_{T\overline{T}} = [3(T+\overline{T}) - 3/2L(T+\overline{T})^{1/2}]/[((T+\overline{T})^{3/2}+L)^2]$ inserted into the supergravity potential

$$V_F = e^K \left(g^{T\overline{T}} D_T W \overline{D_T W} - 3|W|^2 \right) \tag{3.1}$$

it can be seen that the two terms no longer cancel, and a potential for the volume modulus, T, is generated. Since we only consider tree level contributions to the superpotential arising from the fluxes, $W = W_0$ here we find

$$V_T = \frac{3LW_0^2}{(2(T+\overline{T})^{3/2} - L)}. \tag{3.2}$$

As expected, the $L = 0$ limit gives the expected $V_T = 0$ result. Alone, however, the stringy corrections to the Kähler potential cannot stabilise the volume modulus as the potential exhibits runaway behaviour [11].

4. Review of Racetrack Inflation

From a cosmological standpoint, simply finding a potential for the volume modulus is not sufficient. One needs to find a minimum where T can be stabilised and, importantly, with a potential that exhibits a sufficiently flat region along which inflation can occur.

In KKLT [2], the no-scale structure is broken by adding non-perturbative corrections to the superpotential and the resulting AdS minimum is subsequently lifted to a dS minimum by adding a stack of antibranes thus breaking supersymmetry. In [7], the authors include additional non-perturbative potentials of the modified racetrack type and find saddle point regions in the potential where slow-roll inflation can take place. In this sense the authors of [7] have revived the old ideas of modular inflation [19, 20] with a flat enough potential. In the case of [7] the inflaton will be $Y = \Im(T)$.
The superpotential considered includes non-perturbative corrections and is assumed to have the modified racetrack form,

$$W = W_0 + A\, e^{-aT} + B\, e^{-bT}, \tag{4.1}$$

where W_0 is the effective superpotential as a function of all the complex structure moduli and the dilaton, all assumed to have already been stabilized. As in the KKLT scenario, W_0 is required to be small ($W_0 \lesssim 10^{-4}$). This is achieved by discretely tuning fluxes. The exponential terms are expected to arise from gaugino condensation in a theory with a product gauge group [21]. For example, for an $SU(N) \times SU(M)$ gauge group one finds $a = 2\pi/M$ and $b = 2\pi/N$. A and B are expected to be small in Planck units [21].

The scalar potential receives contributions from two terms[2]

$$V = V_F + \delta V. \tag{4.2}$$

The first is the standard $\mathcal{N} = 1$ supergravity F-term potential, (6), [23] and the second term, δV, is induced by the tension of the anti-D3 branes added to break supersymmetry and lift the potential from an AdS to a dS minimum [2] . Conveniently, the introduction of the anti-branes does not introduce extra translational moduli as their position is fixed by the fluxes. Their contribution is positive definitive and is of the form [25]

$$\delta V = \frac{E}{X^\alpha}, \tag{4.3}$$

where the coefficient E depends on the the tension of the branes T_3, the number of branes and the warp factor. For this reason one can discretely tune E and the supersymmetry breaking in the system but not to arbitrary precision. In [7] E is tuned to set the global minimum at the Minkowski vacuum, $V = 0$. In [2] a metastable de Sitter solution is found by tuning E so that the minimum is dS with a small cosmological constant. Depending on the location of the anti-branes one finds different results for the exponent α. If the anti-branes are situated at the bottom of the throat in the region of maximum warping one finds $\alpha = 2$. On the other hand if the anti-branes sit in the unwarped region $\alpha = 3$ [7]. Since the former is energetically favoured we set $\alpha = 2$ henceforth.

The shape of the resulting potential is highly sensitive to the parameter values. Including stringy corrections essentially adds a new parameter and, we show below, this added term has the capacity to destabilise some of the key features found in [7]. The following set of parameters were chosen by [7] to illustrate the presence of a saddle point region where $X = \Re(T)$ has a minimum and can thus be stabilised, and $Y = \Im(T)$ has a sufficently flat maximum to ensure that a field starting at the saddle point and rolling in the Y direction will yield inflation.

[2] In [22] an inflationary potential is claimed to be found using α' corrections instead of an uplifting potential term.

$$A = \frac{1}{50}, \quad B = \frac{-35}{1000}, \quad a = \frac{2\pi}{100}, \quad B = \frac{2\pi}{90}, \quad W_0 = \frac{-1}{25000}, \quad E = 4.14668 \times 10^{-12} \tag{4.4}$$

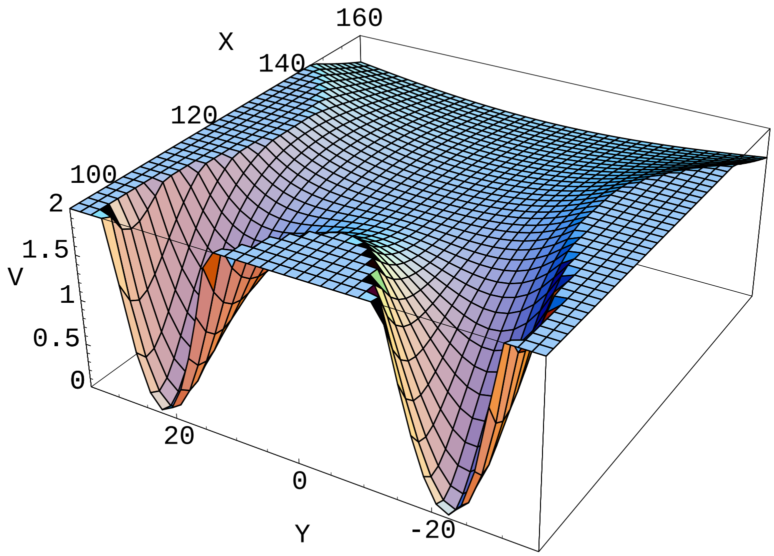

Figure 1: Original Racetrack potential corresponding to $L = 0$, (rescaled by 10^{16})

The potential has a saddle point at

$$X_{\text{sad}} = 123.216, \quad Y_{\text{sad}} = 0, \quad V_{\text{saddle}} = 1.655 \times 10^{-16} \tag{4.5}$$

and minima at

$$X_{\min} = 96.130, \quad Y_{\min} = \pm 22.146 \tag{4.6}$$

In Figure 2, a plot of the $Y = 0$ slice of the potential is included to illustrate the crucial minimum in the X direction.

4.1 Computing Slow Roll Parameters

We illustrate the claim that one can get slow roll inflation near the saddle point for the racetrack potential. For successful slow-roll inflation the following conditions need to be met (in units where $M_P = 1$)[3]

$$\epsilon \equiv \frac{1}{2}\left(\frac{V'}{V}\right)^2 \ll 1\,, \quad \eta \equiv \frac{V''}{V} \ll 1, \tag{4.7}$$

[3]We thank L. McAllister for pointing out a typo in a previous version.

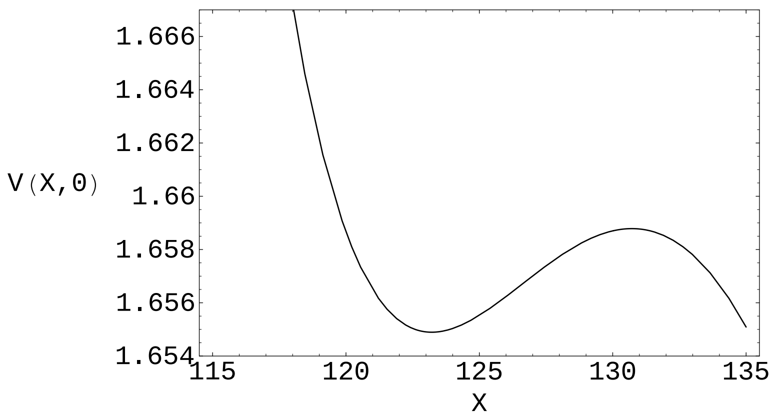

Figure 2: $Y = 0$ slice of original Racetrack potential for $L = 0$, (rescaled by 10^{16})

where the primes refer to derivatives with respect to a canonically normalised scalar field. Since $V' = 0$ at the saddle point, ϵ is exactly zero. To compute η one must take account of the non-canonical kinetic term for the inflaton, Y. It is useful to derive η in general so that the result can be used when we include the correction term. Specifically the kinetic term is

$$\mathcal{L}_{\rm kin} = 2g_{T\overline{T}}\frac{1}{2}(\partial_\mu X \partial^\mu X + \partial_\mu Y \partial^\mu Y), \tag{4.8}$$

where the factor of 2 is a result of the relation between X and T. Taking this normalisation into account yields

$$\eta = \frac{V''}{V} \rightarrow \eta = \frac{V''}{2g_{T\overline{T}}V}. \tag{4.9}$$

For the large radius case, $g_{T\overline{T}} = 3/(4X^2)$, resulting in $\eta = [2X^2V'']/[3V]$ with X evaluated at the saddle point and we find.

$$\eta_{\rm saddle} = -0.0061. \tag{4.10}$$

This agrees with [7].[4] It is now a simple matter to include the effect of the loop term and study its effect on η. Specifically

$$\begin{aligned}\eta &= \frac{1}{2g_{T\overline{T}}}\frac{V''}{V} \\ &= \frac{V''((T+\overline{T})^{3/2}+L)^2}{3V(2(T+\overline{T}) - L(T+\overline{T})^{1/2})} \\ &= \frac{V''((2X)^{3/2}+L)^2}{3V(4X - L(2X)^{1/2})},\end{aligned} \tag{4.11}$$

[4]We thank J.J. Blanco Pillado for allowing us to compare results exactly.

where, in the above expressions V also has L dependance.

5. Effect of α' Corrections

There are three features required of the potential, all of which were met in [7].

- The global minimum must be dS or Minkowski. This step is achieved by including the δV term [2]. One can tune the value of the potential at the minimum by discretely tuning E.
- A de Sitter saddle point with a minimum in the X direction.
- A sufficiently flat maximum in the Y direction to attain a cosmologically significant duration of slow roll inflation.

We find, for any reasonable value of L, the stringy correction spoils the second and third conditions. By adjusting the parameters it may then be possible to re-establish a minimum, but it is difficult to do so while keeping η sufficiently small. Considering the amount of fine-tuning required to find slow roll inflation near the saddle point, this is not unexpected. The correction we are considering amounts to a new, non-tunable term not previously considered in this context. Since some of the parameters in the model can only be fine tuned discretely, it may be that for any specific example, one cannot find regions conducive to inflation.

This possibility can be illustrated by plotting the cross section through the saddle point for non-zero L. Here we choose $L = 60$ which corresponds to the quintic, $\chi = -200$, and string coupling $g_s \approx 1$.

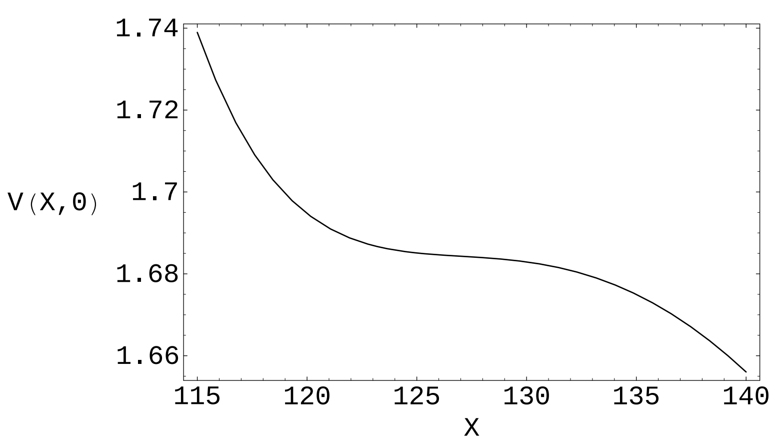

Figure 3: $Y = 0$ slice of the potential for $L = 60$

Typically, though, we would fix the dilaton at a value $g_s \ll 1$, in which case $L \gg 60$. This would make it even harder to re-establish stabilisation. Notice that this destabilisation occurs at large radius, one where we would naively expect to trust a classical supergravity analysis. Notice too that the effect is sensitive to the sign of χ. For the mirror quintic, $\chi = 200 \to L = -60$, we find that stabilisation in the X direction is enhanced. However the conditions for inflation are still destroyed since at the saddle point we find $\eta = -2.46$.

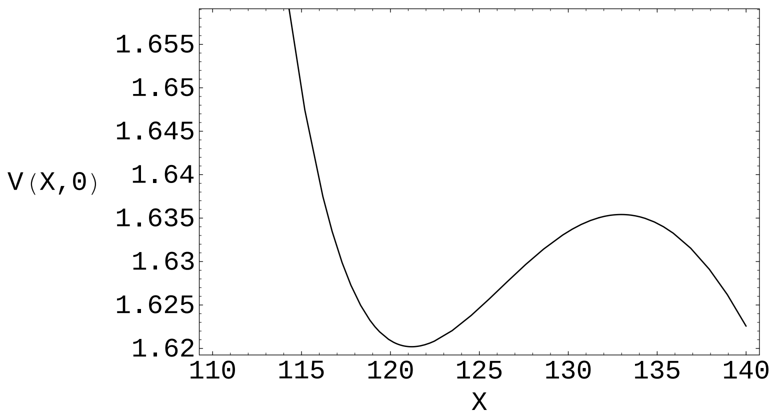

Figure 4: $Y = 0$ slice of the potential for $L = -60$. Note the enhancement of the minimum.

6. How Large is Large Enough?

In the previous section, we saw that α' corrections to the Kähler potential play a significant role, even at values of the volume modulus around $100 M_P$, where one would generally expect such corrections to be irrelevant. At what radius, then, do these effects become negligible for determining the onset of inflation? The answer, of course, depends on the specific compactification manifold–in particular its Euler number, χ, and on the value of g_s. Below we give some examples. To aid our analysis, we take advantage of a scaling symmetry which the racetrack potential obeys in the absence of the correction but which the correction term spoils. Without the correction, this symmetry ensures that the potential and its essential properties, such as slope and slow-roll parameters, remain the same regardless of the location in X of the saddle point. Explicitly, the rescaling is [7]

$$a \to \frac{a}{\lambda}, \quad b \to \frac{b}{\lambda}, \quad E \to \lambda^2 E \tag{6.1}$$

with

$$A \to \lambda^{3/2} A, \quad B \to \lambda^{3/2} B, \quad W_0 \to \lambda^{3/2} W_0 \tag{6.2}$$

$$X \to \lambda X, \quad Y \to \lambda Y \tag{6.3}$$

With the inclusion of the α' corrections, this symmetry is broken but still provides a convenient means for finding where the large radius conclusions are spoiled.

In the following table we have evaluated η for a range of values of λ and L and compared the classical and α' corrected results[5]. The values of L we have chosen correspond to the following cases. $L = 2$ corresponds to $\chi = -6$ and $g_s \approx 0.9$; this represents a value of L on the low end of physical interest. $L = 60$ and $L = -60$ correspond to the quintic and the mirror quintic respectively, with $g_s \approx 1$. $L = 2500$ corresponds to the quintic and $g_s \approx 1/12$.

	$L=0$		$L=2$		$L=60$		$L=-60$		$L=2500$	
λ	X_{saddle}	η	X_{saddle}	η	X_{saddle}	η	X_{saddle}	η	X_{saddle}	η
100000	12321632	−0.0061	12321632	−0.0061	12321632	−0.0061	12321632	−0.0061	12321632	−0.0061
4000	492865.3	−0.0061	492865.3	−0.0061	492865.3	−0.0061	492865.2	−0.0061	492867.0	−0.0056
400	49286.53	−0.0061	49286.53	−0.0061	49286.66	−0.0057	49286.40	−0.0064	49291.92	0.0085
80	9857.305	−0.0061	9857.315	−0.0059	9857.594	−0.0022	9857.017	−0.0099	9869.600	0.1582
50	6160.816	−0.0061	6160.828	−0.0058	6161.182	0.0018	6160.451	−0.0140	6176.740	0.3310
20	2464.326	−0.0061	2464.346	−0.0050	2464.906	0.0252	2463.751	−0.0372	2494.857	1.4940
10	1232.163	−0.0061	1232.190	−0.0032	1232.989	0.0827	1231.355	−0.0935	no min	–
2	246.4326	−0.0061	246.4938	0.0268	248.5787	1.0784	244.7928	−0.9355	no min	–
1	123.2163	−0.0061	123.3035	0.0875	no min	–	121.1970	−2.4635	no min	–
1/2	61.60816	−0.0061	61.73434	0.2622	no min	–	59.34719	−6.3833	no min	–
1/4	30.80408	−0.0061	30.99693	0.7882	no min	–	28.45786	−18.4781	no min	–
1/8	15.40204	−0.0061	no min	–	no min	–	12.81586	37.7937	no min	–

Table 1: Effect of α' corrections on stabilisation and η when we move the minimum using λ.

Notice that for reasonable values of L, say $\Re(T) \sim 10^7$ in Planck units with $2\pi\alpha' = 1$, the α' corrections become negligible and supergravity analysis is both qualitatively and quantitatively unaffected. However, at smaller values of $\Re(T)$–but large enough for perturbation theory to be justified–the corrections not only change the details of the inflationary model but ultimately prevent inflation from initiating. For these models, other choices of parameters might well lead to inflation, but a lowest order calculation is no longer adequate, even though the dimensionless expansion parameter can be on the order of $\alpha'/\sqrt{T} \sim 10^{-2}$.

7. Conclusions

In this note we have studied the effect that stringy corrections to the Kähler potential have on Kähler modulus stabilisation and on racetrack inflation. We find that α'

[5]It is worth noting that not all these examples may be realised with a single Kähler modulus. For example, $\chi > 0$ requires $h^{2,1} < h^{1,1}$. I.e. more Kähler moduli than complex structure moduli, which would require a rigid Calabi-Yau. In principle one could generalise this study to the case of more Kähler moduli, however we expect a similar effect would arise.

corrections can play a significant role even at values of the volume modulus within the perturbative realm. Explicit calculations show that the minimum radius beyond which such corrections are irrelevant depends sensitively on the compactification manifold and on the value of g_s (set by the fluxes). In a given model, successful stabilization and inflation may require a sufficiently large compactification manifold. Turning this around, we expect fluxes to fix W_0 and g_s, the value of the cosmological constant should fix E, and fundamental physics should fix the parameters of the non-perturbative superpotential. Requiring successful moduli stabilization and inflation may then place restrictions on the Euler number of the compactification.

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