A Conic Large Volume Scenario

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(RB, Daniela Herschmann, Florian Wolf, arXiv:1605.06299)

Introduction

Introduction

Moduli stabilization in string theory:

- Race-track scenario
- KKLT
- LARGE volume scenario

Based on instanton effects $\rightarrow$ exponential hierarchies $\rightarrow$ can generate $M_{\rm susy} \ll M_{\rm Pl}$

Experimentally:

- Supersymmetry not found (yet) at LHC with $M < 2$TeV.
- Fate and explanation of 750 GeV excess remains to be seen
- BICEP+PLANCK+KECK: Not yet excluded large field inflation: $M_{\rm inf} \sim M_{\rm GUT}$

Introduction

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If r is detected $\rightarrow$ large field inflation: (currently $r < 0.07$)
Lyth bound implies $\Delta\Phi > M_{\rm pl}$

and
$$\frac{\Delta\phi}{M_{\rm pl}} > O(1)\sqrt{\frac{r}{0.01}}$$

$$M_{\rm inf} = (V_{\rm inf})^{\frac{1}{4}} \sim \left(\frac{r}{0.1}\right)^{\frac{1}{4}} \times 1.8 \cdot 10^{16}\,{\rm GeV}$$

Problem: For a controllable single field inflationary scenario, all moduli need to be stabilized such that

$$M_{\rm Pl} > M_{\rm s} > M_{\rm KK} > M_{\rm inf} > M_{\rm mod} > H_{\rm inf} > |M_{\Theta}|$$

Need: Moduli stabilization scheme generating hierarchies of masses for the moduli (for a review listen to Daniela Herschmann's talk)

Flux generated potential

Flux generated potential

(Bhg, Herschmann, Wolf, arXiv:1605.06299)

Three-form fluxes on a CY: Kähler potential:

$$K = -\log(S+\overline{S}) - 2\log\mathcal{V} - \log\Big(-i\int\Omega_3\wedge\overline{\Omega}_3\Big)$$

with GVW superpotential

$$W = \int_{\mathcal{M}}\Big[F + iS\,H\Big]\wedge\Omega_3$$

No-scale Scalar potential:

$$V = e^K\Big(G^{z\overline{z}}D_zW\,D_{\overline{z}}\overline{W} + G^{S\overline{S}}D_SW\,D_{\overline{S}}\overline{W}\Big)$$

with Minkowski minima at $F_z = D_zW = 0$ and $F_S = D_SW = 0$.

Warped CYs

Warped CYs

Backreaction of a three-form flux leads to a warped CY metric (Giddings, Kachru,Polchinski)

$$ds^2 = e^{2A(y)}\eta_{\mu\nu}dx^\mu dx^\nu + e^{-2A(y)}\tilde{g}_{mn}dy^m dy^n$$

Warp factors:

- stack of D3-branes

$$e^{-4A(y)} = 1 + \frac{4\pi g_s N}{|y|^4}$$

- (H_3, F_3) form flux on an (A, B)-cycle:warped metric on the deformed conifold

$$e^{-4A} \sim 1 + \frac{1}{(\mathcal{V}|z|^2)^{\frac{2}{3}}} \, .$$

Warped CYs

Warped CYs

Dilute flux limit

$$\mathcal{V}|z|^2 \gg 1\,.$$

The physical size of the three-cycle A is

$$\mathrm{Vol}(A) = \mathcal{V}^{\frac{1}{2}} \left| \int_A \Omega_3 \right| = (\mathcal{V}|z|^2)^{\frac{1}{2}}$$

General wisdom: warped compactifications lead to exponential mass hierarchies (RS scenario). Application to inflation in (Kooner, Parameswaran, Zavala)

Question: Does this prevail in the dilute flux limit, where one can employ the usual GVW-type SUGRA formalism?

Note: Effective SUGRA for the strongly warped region is a tough question (DeWolfe,Giddings),(Giddings,Maharana),(Douglas,Shiu,Torroba,Underwood)

Periods close to conifold

Periods close to conifold

Moduli stabilization close to a conifold singularity.

Example: Mirror of threefold $\mathbb{P}_{11226}[12]^{128,2}$

$$P = z_1^{12} + z_2^{12} + z_3^6 + z_4^6 + z_5^2 - 12\psi\, z_1\, z_2\, z_3\, z_4\, z_5 - 2\phi\, z_1^6\, z_2^6\,.$$

Periods follow from the fundamental one (Berglund, Candelas,De la Ossa, Font, Hübsch, Jancic, Quevedo),

$$\varpi_f(\psi,\phi) = -\frac{1}{6}\sum_{n=1}^{\infty} \frac{\Gamma\left(\frac{n}{6}\right)(-12\,\psi)^n\, u_{-\frac{n}{6}}(\phi)}{\Gamma(n)\,\Gamma^2\left(1-\frac{n}{6}\right)\,\Gamma\left(1-\frac{n}{2}\right)}$$

and have been determined up to linear order close to the conifold locus $864\,\psi^6 + \phi = 1$ by Conlon-Quevedo.

Remark: Flux vacua statistically cluster around conifold loci

Periods close to conifold

Periods close to conifold

In terms of "appropriate" coordinates Z and Y:

$$F_0 = 1\,,$$

$$F_1 = Z\,,$$

$$F_2 = (0.46 + 0.11i) + (1.10 - 2.17i)Y - 0.19\,Z$$
$$- (7.34 - 14.73i)\,Y^2 + (2.71 + 1.42i)\,Y Z + (0.11 - 1.69i)\,Z^2$$

and

$$X^0 = (-0.045 + 0.23i) + (1.10 + 0.06i)Y + 0.17\,Z$$
$$- (7.34 + 1.83i)\,Y^2 + (0.55 + 1.42i)\,Y Z + (0.11 - 0.17i)\,Z^2\,,$$

$$X^1 = -\frac{1}{2\pi i} Z \log Z + 0.18 - 0.42\,Y - 1.43i\,Z + \ldots\,,$$

$$X^2 = 0.09 - 2.2\,Y + 14.68\,Y^2 - 2.84i\,Y Z - 0.22\,Z^2\,.$$

Periods close to conifold

Periods close to conifold

Kähler potential simplifies considerably

$$K_{\text{cs}} = -\log\left[-i\Pi^\dagger \Sigma\, \Pi\right]$$

$$= -\log\left[\frac{1}{2\pi}|Z|^2 \log\left(|Z|^2\right) + A + \text{Re}Y + B\,(\text{Re}Y)^2 + C\,|Z|^2 \ldots\right]$$

with $A = 0.44$ and $B = -19.05$ and $C = -2.86$.

Shift symmetries: $Z \to e^{i\theta} Z$ and $\text{Im}(Y) \to \text{Im}(Y) + \theta$.

(Etxebarria, Grimm, Valenzuela)

Study moduli stabilization close to the conifold locus instead of the large complex structure locus.

Moduli stabilization

Moduli stabilization

Neglecting Y, freeze Z via (GKP)

$$W = f\,X^1 + ihSF_1 - ih'SF_0$$
$$= f\left(-\frac{1}{2\pi i} Z \log Z + B + D\,Z + \ldots\right) + ihS\,Z - ih'S\,,$$

$F_Z = 0$ leads to

$$Z \sim \hat{C}\, e^{-\frac{2\pi h}{f} S}\,,$$

Integrating out Z:

$$W_{\text{eff}} = B\,f + \frac{f}{2\pi i} \hat{C}\, e^{-\frac{2\pi h}{f} S} - ih'S$$

Moduli stabilization

Moduli stabilization

$$W_{\rm eff} = B\, f + \frac{f}{2\pi i}\hat{C}\, e^{-\frac{2\pi h}{f}S} - ih'S$$

- Remarkably, $W_{\rm eff}$ contains exponential terms mimicking the behavior of non-perturbative effects.
- Calls for an application to hierarchical moduli stabilization and natural/aligned inflation
- Not generated by an instanton $\rightarrow$ loop-hole in the WGC

With $h' \neq 0$, the axion-dilaton gets stabilized at

$$S = B\frac{f}{h'}$$

Masses

Masses

Mass of axio-dilaton:

$$m_S^2 \sim \frac{M_{\rm pl}^2}{\mathcal{V}^2} \sim \frac{M_{\rm s}^2}{\mathcal{V}}$$

Mass of cs. modulus Z:

$$m_Z^2 \sim \frac{M_{\rm pl}^2}{\mathcal{V}^2|Z|^2} \sim \frac{M_{\rm s}^2}{\mathcal{V}\,|Z|^2}$$

Comments:

- Controllable regime: $m_Z \ll M_s \Rightarrow \mathcal{V}\,|Z|^2 \gg 1$ dilute flux regime
- m_Z is exponentially larger than m_S

Conic Swiss Cheese

Conic Swiss Cheese

Interestingly, the used effective SUGRA theory by itself indicates its limitation, i.e. that it is applicable only in the dilute flux regime where warping is neglegible.

One dynamically needs to freeze the volume at exponentially large values $\Rightarrow$ combine this conic no-scale scheme with the LVS scenario so that

$$m_{\tau_b} < m_{\tau_s} \sim m_S < m_Z \, .$$

Since we do not explicitly know the one-loop Pfaffian, we allow it to depend polynomially on Z

$$W_{\rm inst}(T_s) = W_0 + A_s \, Z^N \, e^{-a_s T_s}$$

Conic Swiss Cheese

Conic Swiss Cheese

Proceed as in LVS with $A_s \to A_s Z^N$ that is now an exponentially small number.
In the non-susy AdS-type large-volume minimum the Kähler moduli get now stabilized at

$$\tau_s = \frac{(4\xi)^{\frac{2}{3}}}{g_s}, \qquad \mathcal{V} = \frac{W_0\, \xi^{\frac{1}{3}}}{2^{\frac{1}{3}}\, g_s^{\frac{1}{2}}\, |a_s A_s Z^N|} e^{a_s \tau_s}\,.$$

For the crucial combination we thus obtain

$$\mathcal{V}|Z|^2 \sim \exp\left[\frac{a_s}{g_s}\left(\frac{h(N-2)}{f} + (4\xi)^{\frac{2}{3}}\right)\right].$$

For $N \geq 2$ this is naturally larger than one and for $N \leq 1$ we can choose $f \gg h$ so that the exponent becomes positive.

Conic Swiss Cheese

Conic Swiss Cheese

Scale	(Mass)^2 in $M_{\rm Pl}^2$
string scale $M_{\rm s}^2$	$\frac{g_s^{1/2}}{\mathcal{V}}$
Kaluza-Klein scale $M_{\rm KK}^2$	$\frac{1}{\mathcal{V}^{4/3}}$
conic modulus M_Z^2	$\frac{f^4 g_s^3}{\mathcal{V}^2 \lvert Z \rvert^2}$
small Kähler modulus $M_{\tau_s}^2$	$\frac{f^2}{g_s \mathcal{V}^2}$
gravitino $M_{3/2}^2$	$\frac{f^2 g_s}{\mathcal{V}^2}$
axio-dilaton M_S^2 and c.s. moduli	$\frac{f^2 g_s}{\mathcal{V}^2}$
large Kähler modulus $M_{\tau_b}^2$	$\frac{f^2}{g_s^{1/2} \mathcal{V}^3}$

Conic Swiss Cheese

Conic Swiss Cheese

Summary:

- Flux stabilization of the complex structure and the axio-dilaton close to the conifold singularity can be consistently combined with the LVS scenario.
- This guarantees a reliable effective field theory approach where warping is negligible.
- The masses of the moduli split up so that one gains parametric control over their ratios.

Applications: Inflation (see parallel session talk by Florian Wolf).

Idea on inflation

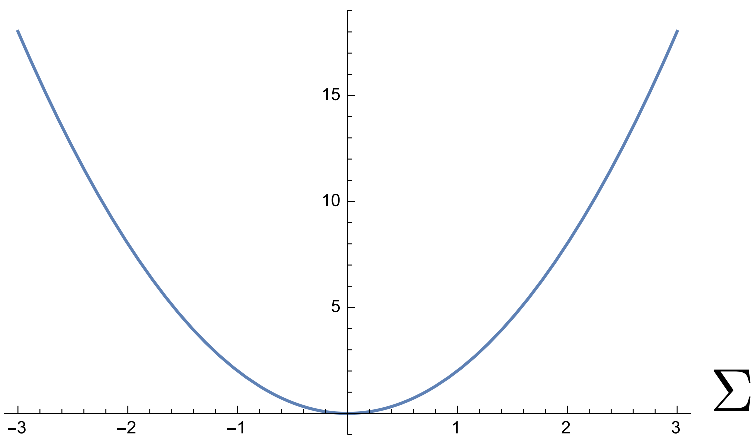
Idea on inflation

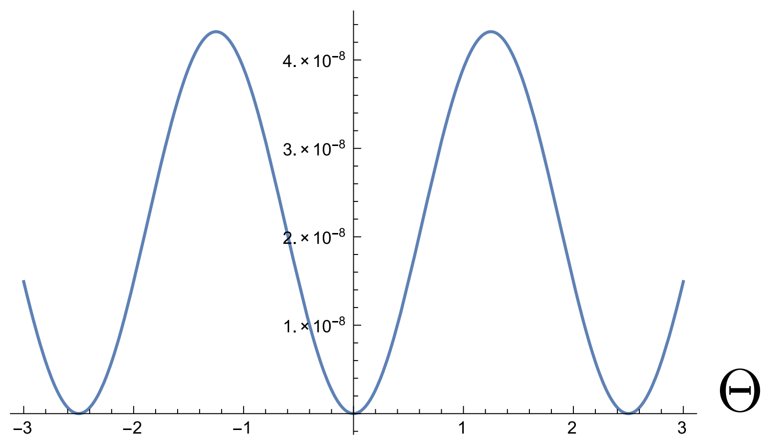
Extend the supergravity model after integrating out Z as

$$W_{\text{eff}} = i\alpha\big(f + h'\,S + \hat{f}'\,Y\big) + \frac{f\hat{C}}{2\pi i}\,\exp\Big(-\tfrac{2\pi}{f}\big(hS + \hat{f}Y\big)\Big)$$

- Axion $\Sigma = h'\,c + \hat{f}'\,\zeta$ stabilized by tree-level fluxes
- Axion $\Theta = \big(hc + \hat{f}\zeta\big)$ by induced exp-terms $\to$ inflaton candidate!

Potential: Alignment for $h'\hat{f} - h\hat{f}' = 0$





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Issues:

- The periods contain higher order Y^n corrections that need to be subleading (Bizet, Loaiza-Brito, Zavala)
- The inflationary mass scale comes out as $M_{\rm inf} < M_Z$ so that the usage of $W_{\rm eff}$ is justified.
- For single field inflation, all Kähler moduli need to be heavier than Θ.

more details in Florian Wolf's talk

Comment on WGC

Comment on WGC

Mild version of WGC admits a situation where (Rudelius), (Brown,Cottrell,Shiu,Soler)

$$V \sim e^{-2\,S_{\rm inst}} \left(1 - \cos\left(\frac{\tilde{\Theta}}{f_{\tilde{\Theta}}}\right)\right) + e^{-2\,S^{(2)}_{\rm inst}} \left(1 - \cos\left(\frac{k\,\tilde{\Theta}}{f_{\tilde{\Theta}}}\right)\right),$$

with $k \in \mathbb{Z}$.

- For $k \gg 1$, one can have $f_{\tilde{\Theta}}/k < 1$
- For $S_{\rm inst} < S^{(2)}_{\rm inst}$ the first term is still dominant enabling inflation.
- In our case the second instanton is a D(-1)-brane.
- Has also been realized by (Hebecker,Mangat,Rompineve,Wittkowski)

Conclusions

Conclusions

Studied moduli stabilization close to a conifold singularity in the dilute flux regime (using the usual SUGRA action).

- One still gets exponential mass hierarchies among bulk modes.
- After integrating out, exponential (NP-like) terms arise.
- This can be combined with LVS to dynamically ensure negligible warping.
- First application to axion inflation.

Summary: The string landscape is rich $\rightarrow$ hide new mechanisms for mass hierarchies

Thank You!