A Conic Large Volume Scenario

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(RB, Daniela Herschmann, Florian Wolf, to appear soon)

Introduction

Introduction

Moduli stabilization in string theory:

- Race-track scenario
- KKLT
- LARGE volume scenario

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

Experimentally:

- Supersymmetry not found at LHC with $M < 2$TeV.
- Not excluded large field inflation: $M_{\rm inf} \sim M_{\rm GUT}$

Introduction

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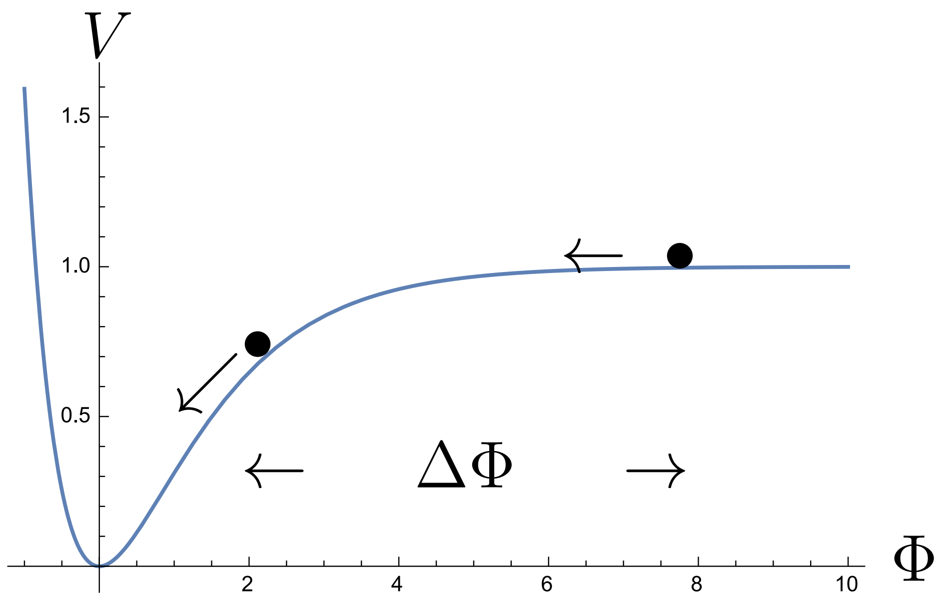
PLANCK 2015, BICEP2 results:

- upper bound: $r < 0.07$
- spectral index: $n_s = 0.9667 \pm 0.004$ and its running $\alpha_s = -0.002 \pm 0.013$.
- amplitude of the scalar power spectrum $\mathcal{P} = (2.142 \pm 0.049) \cdot 10^{-9}$

Single field slow role inflation



Introduction

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

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

and

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

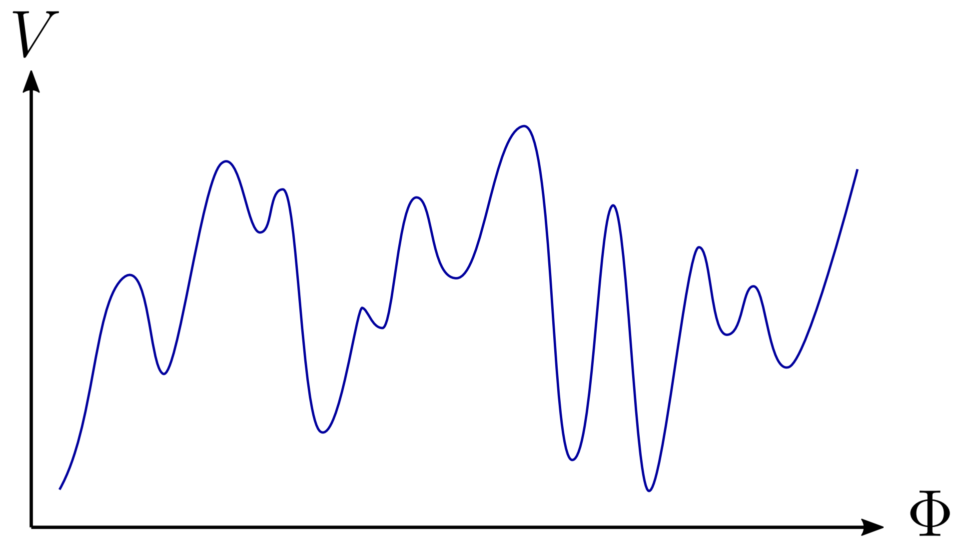
Inflationary mass scales:

- Hubble constant during inflation: $H \sim 10^{14}$ GeV.
- mass scale of inflation: $V_{\rm inf} = M_{\rm inf}^4 = 3M_{\rm Pl}^2 H_{\rm inf}^2 \Rightarrow$
  $M_{\rm inf} \sim 10^{16}$ GeV
- mass of inflaton during inflation: $M_\Theta^2 = 3\eta H^2 \Rightarrow$
  $M_\Theta \sim 10^{13}$ GeV

UV sensitivity

UV sensitivity

Quantum gravity generates Planck suppressed operators of the form $(\Phi/M_{\rm pl})^n$



Impossible to control flatness over a large region in field space.

- Makes it important to control Planck suppressed operators (eta-problem)
- Invoking a symmetry like the shift symmetry of axions helps

Axion inflation

Axion inflation

Axions are ubiquitous in string theory so that many scenarios have been proposed

- Natural inflation with a potential $V(\theta) = Ae^{-S_{\rm E}}(1 - \cos(\theta/f))$. Hard to realize in string theory, as $f > 1$ lies outside perturbative control.
  (Freese,Frieman,Olinto)
- Aligned inflation with two axions, $f_{\rm eff} > 1$. (Kim,Nilles,Peloso)
- N-flation with many axions and $f_{\rm eff} > 1$.
  (Dimopoulos,Kachru,McGreevy,Wacker)

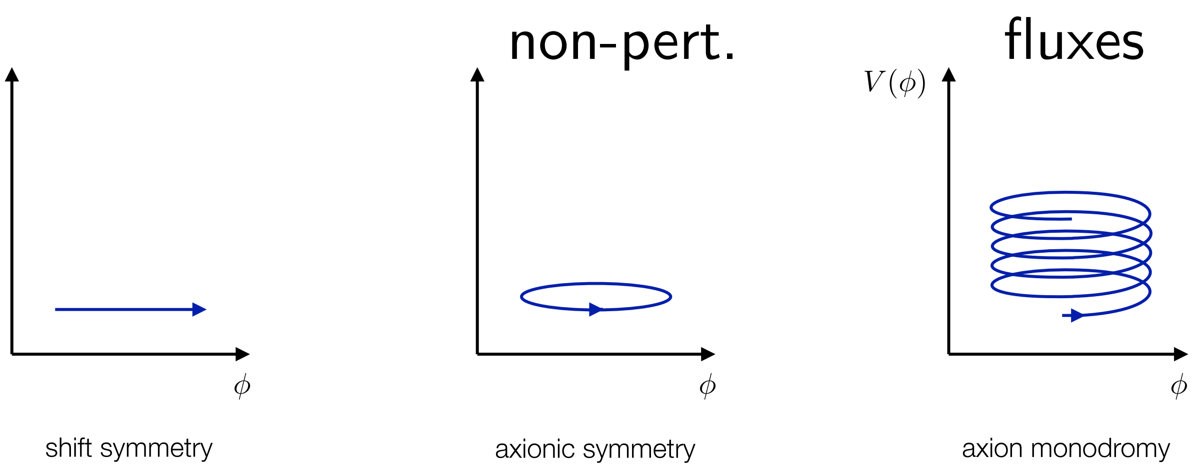
Comment: These models have come under pressure by the weak gravity conjecture, which for instantons was proposed to be $f \cdot S_{\rm E} < 1$.

(Rudelius),(Montero,Uranga,Valenzuela),(Brown,Cottrell,Shiu,Soler)

Axion monodromy inflation

Axion monodromy inflation

- Monodromy inflation: Shift symmetry is broken by branes or fluxes unwrapping the compact axion $\rightarrow$ polynomial potential for θ. (Kaloper, Sorbo), (Silverstein,Westphal)



Recently: F-term axion monodromy inflation

(Marchesano,Shiu,Uranga),

(Bhg,Plauschinn),(Hebecker,Kraus,Wittkowski),(Ibanez,Valenzuela)...

Objective

Objective

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

Commercial Break

Commercial Break

Sorry folks, we interrupt this talk for this important message:

Flux generated potential

Flux generated potential

(Bhg, Herschmann, Wolf, work in progress, arXiv:1605.nnnnn)

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:

$$F_0 = 1\,,$$

$$F_1 = Z\,,$$

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

and

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

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

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

Periods close to conifold

Periods close to conifold

Kähler potential simplifies considerably

$$K_{\rm cs} = -\log\left[-i\Pi^\dagger \Sigma\, \Pi\right]$$
$$= -\log\left[\frac{1}{2\pi}|Z|^2 \log\left(|Z|^2\right) + A + {\rm Re}Y + B\,({\rm Re}Y)^2 + C\,|Z|^2 \ldots\right]$$

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

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

(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

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

- Remarkably, W_{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

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

More details will follow at SPHENO2016 and in arXiv:1605.nnnnn.

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

Idea on inflation

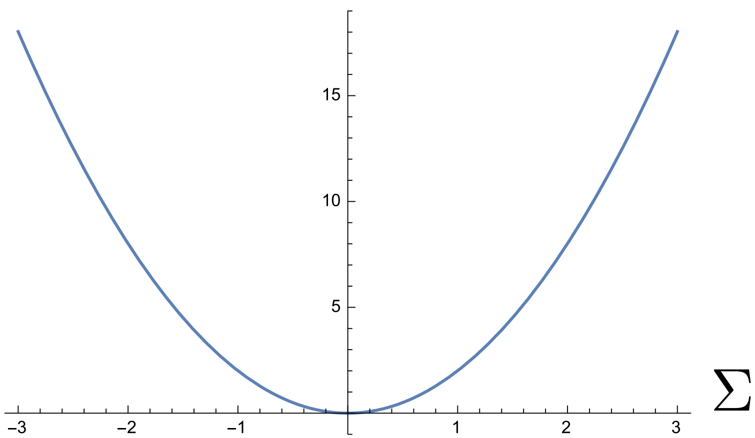
Idea on inflation

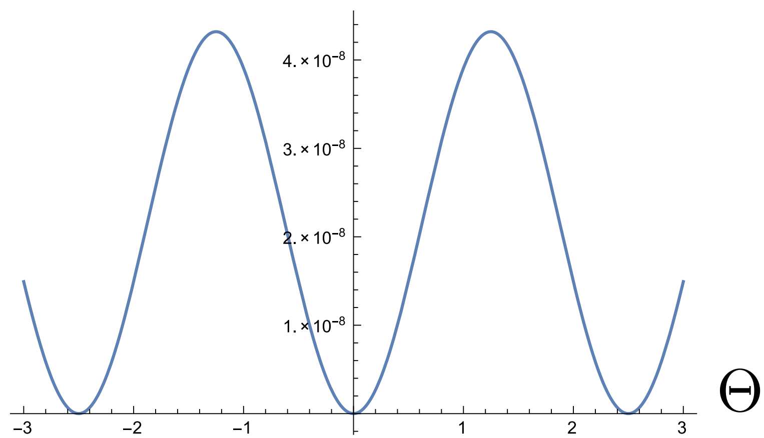
Extend the supergravity model after integrating out Z as

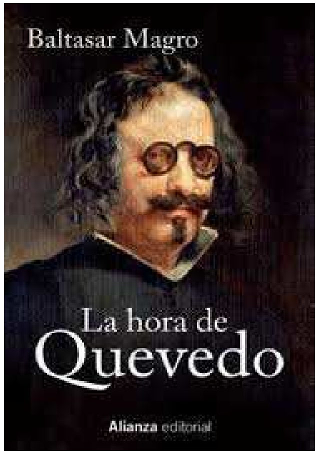
$$W_{\text{eff}} = i\alpha\big(f + h'\,S + \hat{f}'\,Y\big) + \frac{f\hat{C}}{2\pi i}\,\exp\Big(-\,\tfrac{2\pi}{f}\big(hS + \hat{f}Y\big)\Big)$$

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

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







beech marten?

L(arge) H(ole) C(heese)

Happy Birthday Fernando!