Stringy Corrections from (Almost) Classical Supergravity

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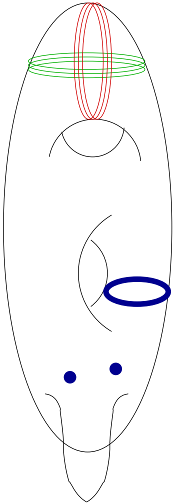
work with J. Roberts 1308.0323

Outline

Very Brief Flux Compactification Review

Building on the Calabi-Yau framework...



- Nontrivial background form flux
  G_3 harmonic
- Local objects: branes and O-planes
- Backreact on geometry: warping
  Also self-dual $\tilde{F}_5$

Profound effect phenomenologically

- Partial classical stabilization of moduli
- Origin of string landscape
  Based on quantum gaugino condensation
- Sandbox for string cosmology
  Especially embedding inflation

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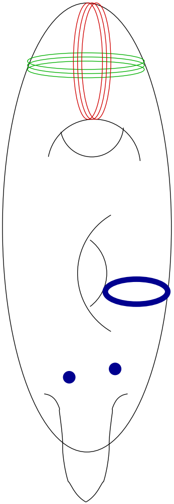

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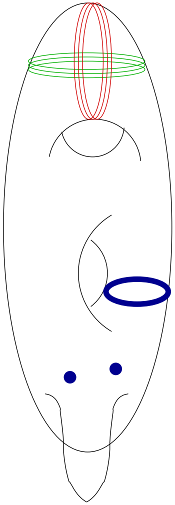

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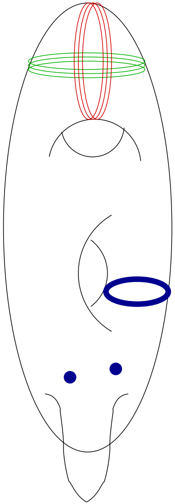

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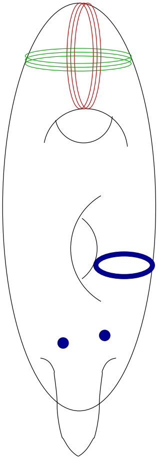
The simplest of warped compactifications in IIB strings

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



- $\tilde{g}_{mn}$ is Calabi-Yau
- Self-dual 5-form flux $\tilde{F}_5 = \hat{\epsilon} \wedge \tilde{d} e^{4A} + \tilde{\star} \tilde{d} e^{-4A}$
- O3- or O7-planes
- D3- and/or D7-branes
- 3-form satisfies 6D self-duality $G_3 = i \tilde{\star} G_3$
- Complex structure, dilaton stabilized
- Warp factor given by Poisson equation

$$\tilde{\nabla}^2 e^{-4A} = -\frac{g_s}{2} \left|G_3\right|^{\tilde{2}} - \text{local}$$

- Einstein-frame factor for convenience

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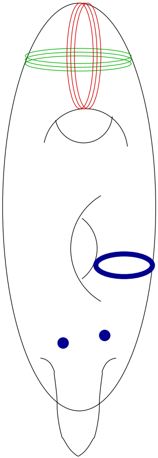

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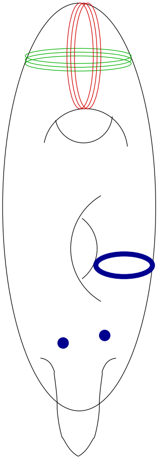

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Kähler Potential and Corrections

4D effective theory usually assumed = unwarped CY

$$\mathcal{K} = -2\ln V(\text{moduli})$$

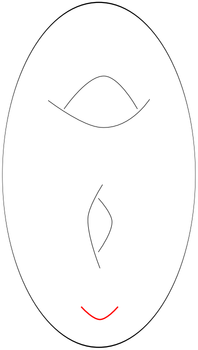
- Reasonable at large volume $e^{2A} \to 1$
- Required by SUSY in some toroidal models

Higher-curvature terms in 10D correct $\mathcal{K}$

- Large-Volume compactifications rely on R^4 terms (*many including Conlon, Quevedo*)
$$\delta\mathcal{K} = -\xi\alpha'^3/V$$
and related moduli stabilization mechanisms
- Also α'^2 corrections by duality chasing (*Grimm, Savelli, Weissenbacher*) Apparently from D-brane actions
- We will see α'^2 from warping and flux

Kähler Potential and Corrections

Example of volume modulus (*AF, Torroba, Underwood, & Douglas*)



Allow internal manifold to change size

- Do not scale $\tilde{g}_{mn}$
- Instead shift warp factor

$$e^{-4A(y)} \to e^{-4A_0(y)} + c(x) \; , \; e^{-2\Omega} \to e^{-2\Omega_0} + c$$

- Must introduce compensator

$$\delta g_{\mu m} = -e^{2\Omega} e^{-2A} \partial_\mu c \, \partial_m K \; , \; \delta \tilde{F}_5 = \cdots$$

$$\tilde{\nabla}^2 K = e^{-4A_0} - e^{-2\Omega_0}$$

- $\mathcal{K}$ protected by no-scale structure

$$\mathcal{K} = -3 \ln e^{-2\Omega} = -3 \ln(\rho + \bar{\rho}) \sim -2 \ln V$$

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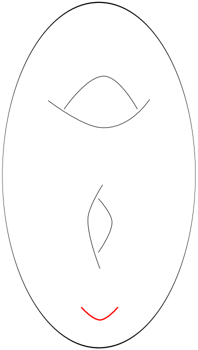

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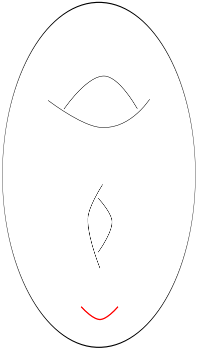

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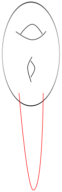

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Axionic Kähler Moduli

Generically all Kähler moduli remain even in flux

- Metric deformations corresponding to harmonic $(1,1)$ forms
  Includes volume modulus
- Wilson lines of C_4 with legs on harmonic $(1,1)$ forms
  Pair with metric Kähler moduli
- Wilson lines of A_2 with legs on negative parity* $(1,1)$ forms
  *Depending on orientifold projection
- Wilson lines have classical shift symmetries, so axions

Plan of attack

- Find solutions to constraints at 1st order
- Ansatz + quadratic action = 4D effective action

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Axionic Kähler Moduli

First C_4 axions $\delta C_4 = b^I \omega_4^I$, ω_4 harmonic

- Constraints require compensators

$$\delta C_4 = -\hat{d} b^I K_3^I + \cdots \ , \ \delta A_2 = -\hat{d} b^I \Lambda_1^I \ , \ \delta g_{\mu m} = e^{2\Omega} e^{2A} \partial_\mu b^I B_m^I$$

- Key to solution is identification

$$e^{4A} \left[\tilde{\star} \left(\omega_4 + \tilde{d} K_3 - \frac{i g_s}{2} \left(\Lambda_1 \bar{G}_3 - \bar{\Lambda}_1 G_3 \right) \right) + e^{2\Omega} \tilde{d} B_1 \right] = \gamma_2$$

  with γ_2 harmonic

- Λ_1, B_1, K_3 from Poisson-like equations

The A_2 axions similar but more complicated

Kinetic Terms

At the end of the day

$$S = -\frac{3}{4}\frac{\tilde{V}}{\kappa^2}\int d^4x \Big\{ e^{4\Omega}\partial_\mu c \partial^{\hat{\mu}} c + e^{2\Omega} C^{IJ}\partial_\mu b^I \partial^{\hat{\mu}} b^J + g_s \partial_\mu a^i \partial^{\hat{\mu}} \bar{a}^j + 2e^{2\Omega} C^{IJ} d^{Jij} \partial_\mu b^I \alpha^{\hat{\mu}\, ij} + e^{2\Omega} C^{IJ} d^{Iij} d^{Jkl} \alpha_\mu^{ij} \alpha^{\hat{\mu}\, kl} \Big\}$$

- $\alpha_1^{ij} = (ig_s/4)(a^i \hat{d}\bar{a}^j - \bar{a}^i \hat{d} a^j)$
- $d^{Iij} = (1/3\tilde{V}) \int \omega_2^I \omega_2^i \omega_2^j$ triple intersection
- $C^{IJ} = (1/3\tilde{V}) \int \omega_4^I \gamma_2^J$
  Inverse of some flux- & warping-dependent inner product
- $C^{IJ} = e^{2\Omega}\delta^{IJ}$ gives usual result

Kinetic Terms

$$C = 3\tilde{V}\left[\int e^{-4A}\omega_2\tilde{\star}\omega_2 - \frac{g_s}{2}\int\left(Q_4\tilde{\star}\bar{Q}_4 + \bar{Q}_4\tilde{\star}Q_4\right)\right]^{-1}$$

Flux appears through $\tilde{d}Q_4^I = \omega_2^I G_3$

If wedges of harmonic forms are all harmonic:

- $Q_4^I = 0$
- $\omega_2^I\tilde{\star}\omega_2^J$ =constant$\times\tilde{\epsilon}$
- Then warping and flux drop out completely
  Consistent with high-SUSY compactifications on tori

But mostly this is not true:

- Typically CY manifolds are not *geometrically formal*
- Fortunately, Kähler form $\tilde{J}$ acts as if $\tilde{g}_{mn}$ is formal

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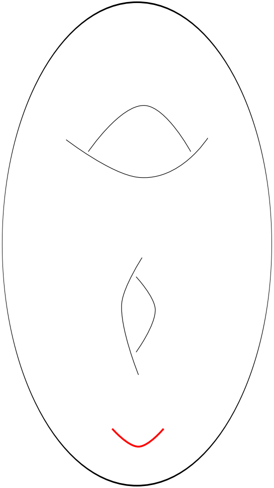
At large volume, warping is perturbation around constant



$$e^{-4A(y)} = e^{-2\Omega} + Z(y)$$

- $C^{IJ} = e^{2\Omega}\delta^{IJ} + \mathcal{O}\left(e^{4\Omega}\right)$
- Scales as $\alpha'^2/V^{2/3}$
- Flux quanta $G_3 \sim \alpha'$
- With sources $Z \sim g_s e^{4\Omega}\alpha'^2/\tilde{V}^{2/3}$

Appears in (almost) classical SUGRA!
But scales with warped string scale $\alpha'_w \sim \sqrt{Z_0}\alpha'$

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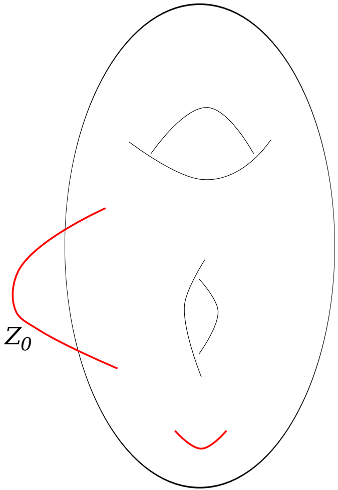

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2. **Kähler Potential and Corrections**
3. **Axionic Kähler Moduli**
4. **Kinetic Terms**
5. **Large-Volume Expansion**

THANK YOU