Brane Curvature Corrections to the $\mathcal{N} = 1$ Type II/F-theory Effective Action

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Based on: 1407.0019   with Gary Shiu

Outline

Introduction

Corrections at $\alpha'^2 g_s$?

Corrections from induced Einstein-Hilbert term

Corrections from induced D3-brane charge

Conclusions

Outline

Introduction

Perturbative corrections in string theory

▶ 4D effective action of type II string theory best understood in
perturbative corner (large volume, small g_s)

Some corrections known but knowledge still rather fragmentary!

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Becker, Becker, Haack, Louis 02;

Berg, Haack, Körs 05; Cicoli, Conlon, Quevedo 08; ...

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▶ All known moduli stabilization techniques rely on parametric control
over corrections

KKLT, LVS, Kähler uplifting

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Kachru, Kalloch, Linde, Trivedi 03; Balasubramanian, Berglund, Conlon, Quevedo 05;

Louis, Rummel, Valandro, Westphal 12; ...

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Classical moduli stabilization

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DeWolfe, Giryavets, Kachru, Taylor 05; Silverstein 08;

Caviezel, Koerber, Körs, Lüst, Wrase, Zagermann 08;

Danielsson, Haque, Shiu, Van Riet 08; ...

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New corrections at order $\alpha'^2 g_s$?

▶ Interesting proposal by GSW: new correction to the Kähler potential of $\mathcal{N} = 1$ F-theory compactifications at order $\alpha'^2 g_s$?

$$K = -2\ln(\mathcal{V} + \Delta\mathcal{V}), \qquad \Delta\mathcal{V} \propto \alpha'^2 g_s \mathcal{V}_{\mathrm{D7 \cap O7}}$$

Due to induced Einstein-Hilbert term via the M/F-theory duality

$$S \supset \int \mathrm{d}^4 x \sqrt{-g^{(4)}} (\mathcal{V} + \Delta\mathcal{V}) R^{(4)}$$

Proposed to arise from open string worldsheets

Grimm, Savelli, Weißenbacher 13

▶ Dangerous effects for moduli stabilization? No loop suppression!

Pedro, Rummel, Westphal 13

▶ Analysis of $G_4^2 R^3$ M-theory terms: Correction to the definition of the Kähler coordinates, no-scale structure of K preserved!

$$T \to T + \Delta T, \qquad K = -3\ln(T + \bar{T})$$

Grimm, Keitel, Savelli, Weißenbacher 13

Open questions

▶ Puzzle: Why can't we see the G(K)SW correction ΔT in perturbative type IIB string theory? What is the relevant string diagram?

Einstein-Hilbert term on D-branes only induced at one-loop but not at tree-level!

Bachas, Bain, Green 99; Epple 04

In F-theory, 7-branes generically wrap singular surfaces even at weak coupling (Whitney branes), can lead to subtle effects

Collinucci, Denef, Esole 09

Genuine new F-theory effect not captured by naive type IIB picture?

This talk:
No, correction can be removed by choosing a suitable 11D metric frame, not associated to any string diagram
Reconciles M/F-theory result with type IIB expectation

Open questions

▶ Are there further, so far unknown corrections of a similar kind, perhaps with more severe consequences for moduli stabilization?

Do D-branes and O-planes in type II string theory correct the volume dependence of the Kähler potential?

This talk:
Yes, corrections can come from curvature corrections to the DBI and WZ action
Induced Einstein-Hilbert terms (shifts in the volume) earliest at one-loop order

Outline

Curvature corrections in M-theory

▶ M-theory action including curvature corrections:

$$S = \frac{1}{2\kappa_{11}^2} \int \mathrm{d}^{11}x \sqrt{g_{11}} \left[R - \frac{1}{2}|G_4|^2 + k \left(t_8 t_8 R^4 - \frac{1}{4!}\epsilon_{11}\epsilon_{11}R^4 \right) \right.$$
$$\left. - k \left(t_8 t_8 G_4^2 R^3 + \frac{1}{96}\epsilon_{11}\epsilon_{11}G_4^2 R^3 \right) \right] + \dots$$

Vafa, Witten 95; Duff, Liu, Minasian 95; Green, Gutperle, Vanhove 97;

Kiritsis, Pioline 97; Russo, Tseytlin 97; Antoniadis, Ferrara, Minasian, Narain 97;

Liu, Minasian 13

t_8, ϵ_{11}: compact way of writing huge amount of different contractions

▶ Restrict to case relevant for duality with F-theory: $\mathcal{M} = \mathcal{M}_3 \times \mathrm{CY}_4$

$$R = R^{(3)} + R^{(8)}, \qquad G_4 = \sum_i F_2^{(3)i} \wedge \omega_2^{(8)i}.$$

Grimm, Keitel, Savelli, Weißenbacher 13

Corrections at $\alpha'^2 g_s$?

▶ Use computer algebra (Cadabra) to analyze R^4 and $G_4^2 R^3$ terms
  Terms relevant for the G(K)SW correction are of the form

$$\text{corrections} \supset R^{(3)} \cdot H(R) - \frac{1}{2}|G_4|^2 \cdot H(R) - |G_4|^2_{\bar{m}n} K^{\bar{m}n}(R)$$

  $H(R), K_{\bar{m}n}(R)$: sums of contractions of 3 internal Riemann tensors

▶ Terms can be removed from the action by redefining the M-theory
  metric

$$g_{\bar{m}n} \to g_{\bar{m}n} + h_{\bar{m}n}, \qquad h_{\bar{m}n} = H(R)\, g_{\bar{m}n} + K_{\bar{m}n}(R)$$

  In appropriate metric frame, ΔT is absent!

▶ Corrections that are removable by field redefinitions vanish on-shell:

$$\mathcal{L}(\phi + \delta\phi) = \mathcal{L}(\phi) + \frac{\delta\mathcal{L}(\phi)}{\delta\phi}\delta\phi + \mathcal{O}\left((\delta\phi)^2\right)$$

  Terms that vanish on-shell are not fixed by string amplitudes!

Gross, Witten 86; Tseytlin 86; ...

Corrections at $\alpha'^2 g_s$?

No string diagram associated to ΔT, possibility to redefine the metric reconciles M/F-theory picture with type IIB picture! Puzzle resolved!

Not all corrections to the Kähler potential/the Kähler coordinates are field redefinitions! Counter-examples:

▶ BBHL correction:

$$K = -2\ln(\mathcal{V} + \Delta\mathcal{V}) \stackrel{?}{=} -2\ln(\mathcal{V}'), \qquad \Delta\mathcal{V} \propto \alpha'^3 \chi(CY_3)$$

No! Correction can be obtained from string scattering

Becker, Becker, Haack, Louis 02; Antoniadis, Minasian, Vanhove 02

▶ D3-branes: redefinition of Kähler coordinates!
Physical effects (e.g., η problem in warped brane inflation)

$$K = -3(T + \bar{T} - k(\bar{\phi}\phi)), \quad T \to T + \frac{1}{2}k(\bar{\phi}\phi)$$

DeWolfe, Giddings 03; Graña, Grimm, Jockers, Louis 04;

Kachru, Kallosh, Linde, Maldacena, McAllister, Trivedi 03

Outline

Curvature corrections to DBI action

▶ D-branes and O-planes receive α'^2 corrections to their DBI action

$$\delta S_{\text{DBI}} \propto \alpha'^2 \mu_p \int_{\mathcal{W}} \mathrm{d}^{p+1}\xi \, e^{-\phi} \sqrt{g} \left[R_{\alpha\beta\gamma\delta} R^{\alpha\beta\gamma\delta} - 2 R_{\alpha\beta} R^{\alpha\beta} \right. $$
$$\left. - R_{ab\gamma\delta} R^{ab\gamma\delta} + 2 R_{ab} R^{ab} \right] + \dots$$

Bachas, Bain, Green 99; Fotopoulos 01; Wyllard 01;
Schnitzer, Wyllard 02; Garousi 06; Robbins, Wang 14

▶ Consider a warped (string frame) metric $\mathrm{d}s^2 = e^{2A} \mathrm{d}\tilde{s}_4^2 + \mathrm{d}s_6^2$

Rewrite corrections in terms of curvature of unwarped metric:

$$[\dots] = \tilde{R}^{(4)} \cdot f\left((\partial A)^2, \nabla^2 A \right) + \dots$$

Curvature corrections to DBI action

▶ The dimensional reduction of the DBI correction then yields a correction to the bulk Einstein-Hilbert term,

$$\Delta S_{\text{EH}} = \frac{1}{2\kappa^2 g_s^2} \int \text{d}^4x \sqrt{-\tilde{g}^{(4)}} \, \Delta\mathcal{V} \tilde{R}^{(4)}$$

with volume shift

$$\Delta\mathcal{V} \propto \alpha'^2 2\kappa^2 g_s^2 \, \mu_p \int \text{d}^{p-3}y \, \sqrt{\tilde{g}^{(p-3)}} \, \text{e}^{-\phi} \cdot f\Big((\partial A)^2, \nabla^2 A\Big)$$

Full Einstein-Hilbert term:

$$S_{\text{EH}} = \frac{1}{2\kappa^2 g_s^2} \int \text{d}^4x \sqrt{-\tilde{g}^{(4)}}(\mathcal{V}_{\text{w}} + \Delta\mathcal{V})R^{(4)}, \qquad \mathcal{V}_{\text{w}} = \int \sqrt{\tilde{g}^{(6)}} \, \text{e}^{2A}$$

DeWolfe, Giddings 02; Giddings, Maharana 05

▶ General mechanism to correct the volume dependence of the Kähler potential in the presence of (string frame) warping

$$K = -2\ln(\mathcal{V}_{\text{w}} + \Delta\mathcal{V}) + \dots$$

Curvature corrections to DBI action

▶ At which order could such corrections appear in the effective action? Specialize to the case of Dp-branes/Op-planes intersecting with Dp'-branes/Op'-planes:

$$\tilde{\nabla}^2 A \sim 2\kappa^2 g_s \, \mu_{p'} \, \delta^{(9-p')}$$

Parametric dependence of possible corrections:

$$\Delta \mathcal{V} \sim g_s^2 \, \alpha'^{10-(p+1)/2-(p'+1)/2}$$

Proportional to intersection volume, expected to arise at one loop!

▶ Duality of string diagrams: infer presence of one-loop correction from tree-level supergravity analysis

Intersecting D-branes: correction due to one-loop effect of open strings or tree-level exchange of closed strings

Curvature corrections to DBI action

Is this mechanism actually realized in concrete string compactifications?

- ▶ Coefficient zero or non-zero? Probably model-dependent...

- ▶ Removable by field redefinition? Hard to check explicitly, but probably no:

  $p = p' = 6$: intersecting D6-branes/O6-planes, $\Delta \mathcal{V} \sim \mathcal{V}_{D6 \cap O6} \alpha'^3 g_s^2$
  Parametric form agrees with explicit loop calculations on orbifolds

  Epple 04

  $p = p' = 7$: intersecting D7-branes/O7-planes, $\Delta \mathcal{V} \sim \mathcal{V}_{D7 \cap O7} \alpha'^2 g_s^2$
  No explicit result in the literature, but one-loop corrections on general grounds expected at order $\alpha'^2 g_s^2$

  Berg, Haack, Körs 05; Berg, Haack, Pajer 07; Cicoli, Conlon, Quevedo 08

- ▶ Dangerous for moduli stabilization? Unlikely, due to extended no-scale structure: $\alpha'^2 g_s^2$ corrections subleading in the scalar potential!

  Berg, Haack, Pajer 07; Cicoli, Conlon, Quevedo 08

Outline

Curvature corrections to WZ action

▶ D-branes and O-planes receive α'^2 corrections to their WZ action (neglect B, F)

$$\delta S_{WZ} \propto \alpha'^2 \mu_p \int_{\mathcal{W}} C \wedge (p_1(N\mathcal{W}) - p_1(T\mathcal{W}))$$

Bershadsky, Vafa, Sadov 96; Green, Harvey, Moore 96; Cheung, Yin 97;

Dasgupta, Jatkar, Mukhi 98; Stefanski 98; Craps, Roose 98; Morales, Scrucca, Serone 99

▶ Induced D3-brane charge on a D7-brane wrapped on 4-cycle S:

$$Q_3^{D7} = \frac{\mu_3}{48} \int_S (p_1(NS) - p_1(TS)) = \frac{\mu_3}{24} \chi(S)$$

for a smooth brane on a CY 3-fold

F-theory: branes generically wrap singular, self-intersecting surfaces
Corrected charge: $Q_3^{D7} = \frac{\mu_3}{24} \chi_o(S)$.

Collinucci, Denef, Esole 09

Kähler potential

▶ Objects that carry D3-brane charge lead to a shift both in the Kähler potential and the Kähler coordinates

$$K = -2\ln\mathcal{V} = -3\ln\left(T + \bar{T} - k(\bar{\Phi}\Phi)\right), \qquad T \to T + \frac{1}{2}k(\bar{\Phi}\Phi)$$

DeWolfe, Giddings 02; Graña, Grimm, Jockers, Louis 04

Corrections are such that the volume itself is left invariant!

▶ Due to induced D3-brane charge, same corrections expected to appear for a D7-brane! Open string tree-level effect, no correction to the volume itself

Outline

Conclusions

▶ Understanding perturbative corrections to the Kähler potential due to the presence of D-branes/O-planes is important for the 4D effective action of type II/F-theory compactifications

▶ $\alpha'^2 g_s$ corrections to the Kähler coordinates due to 7-brane intersections can be removed by redefining the 11D M-theory metric

Not associated to a string diagram, reconciles M/F-theory results with type IIB expectation

▶ Corrections to the classical volume from brane intersections can appear earliest at one loop, not dangerous for moduli stabilization

Future work: confirm in explicit models

▶ Improving on the knowledge of α' and g_s corrections is important for moduli stabilization, cosmology, etc. Systematic program desirable!

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Thank you!