Towards the 1-loop effective action of type IIB orientifolds

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1407.0027 (with Marcus Berg, Jin U Kang and Stefan Sjörs)
1511.03957 (with Jin U Kang)
+ work in progress (with Jin U Kang)

Overview

- Motivation
- Calculational setup
- Results

Motivation

(Perturbative) quantum corrections to effective action can be important

- if "zero effect" at tree level
  (e.g. no-scale structure of potential)
- for "precision phenomenology"
  (e.g. structure of soft SUSY breaking terms)
- increase possibilities for model building and moduli stabilization, cf. LVS

$\mathcal{N} = 1,\ d = 4$ Supergravity

$$\frac{\mathcal{L}_{\rm bos}}{(-G)^{1/2}} = \frac{1}{2\kappa^2}R - K_{,\bar{I}J}D_\mu\bar{\Phi}^{\bar{I}}D^\mu\Phi^J - \frac{1}{4}\mathrm{Re}(f_{ab}(\Phi))F^a_{\mu\nu}F^{b\mu\nu}$$
$$-\frac{1}{8}\mathrm{Im}(f_{ab}(\Phi))\epsilon^{\mu\nu\rho\sigma}F^a_{\mu\nu}F^b_{\rho\sigma} - V(\Phi,\bar{\Phi})$$

with $V(\Phi,\bar{\Phi}) = e^K(G^{\bar{I}J}D_{\bar{I}}\overline{W}D_JW - 3|W|^2) + \mathrm{Re}(f_{ab})\mathcal{D}^a\mathcal{D}^b$

$$D_JW \equiv \partial_{\phi^J}W + \partial_{\phi^J}K\,W$$

- Superpotential W
- Gauge kinetic function f_{ab}
- Kähler potential K

Quantum Corrections

- Superpotential $W = W^{\rm tree} + W^{\rm non-pert}$

- Gauge kinetic function $f = f^{\rm tree} + f^{\rm 1-loop} + f^{\rm non-pert}$

- Kähler potential $K = K^{\rm tree} + \sum_{n=1}^{\infty} K^{n-{\rm loop}} + K^{\rm non-pert}$

Calculational setup

- Focus on type I theory and K for moduli
- Methods:
  - ★ Truncation of type II results
  - ★ Duality (heterotic theory / F-theory)
  - ★ Scattering amplitudes in type I ← focus of this talk

- String amplitudes give corrections in string frame
- Need 1-loop correction to:

  (i) scalar metric in string frame

  (ii) Einstein-Hilbert term

  (iii) definition of field variables ($\tau = \tau^{(0)} + \delta\tau$)

- Reason: in string frame we have

$$S = \frac{1}{\kappa^2} \int d^4x \sqrt{-g} \Big[(e^{-2\phi_4} + \delta E) \tfrac{1}{2} R + (\tilde{G}^{(0)} + \tilde{G}^{(1)}) \partial_\mu \tau^{(0)} \partial^\mu \tau^{(0)} + \ldots \Big]$$

$(ii) \implies$ Weylrescaling:

$$g^{(E)}_{\mu\nu} = \underbrace{(e^{-2\Phi_4} + \delta E)}_{\equiv \Omega^{-2}} g^{(S)}_{\mu\nu}$$

$\implies$ • $\tilde{G}^{(0)}$ is multiplied by Ω^2

• $$R^{(S)} = \Omega^{-2}\Big(R^{(E)} - 2(D-1) g^{(E)\mu\nu} \nabla_\mu \partial_\nu \ln \Omega - (D-2)(D-1) g^{(E)\mu\nu} \underbrace{\partial_\mu \ln \Omega}_{= \frac{1}{\Omega}\partial_\tau \Omega \partial_\mu \tau + \dots} \partial_\nu \ln \Omega \Big)$$

δE depends on τ

$(iii) \implies$

$$\tau - \delta\tau$$

$$\tilde{G}^{(0)}(\tau^{(0)})\partial_\mu \tau^{(0)} \partial^\mu \tau^{(0)}$$

$$= \tilde{G}^{(0)}(\tau)\partial_\mu \tau \partial^\mu \tau$$

$$-\partial_\tau \tilde{G}^{(0)}(\tau)\delta\tau \partial_\mu \tau \partial^\mu \tau - 2\tilde{G}^{(0)}(\tau)(\partial_{\tau^{(0)}}\delta\tau)\partial_\mu \tau \partial^\mu \tau$$

Some generalities of the amplitude calculations

- Aim: read off scalar metric from scalar 2-pt fct.
- 2-pt fct. $= 0$ on-shell
- Trick: use $p_1 + p_2 \neq 0 \Longleftrightarrow \delta \equiv p_1 \cdot p_2 \neq 0$ in intermediate steps

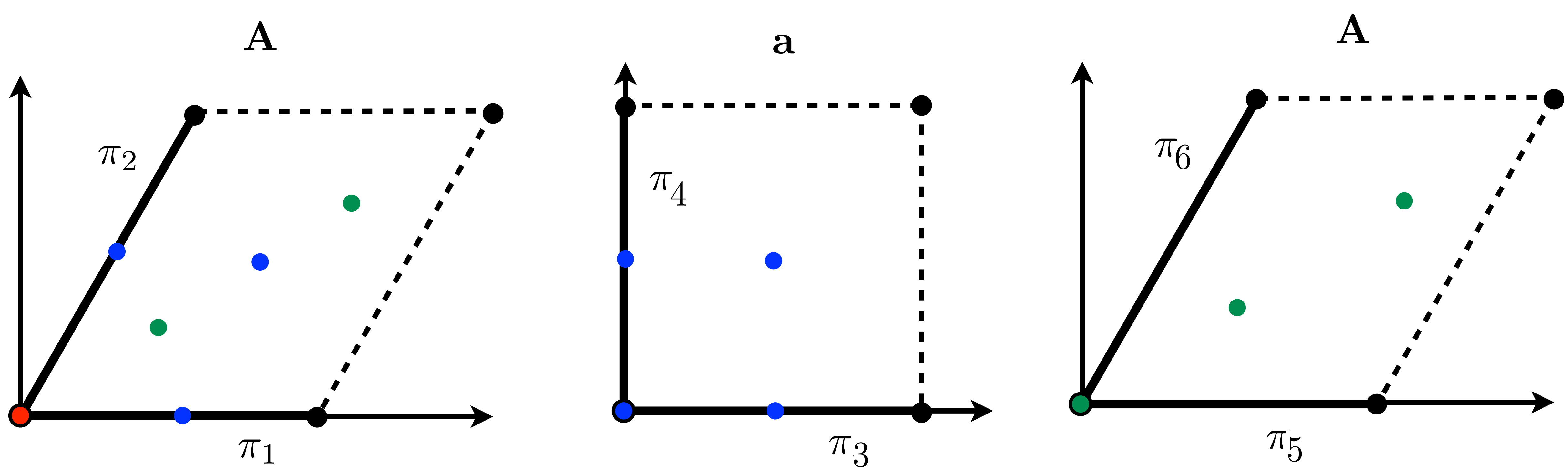
[Atick, Dixon, Sen; Minahan; Antoniadis, Bachas, Fabre, Partouche, Taylor; Antoniadis, Kirtsis, Rizos; cf. also Kiritsis, Kounnas, ...]

- $\langle \Phi_i \Phi_j \rangle = \delta \, G_{ij} + \mathcal{O}(\delta^2)$
- Similarly for gravitons: $\langle hh \rangle \sim \delta E \, p_2^\mu \epsilon_{1\mu\nu} \eta^{\nu\lambda} \epsilon_{2\lambda\rho} p_1^\rho$

$T^6/\mathbb{Z}_6'$

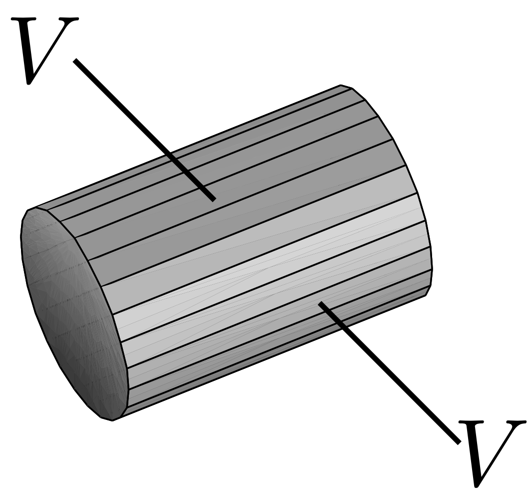
- $\Theta Z^1 = e^{2\pi i v_1} Z^1 \quad \Theta Z^2 = e^{2\pi i v_2} Z^2 \quad \Theta Z^3 = e^{2\pi i v_3} Z^3$

  $(v_1, v_2, v_3) = \left(\frac{1}{6}, -\frac{1}{2}, \frac{1}{3}\right)$

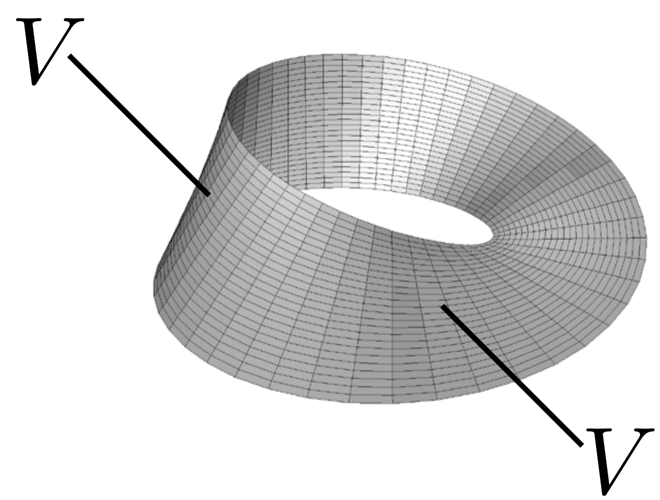
- 

- Resulting 4D effective action has $\mathcal{N} = 1$
- Model contains D9- and D5-branes (wrapped around 3rd torus)
- In addition to torus, need to calculate:

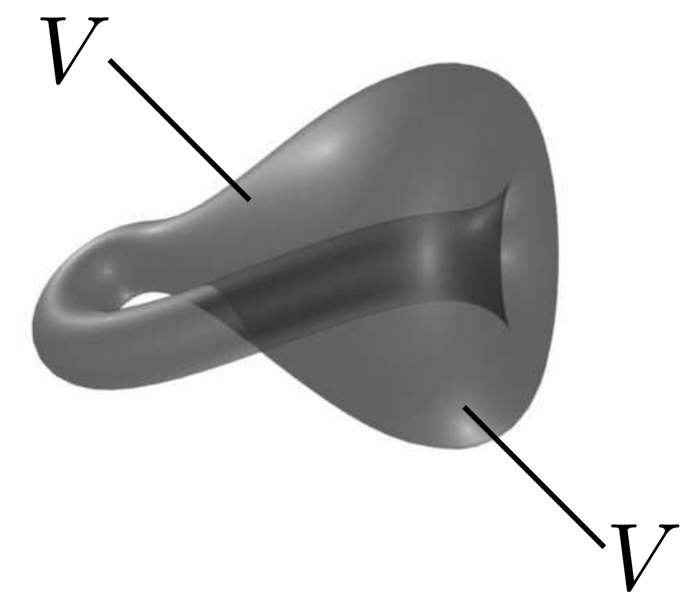
Annulus:



Möbius strip:



Klein bottle:



All of them have Euler number $\chi = 2 - 2h - b - c = 0$

- E.g. annulus:

projection operator
on orbifold invariant states

$$\mathcal{A} \sim \int_0^\infty \frac{dt}{t} \mathrm{Tr}_{open}\Big(\Big[\frac{1}{6}\sum_{k=0}^{5}\Theta^k\Big] q^{(p^2+m^2)/2} V V\Big)$$

$$= \frac{1}{6}\sum_{k=0}^{5}\int_0^\infty \frac{dt}{t} \mathrm{Tr}_{open}\Big(\Theta^k q^{(p^2+m^2)/2} V V\Big)$$

$e^{-\pi t}$

vertex operator

- $\mathcal{N} = 1$ contribution, if strings twisted along all 3 tori

Results: Scalar kinetic term

$10D$ dilaton

- Concretely considered: $\tau = \mathrm{Im}(T_3)$ with $\tau^{(0)} \sim e^{-\Phi}\mathcal{V}_3$

volume of 3rd torus measured
with string frame metric

- Prior results: sphere, torus and $\mathcal{N}=2$ -sectors:

$$\tilde{G}^{(0)} = -\frac{e^{-2\Phi}\mathcal{V}}{4(\tau^{(0)})^2}\left(1+\frac{\zeta(3)\chi}{\mathcal{V}}\right)$$

Euler number (48 for $\mathbb{Z}_6'$)

overall string frame volume

$$\tilde{G}^{(1)} \sim \frac{\chi}{(\tau^{(0)})^2} + a_1 \frac{e^{-\Phi}}{(\tau^{(0)})^3} E_2(U_3) + a_2 \frac{\mathcal{V}_2}{(\tau^{(0)})^2} E_2(-1/U_2)$$

complex structure of 3rd torus

$$E_2(U) \equiv \sum_{(m,n)\neq(0,0)} \frac{(\mathrm{Im(U)})^2}{|m+nU|^2}$$

- New result: $\mathcal{N}=1$ sectors [Berg, M.H., Kang, Sjörs]

- Usual lore: $\mathcal{N}=1$ sectors less interesting, because they do not lead to moduli dependent results

- Moduli dependence in $\mathcal{N}=1$ sectors via:
  - ★ Normalization of vertex operators
  - ★ Weyl rescaling to Einstein frame

- Expect further moduli dependence in $\mathcal{N}=1$ in presence of world volume fluxes or for branes at angles [Berg, M.H., Kang]

Gauge coupling thresholds

- $$\frac{1}{g_a^2(\mu)} = \frac{1}{g_{a,\mathrm{string}}^2} + \frac{b_a}{16\pi^2}\ln\left(\frac{M_s^2}{\mu^2}\right) + \Delta_a$$

- Branes at angles: [Lüst, Stieberger; Akerblom, Blumenhagen, Lüst, Schmidt-Sommerfeld]

$$\Delta_a \sim \sum_b \ln\left(\frac{\Gamma(\varphi_{ab}^1)\Gamma(\varphi_{ab}^2)\Gamma(1+\varphi_{ab}^3)}{\Gamma(1-\varphi_{ab}^1)\Gamma(1-\varphi_{ab}^2)\Gamma(-\varphi_{ab}^3)}\right)$$

- $\varphi_{ab} = \varphi_a - \varphi_b$ depend on torus complex structure

- For $\tau = \mathrm{Im}(T_3)$ in $\mathbb{Z}_6'$ from $\mathcal{A}, \mathcal{M}, \mathcal{K}$: [Berg, M.H., Kang, Sjörs]

$$\tilde{G}^{(1)}_{(\mathcal{N}=1)} = \frac{5}{2^9 \pi^3} \overbrace{\mathrm{Cl}_2\left(\frac{\pi}{3}\right)}^{\approx 3.197 \cdot 10^{-4}} \frac{1}{(\tau^{(0)})^2}$$

2nd Clausen function $\mathrm{Cl}_2(\varphi) = \sum_{k=1}^{\infty} \frac{\sin(k\varphi)}{k^2}$

- This is a correction to the usual torus contribution

$$\sim \frac{\chi}{(\tau^{(0)})^2}$$

Results: EH-term

- Prior results:
  - ★ Type II: [Antoniadis, Ferrara, Minasian, Narain]

$$S^{(II)} = \frac{1}{\kappa^2}\int d^4x\sqrt{-g}\Big[e^{-2\Phi_4} + \chi(\zeta(3)e^{-2\Phi_4} \underset{\text{IIA}}{\overset{\text{IIB}}{\pm}} \frac{\pi^2}{6})\Big]\frac{R}{2} + \dots$$

  - ★ Type I (on $K_3 \times T^2$): [Antoniadis, Bachas, Fabre, Partouche, Taylor]

$$S^{(I)} = \frac{1}{\kappa^2}\int d^4x\sqrt{-g}\Big[e^{-2\Phi_4} + a\underbrace{\frac{1}{\mathcal{V}_{T^2}}E_2(U)}_{\text{from } \mathcal{A},\mathcal{M},\mathcal{K}}\Big]\frac{R}{2} + \dots$$

★ Heterotic string: No 1-loop contribution, i.e.

$$S^{(het)} = \frac{1}{\kappa^2}\int d^4x\sqrt{-g}\Big[e^{-2\Phi_4}\Big(1+\frac{\chi\zeta(3)}{\mathcal{V}}\Big)\Big]\frac{R}{2}+\dots$$

[Antoniadis, Gava, Narain; Kiritsis, Kounnas]

This can be understood via

- World sheet calculation: integrand of torus & higher loop graviton 2-point function is total derivative

  [Kiritsis, Kounnas, Petropoulos,Rizos]

- $10D\ R^4$-terms

- Type II: [Gross, Witten; Green, Schwarz; Grisaru, van de Ven, Zanon]

$$\underbrace{(\zeta(3)e^{-2\Phi} + \frac{\pi^2}{6})t_8 t_8 R^4}_{\text{leads to correction to 4D kinetic terms of scalars}} - \underbrace{(\zeta(3)e^{-2\Phi} \overset{\text{IIB}}{\underset{\text{IIA}}{\pm}} \frac{\pi^2}{6})\epsilon_{10}\epsilon_{10}R^4}_{\text{leads to correction to 4D EH-term}}$$

- Heterotic: [Cai, Nunez; Gross, Sloan; Sakai, Tanii; Abe, Kubota, Sakai]

$$(\zeta(3)e^{-2\Phi} + \frac{\pi^2}{6})t_8 t_8 R^4 - \zeta(3)e^{-2\Phi}\epsilon_{10}\epsilon_{10}R^4$$

- How is this compatible with heterotic / type I duality?

[Tseytlin; Green, Rudra]

$$g_{\mu\nu}^{(I)} = e^{-\Phi_{het}} g_{\mu\nu}^{(het)} \quad , \quad \Phi_I = -\Phi_{het}$$

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$$g^{(I)}_{\mu\nu} = e^{-\Phi_{het}} g^{(het)}_{\mu\nu} \quad , \quad \Phi_I = -\Phi_{het}$$

- Possible answer: $S^{(het)}$ in 10D contains

[Green, Rudra]

$$\sqrt{g^{(het)}} e^{-\Phi_{het}/2} J_0 E_{3/2}(e^{-\Phi_{het}}) - \sqrt{g^{(het)}} \frac{\pi^2}{6} \mathcal{I}_2$$

★ $J_0 = t_8 t_8 R^4 - \frac{1}{8} \epsilon_{10} \epsilon_{10} R^4$

★ $\mathcal{I}_2 = -\frac{1}{8} \epsilon_{10} \epsilon_{10} R^4 + \dots$

★ $E_{3/2} = \zeta(3) e^{-3/2\Phi_{het}} + \frac{\pi^2}{6} e^{\Phi_{het}/2} + non - pert.$

S-duality invariant

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$$\to \sqrt{g^{(I)}} e^{-\Phi_I/2} J_0 E_{3/2}(e^{-\Phi_I})$$

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Disk level!

★ $J_0 = t_8 t_8 R^4 - \frac{1}{8}\epsilon_{10}\epsilon_{10} R^4$

★ $\mathcal{I}_2 = -\frac{1}{8}\epsilon_{10}\epsilon_{10} R^4 + \ldots$

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Disk level!

Disk level correction to 4D EH-term?

★ $E_{3/2} = \zeta(3) e^{-3/2\Phi_{het}} + \frac{\pi^2}{6} e^{\Phi_{het}/2} + non - pert.$

S-duality invariant

- New results for $\mathbb{Z}'_6$: [M.H., Kang]

from $\mathcal{N}=1$-sectors of $\mathcal{A},\mathcal{M},\mathcal{K}$

$$\delta E = \frac{\chi}{(2\pi)^3}\left(2\zeta(3)e^{-2\Phi}+\frac{\pi^2}{3}\right)+\frac{5}{64\pi^2}\mathrm{Cl}_2\left(\frac{\pi}{3}\right)$$
$$-\frac{5}{256\pi^2}\left[\frac{64\pi^2\alpha'}{\mathcal{V}_3}E_2(U_3)-\frac{12\pi^2\alpha'}{\mathcal{V}_2}E_2(U_2)-\frac{3\mathcal{V}_2}{4\pi^2\alpha'}E_2(-1/U_2)\right]$$

from $\mathcal{N}=2$-sectors of $\mathcal{A},\mathcal{M},\mathcal{K}$

- Follows closely a calculation by [Epple]

- Generalization to $\mathbb{Z}_3$ [M.H., Kang] and $\mathbb{Z}_6,\mathbb{Z}_7,\mathbb{Z}_{12}$ [with Tailin Li, unpublished]

Results: Field redefinitions

- Examples:

  ★ Type I (on $K_3 \times T^2$): $\tau = \tau^{(0)} + a^2 + \frac{E_2(U)}{e^{-\Phi}\mathcal{V}}$

  [Antoniadis, Bachas, Fabre, Partouche, Taylor]

  open string scalars (cf. KKLMMT)

  ★ Type II on CY: $e^{-2\tilde{\Phi}_4} = e^{-2\Phi_4}\left(1 + a_1\frac{\chi}{\mathcal{V}} + \ldots\right)$

  [Antoniadis, Minasian, Theisen, Vanhove]

  $$\tilde{\mathcal{V}} = \mathcal{V}\left(1 + a_2\chi e^{2\Phi_4} + \ldots\right)$$

- Kählerness of metric and shift symmetry in c, i.e.
  $G_{\tau_i\tau_j} = G_{\tau_i\tau_j}(\tau),\ G_{c_i c_j} = G_{c_i c_j}(\tau),\ K = K(\tau)$,
  fix the field variables $T = c + i\tau$ completely!
- $K_{T\bar{T}}\partial_\mu T\partial^\mu \bar{T} = \frac{1}{4}K_{\tau\tau}(\partial_\mu c\partial^\mu c + \partial_\mu \tau\partial^\mu \tau)$ implies:
  - ★ $G_{c_i\tau_j} = 0$
  - ★ $G_{\tau_i\tau_j} = \frac{1}{4}\frac{\partial^2 K}{\partial\tau_i\partial\tau_j} = G_{c_i c_j}$
  - ★ $\partial_{\tau_k} G_{c_i c_j} = \partial_{\tau_i} G_{c_j c_k} = \partial_{\tau_j} G_{c_k c_i}$
- $\delta c_i = 0$

- E.g. (for $\mathbb{Z}_6'$)

$\mathcal{T}, \mathcal{A}, \mathcal{M}, \mathcal{K}$
$\mathcal{N} = 1$

$$\delta\tau_3 = a_1 \sqrt{\frac{T_3^{(0)} - \bar{T}_3^{(0)}}{(S^{(0)} - \bar{S}^{(0)})(T_1^{(0)} - \bar{T}_1^{(0)})(T_2^{(0)} - \bar{T}_2^{(0)})}}$$

$e^{-\Phi}\mathcal{V}$

$$\left.\begin{aligned} &+a_2 \frac{(T_3^{(0)} - \bar{T}_3^{(0)}) E_2(U_2)}{(S^{(0)} - \bar{S}^{(0)})(T_2^{(0)} - \bar{T}_2^{(0)})} \\ &+a_3 \frac{E_2(-1/U_2)}{(T_1^{(0)} - \bar{T}_1^{(0)})} + a_4 \frac{E_2(U_3)}{(S^{(0)} - \bar{S}^{(0)})} \end{aligned}\right\}$$

$\mathcal{A}, \mathcal{M}, \mathcal{K}$
$\mathcal{N} = 2$

- E.g. (for $\mathbb{Z}_6'$)

$\mathcal{T}, \mathcal{A}, \mathcal{M}, \mathcal{K}$
$\mathcal{N} = 1$

$$\delta\tau_3 = a_1 \sqrt{\frac{T_3^{(0)} - \bar{T}_3^{(0)}}{(S^{(0)} - \bar{S}^{(0)})(T_1^{(0)} - \bar{T}_1^{(0)})(T_2^{(0)} - \bar{T}_2^{(0)})}}$$

$e^{-\Phi}\mathcal{V}$

$$+a_2 \frac{(T_3^{(0)} - \bar{T}_3^{(0)})E_2(U_2)}{(S^{(0)} - \bar{S}^{(0)})(T_2^{(0)} - \bar{T}_2^{(0)})}$$

$$+a_3 \frac{E_2(-1/U_2)}{(T_1^{(0)} - \bar{T}_1^{(0)})} + a_4 \frac{E_2(U_3)}{(S^{(0)} - \bar{S}^{(0)})}$$

$\mathcal{A}, \mathcal{M}, \mathcal{K}$
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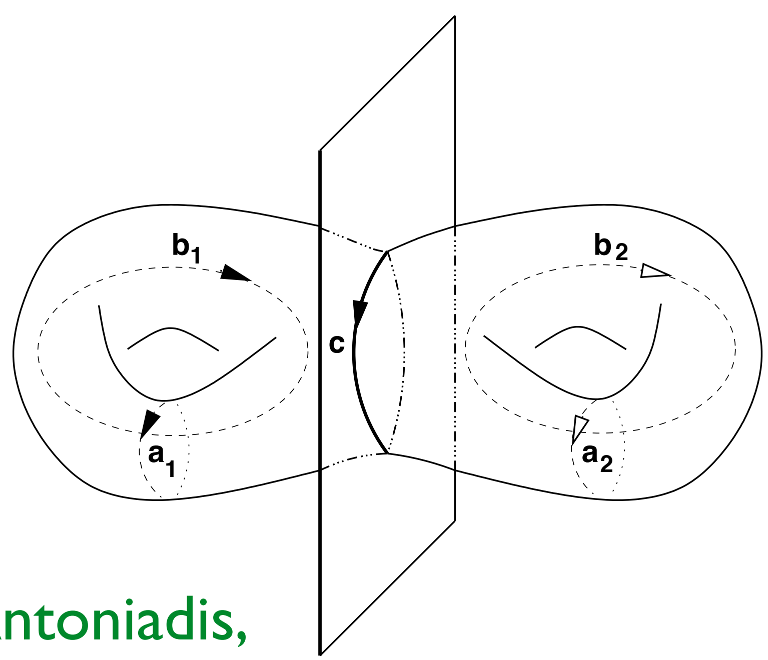
analog of correction by
[Antoniadis, Bachas, Fabre, Partouche, Taylor]

Check of field redefinition of T_3 from holomorphic gauge kinetic function of D5-branes (wrapped around 3rd torus)

- At disk level: $f_{D5} = T_3^{(0)}$ $\sim e^{-\Phi}$
- 1-loop correction to $T_3^{(0)}$ appears at $\chi = 2 - 2h - b - c = -1$:

E.g.



[from: Antoniadis, Taylor]

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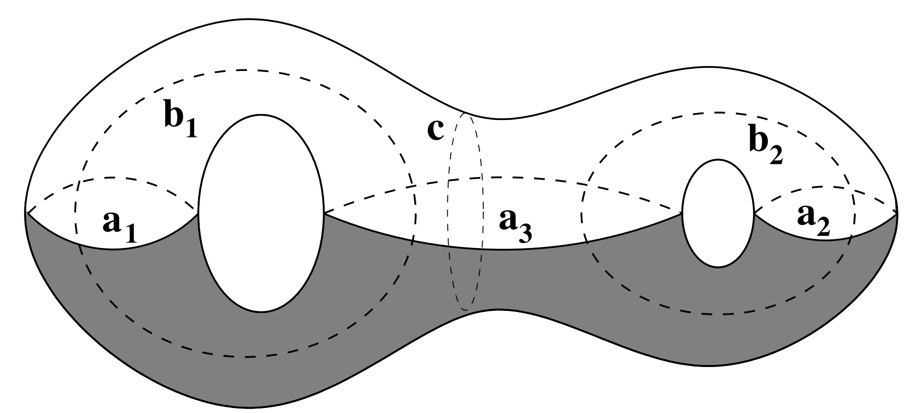

[from: Antoniadis, Narain, Taylor]

+ 3 more diagrams

$$(b=1, c=2), (b=2, c=1), (h=1, c=1)$$

Preliminary conjecture for Kähler potential of untwisted closed moduli for $T^6/\mathbb{Z}_6'$ (up to 1-loop):

$$K = -\ln(S-\bar{S}) - \ln[(T_1-\bar{T}_1)(T_2-\bar{T}_2)(T_3-\bar{T}_3)] - \ln(U_2-\bar{U}_2)$$

$$+c_1\chi\zeta(3)\sqrt{\frac{(T_1-\bar{T}_1)(T_2-\bar{T}_2)(T_3-\bar{T}_3)}{(S-\bar{S})^3}}$$

$$+c_2\frac{E_2(U_2)}{(T_2-\bar{T}_2)(S-\bar{S})} + c_3\frac{E_2(-1/U_2)}{(T_1-\bar{T}_1)(T_3-\bar{T}_3)} + c_4\frac{E_2(U_3)}{(T_3-\bar{T}_3)(S-\bar{S})}$$

$$+c_5\frac{1}{\sqrt{(T_1-\bar{T}_1)(T_2-\bar{T}_2)(T_3-\bar{T}_3)(S-\bar{S})}}$$

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$$+c_2\frac{E_2(U_2)}{(T_2-\bar{T}_2)(S-\bar{S})} + c_3\frac{E_2(-1/U_2)}{(T_1-\bar{T}_1)(T_3-\bar{T}_3)} + c_4\frac{E_2(U_3)}{(T_3-\bar{T}_3)(S-\bar{S})}$$

$\mathcal{A}, \mathcal{M}, \mathcal{K}$
$\mathcal{N}=2$

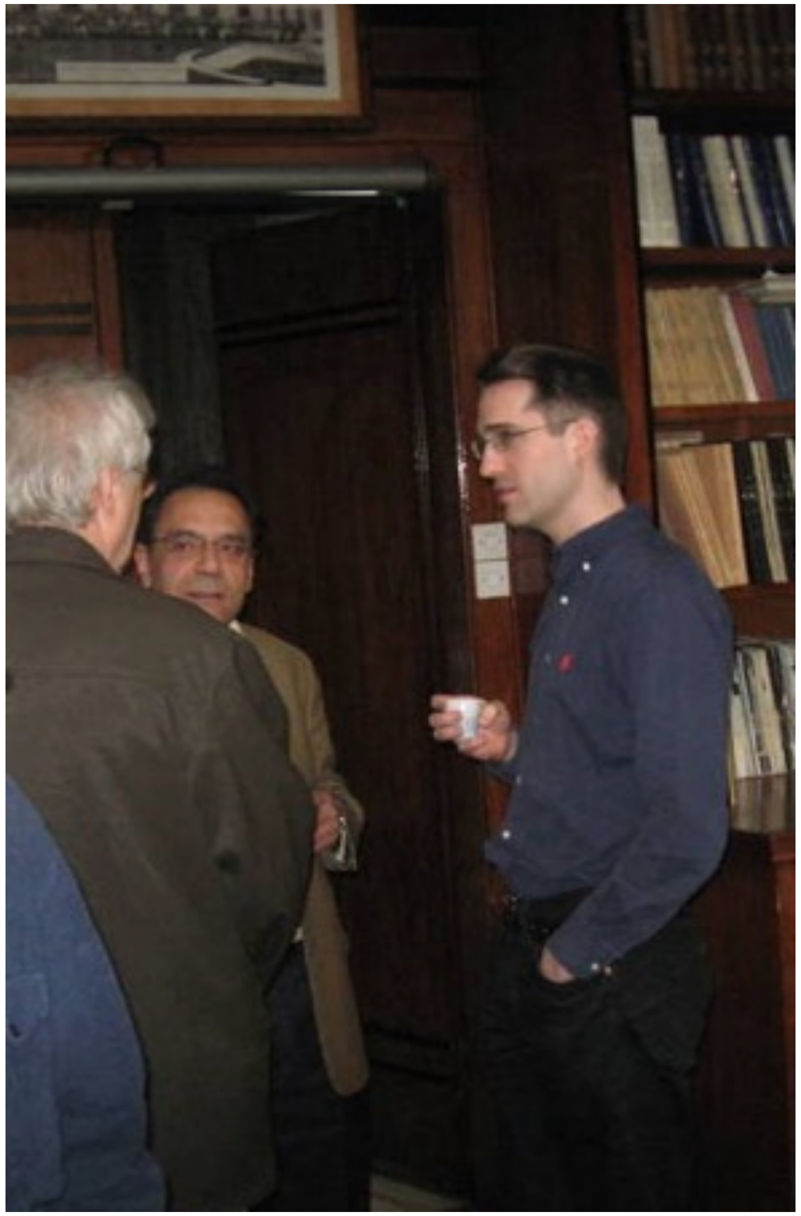
$$+c_5\frac{1}{\sqrt{(T_1-\bar{T}_1)(T_2-\bar{T}_2)(T_3-\bar{T}_3)(S-\bar{S})}}$$

$\mathcal{T}, \mathcal{A}, \mathcal{M}, \mathcal{K}$
$\mathcal{N}=1$

Outlook

- Work out coefficients in K and field redefinitions
- Check indirect prediction of field variables by direct string calculation (indirect arguments make many predictions for string calculations)
- Check field redefinition by $\chi = -1$ amplitudes
- Applications to string model building?

Thank You!



Spring School on „Strings, Cosmology and Particles"
(Serbia 2009, Belgrade and Nis)