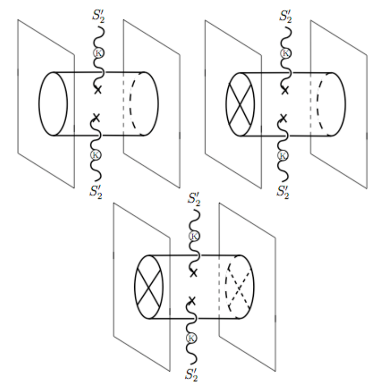
Michigan, Sep 15 2008



Recent Progress in Orientifold Effective Actions

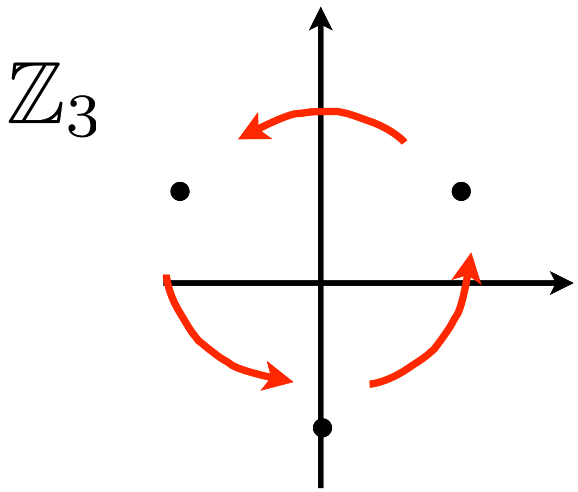
Marcus Berg
Cosmology, Particle Astrophysics and String theory (CoPS)
Stockholm University

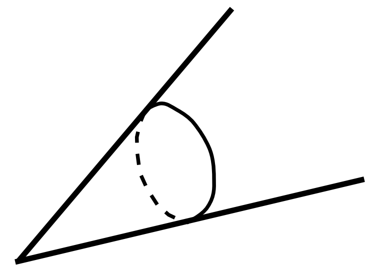
Outline

- Q: Why orientifolds? (A: phenomenology)
- Overview of "older" work (-2004)
- "Recent" progress (2005-2008)
- Work in progress

Orientifold

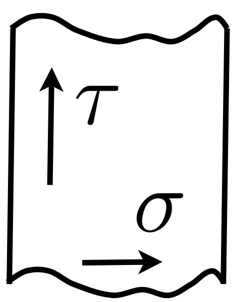
Orbifold: Identify under spacetime rotation





cone

Orientifold: Identify under worldsheet reflection

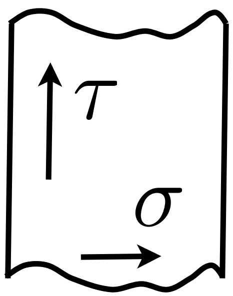


$$z = e^{i(\sigma + i\tau)} \xrightarrow{\Omega} e^{i(-\sigma + i\tau)} = \bar{z}$$

(and possibly spacetime reflection)

Orientifold

Orientifold: Identify under worldsheet reflection



$$z = e^{i(\sigma + i\tau)} \xrightarrow{\Omega} e^{i(-\sigma + i\tau)} = \bar{z}$$

(and possibly spacetime reflection)

Eigenstates with eigenvalue $\Omega = +1$

$\frac{1}{\sqrt{2}}\Big(\Big|$ 

$\Big\rangle + \Big|$ 

$\Big\rangle \Big)$

A few historical highlights

- Sagnotti '87 (hep-th/0208020)
  - ⁕ Fermionic constructions, calculated spectra
- Dai-Leigh-Polchinski '89
  - ⁕ Coined "orientifold"
  - ⁕ emphasized spacetime point of view:

    D-branes, orientifold planes
- Gimon, Polchinski '96
  - ⁕ Systematic tadpole calculations

Review: Angelantonj, Sagnotti, Phys. Rep. hep-th/0204089

A few historical highlights

- Sagnotti '87 (hep-th/0208020)
  - * Fermionic constructions, calculated spectra
- Dai-Leigh-Polchinski '89

> the Z_2 twist Ω is the product of a Z_2 symmetry of the dual spacetime and a Z_2 symmetry, orientation reversal, on the world-sheet. We therefore refer to the space as an "orientifold." Away from the orientifold (hyper)plane $y_i = 0$, the spectrum and interactions are locally indistinguishable from the closed oriented string; near the plane, unoriented topologies contribute.

- Gimon, Polchinski '96
  - * Systematic tadpole calculations

Review: Angelantonj, Sagnotti, Phys. Rep. hep-th/0204089

Why orientifolds?

A few reasons:

- In compact D-brane models: consistency conditions
- Supersymmetry reduced (e.g. Type IIB to Type I)
- As orbifolds: wide range (toroidal, Calabi-Yau, F, ...)

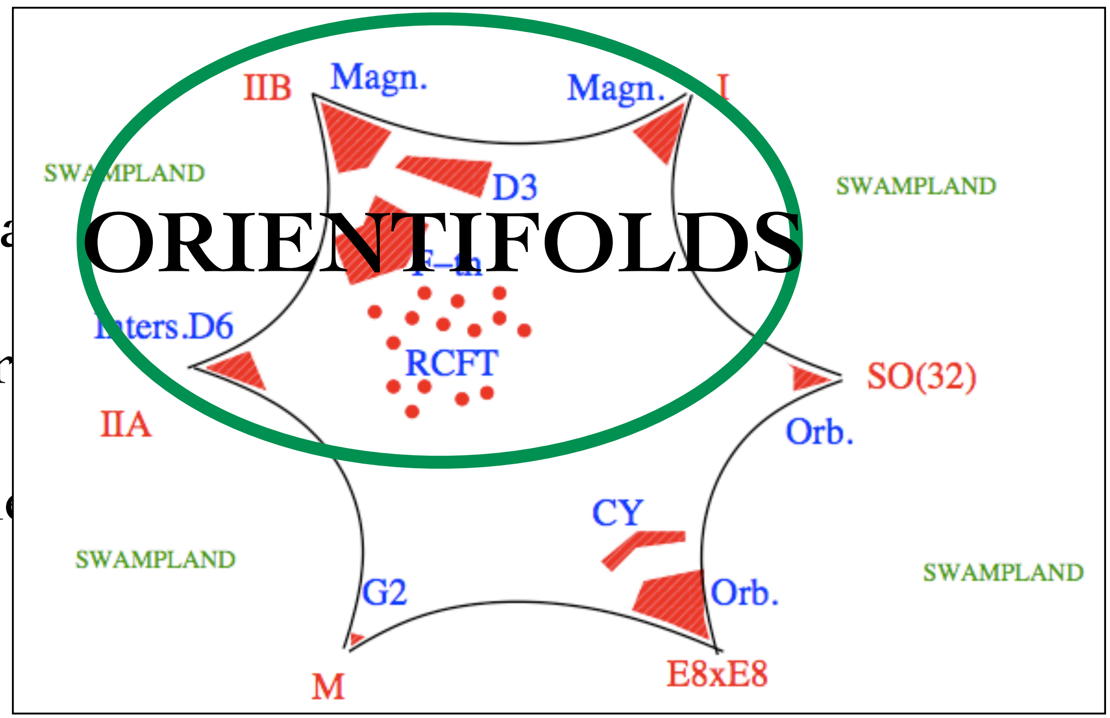
free CFT

Why orientifolds?

Ibanez, Strings '08: "state of string model building"

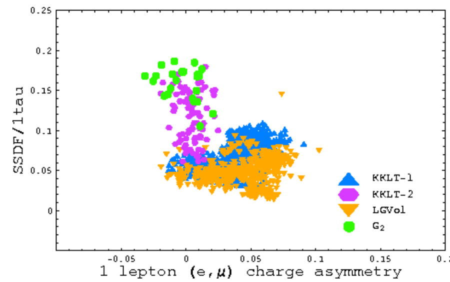
A few reasons:

- In compact D-bra
- Supersymmetry r
- As orbifolds: wide



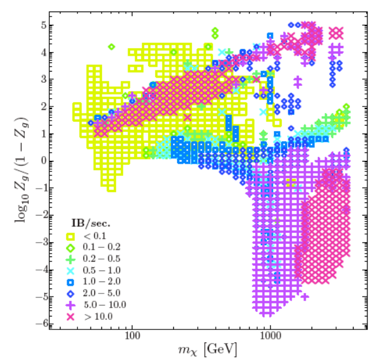
Hopes in string phenomenology

LHC observables



MSSM-like effective field theory models

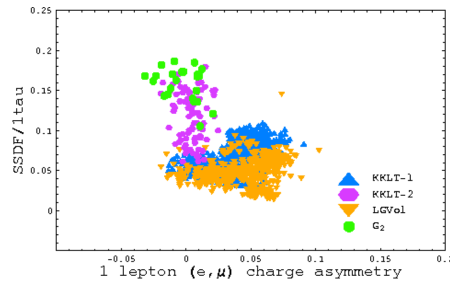
SUSY dark matter



Hopes in string phenomenology

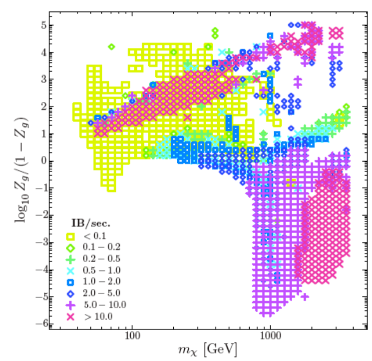
MSSM-like effective field theory models

LHC observables



e.g.

SUSY dark matter

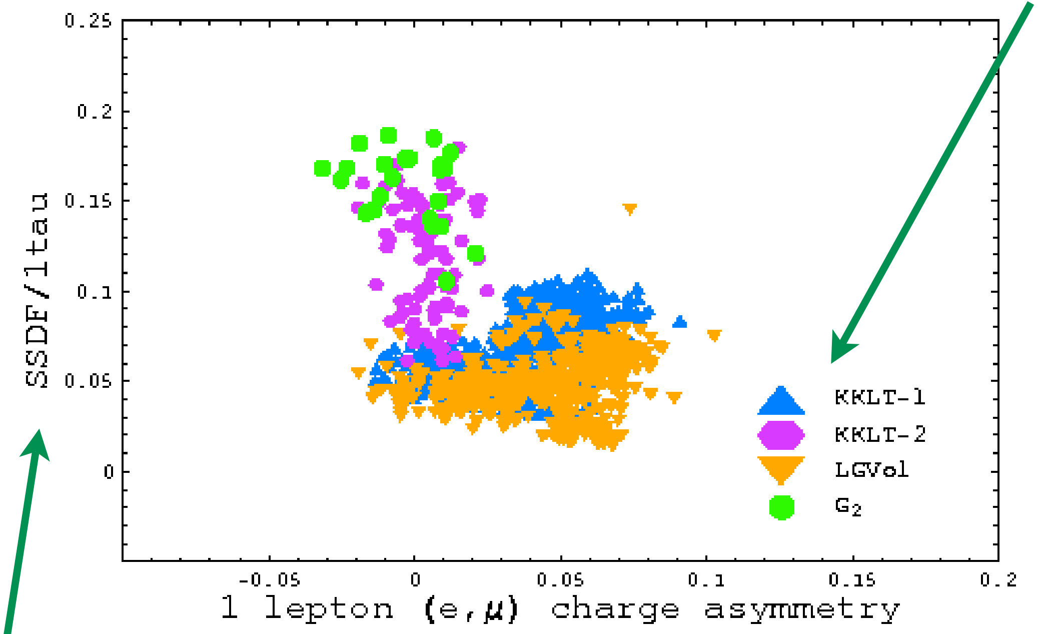


e.g.

LHC counting signatures

Kane, Kumar, Shao '07 (hep-ph)

different "string" models



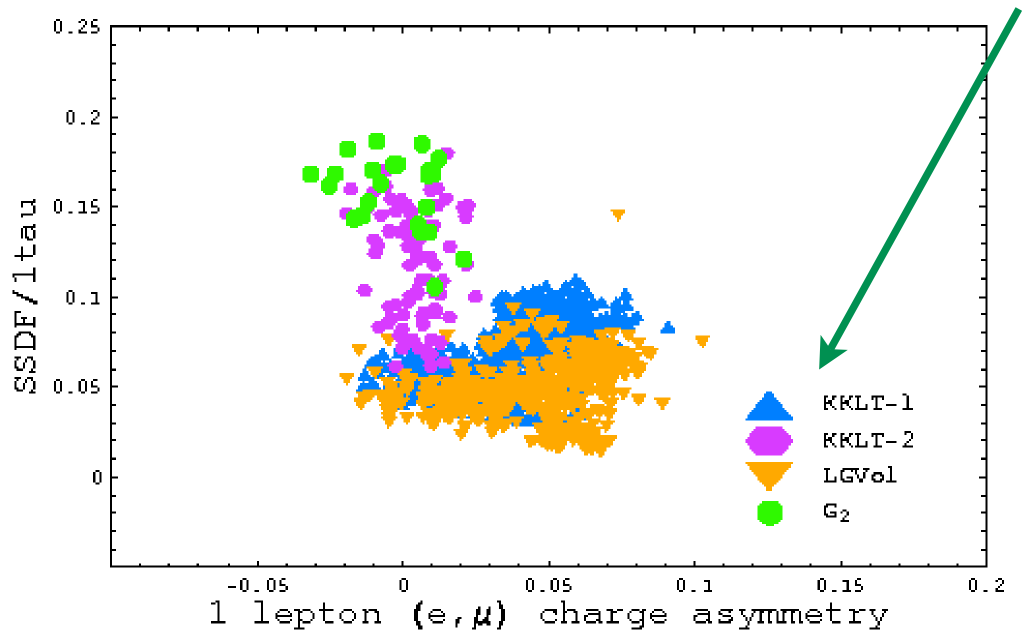
$$\frac{\text{same sign, different flavor dilepton events}}{1\ \tau\ \text{events}}$$

$$\frac{N_\ell^+ - N_\ell^-}{N_\ell^+ + N_\ell^-}$$

LHC counting signatures

Kane, Kumar, Shao '07 (hep-ph)

different "string" models

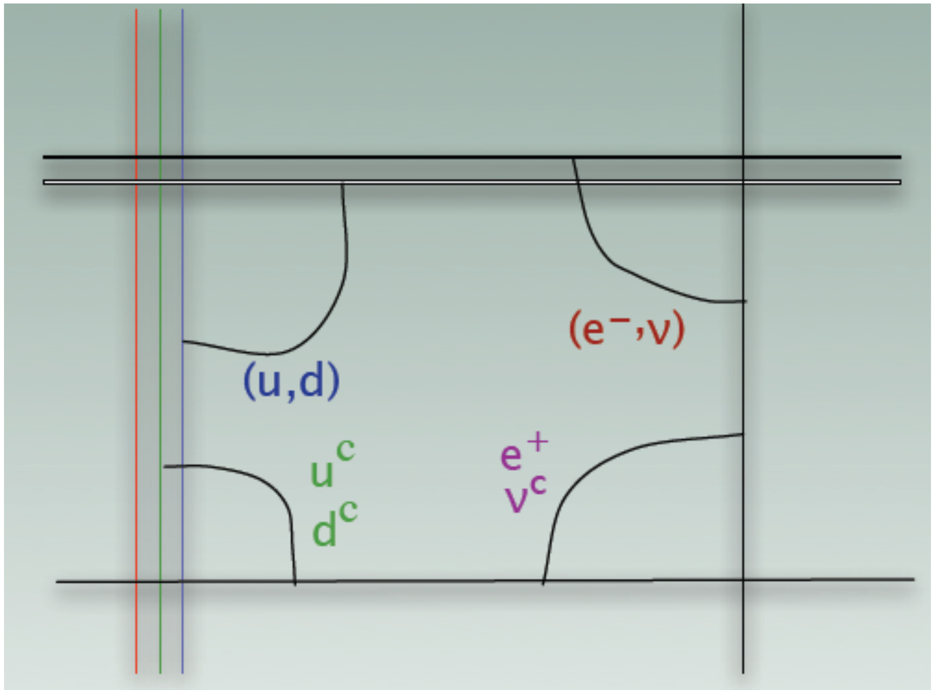


still early days of string phenomenology...
for example, shouldn't we construct the
MSSM in a stabilized model first?

The MSSM in string theory?

one way: D-branes intersecting at angles

...
Cvetic, Shiu, Uranga '00
...



Schellekens '07

minimal!

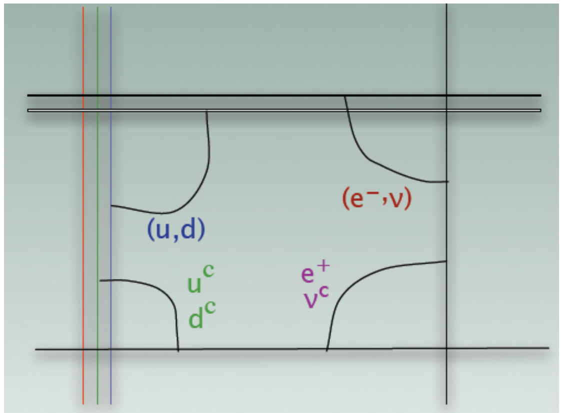
The MSSM in string theory?

one way: D-branes intersecting at angles

...
Cvetic, Shiu, Uranga '00
...

Some problems:

- Non-minimal (e.g. 24 Higgs fields)
- Couplings hard to compute
- Unstabilized closed string modes
  – branes could rearrange!



minimal!

The MSSM in string theory?

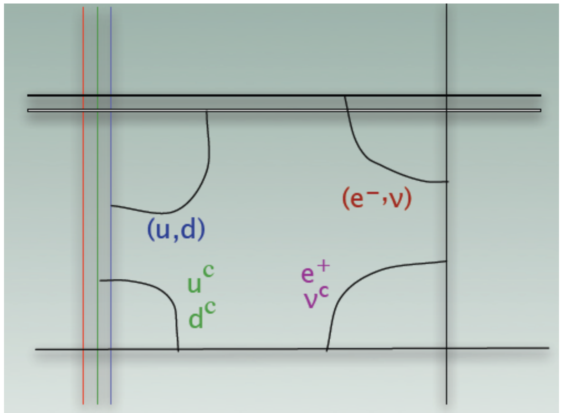
one way: D-branes intersecting at angles

...
Cvetic, Shiu, Uranga '00
...

Some problems:

- Non-minimal (e.g. 24 Higgs fields)
- Couplings hard to compute
- Not **stabilized** closed string modes

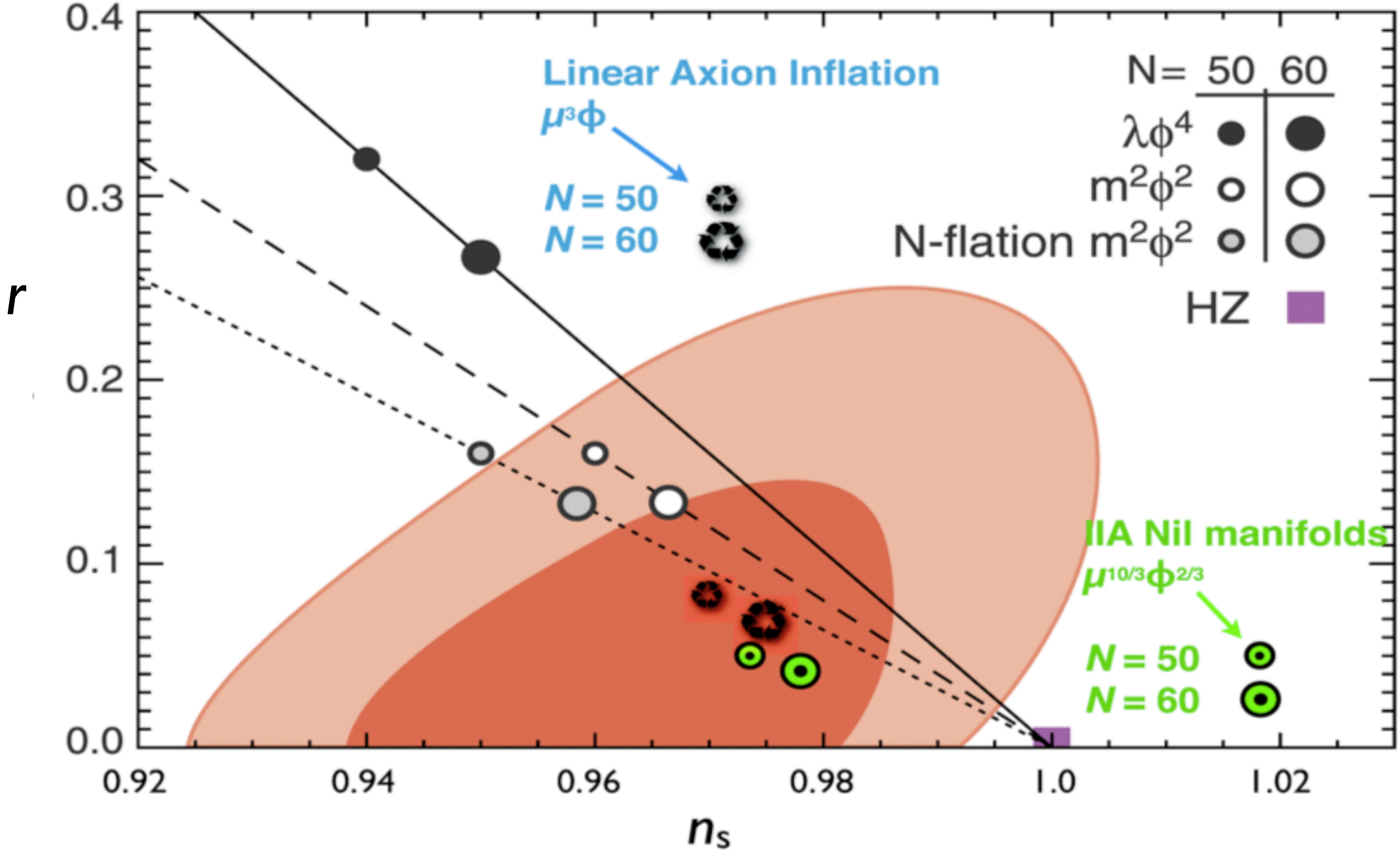
  – branes could rearrange!



More recently: interesting decoupling limits

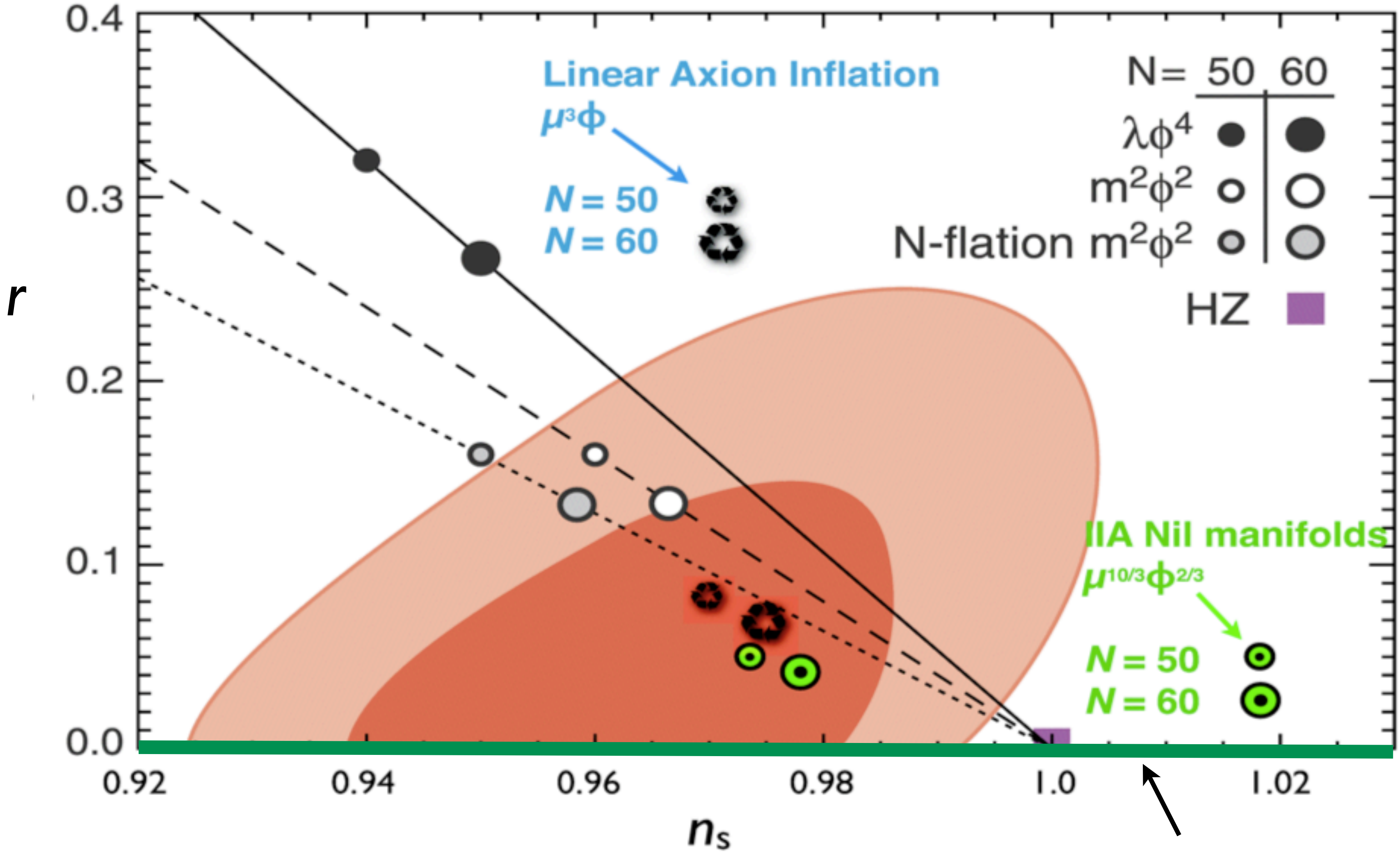
McAllister (ICHEP '08)

Another frontier: string cosmology



McAllister (ICHEP '08)

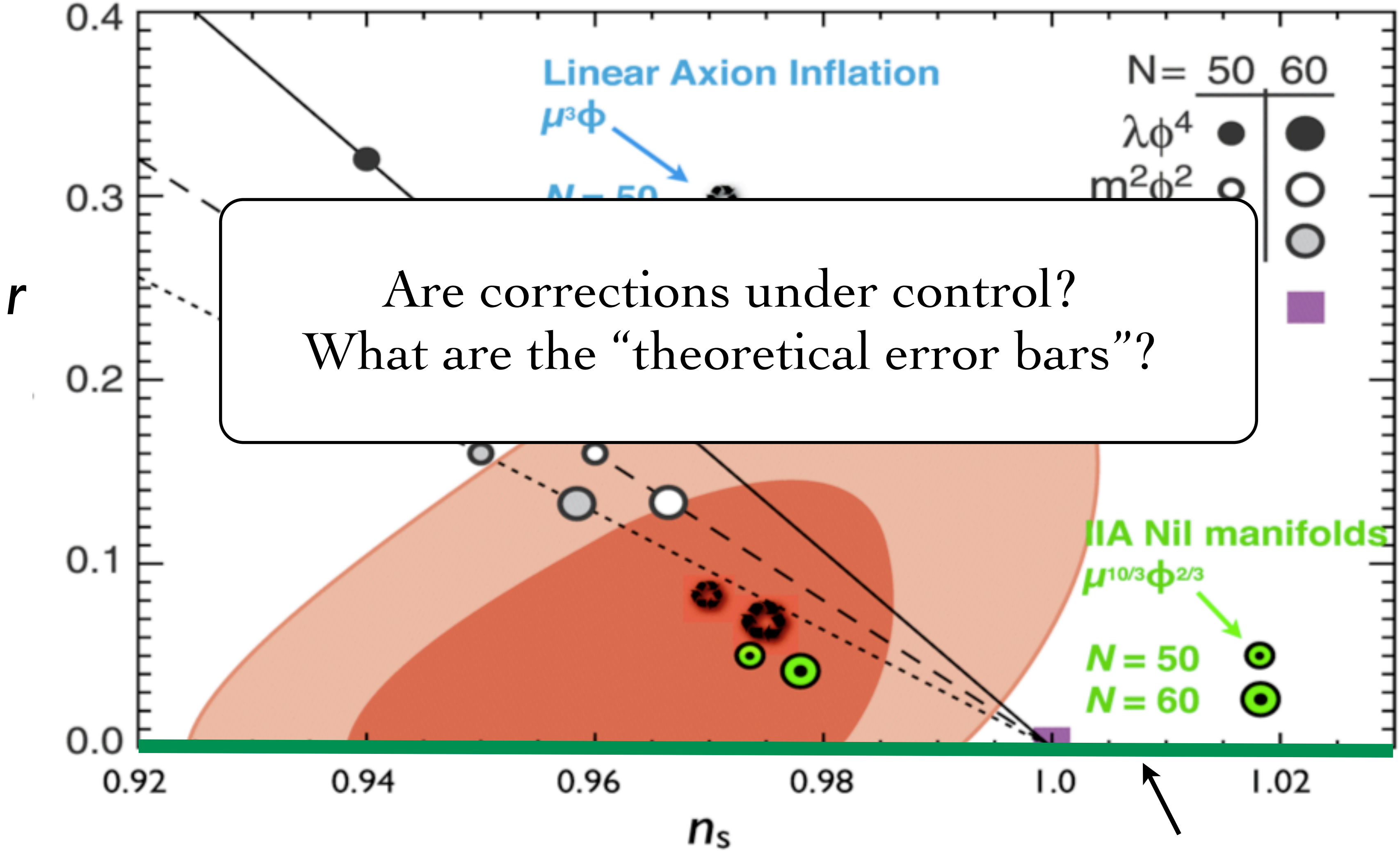
Another frontier: string cosmology



most models so far

McAllister (ICHEP '08)

Another frontier: string cosmology



Are corrections under control?
What are the "theoretical error bars"?

most models so far

Setting common-sense standards for string phenomenology

(not meant as criticism of existing work: one does what one can)

- If we make numerical claims even for a given model (let alone “string theory predicts...”), what is the range of validity? $g < 0.1, \ldots$
- Similarly, what is the numerical precision?

$$n_{\rm s} = 0.96 \pm 0.02$$

What is the "added value" of string phenomenology?

(compared to standard MSSM phenomenology)

Depends!

- Heterotic: $M_{\text{string}} \sim M_{\text{Planck}}$ 10^{18} GeV
- Large extra dimensions: $M_{\text{string}} \sim$ TeV 10^{3} GeV

- What about intermediate string scale? e.g. 10^{11} GeV

e.g. Benakli '98,
Burgess, Ibanez, Quevedo '98

What is the "added value" of string phenomenology?

(compared to standard MSSM phenomenology)

Intermediate (or high, but let's focus...) string scale

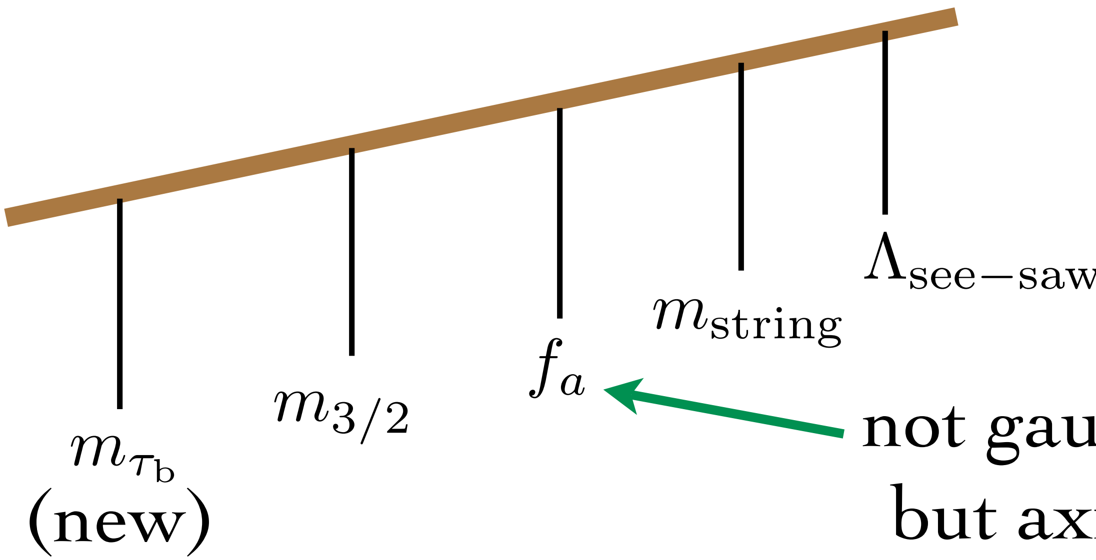
$$M_{\text{string}} \sim \; 10^{11}\text{GeV}$$

string theory gives some effective field theory... but if that's it, so what?

Example of added value: moduli stabilization

the scales are "yoked"
by moduli stabilization

yoke

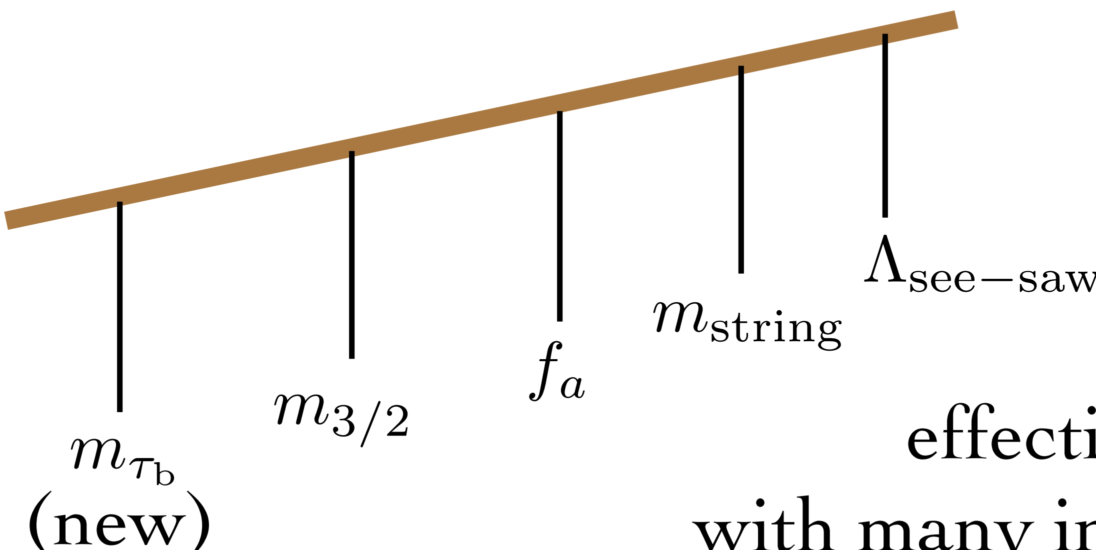


not gauge kinetic function,
but axion decay constant

Example of added value: moduli stabilization

yoke

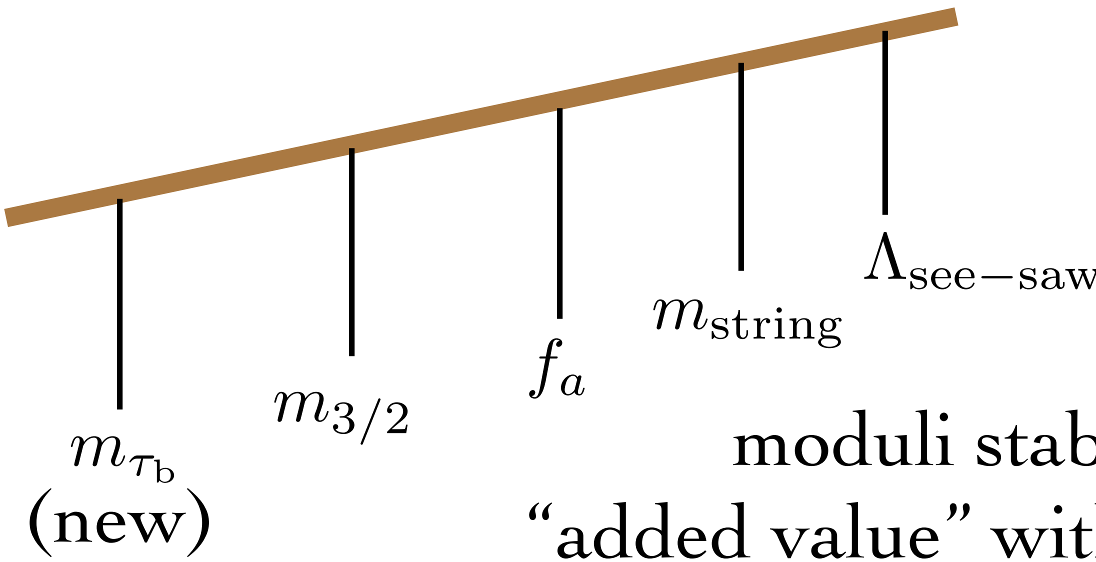
the scales are "yoked"
by moduli stabilization



effective field theory
with many interesting mass scales

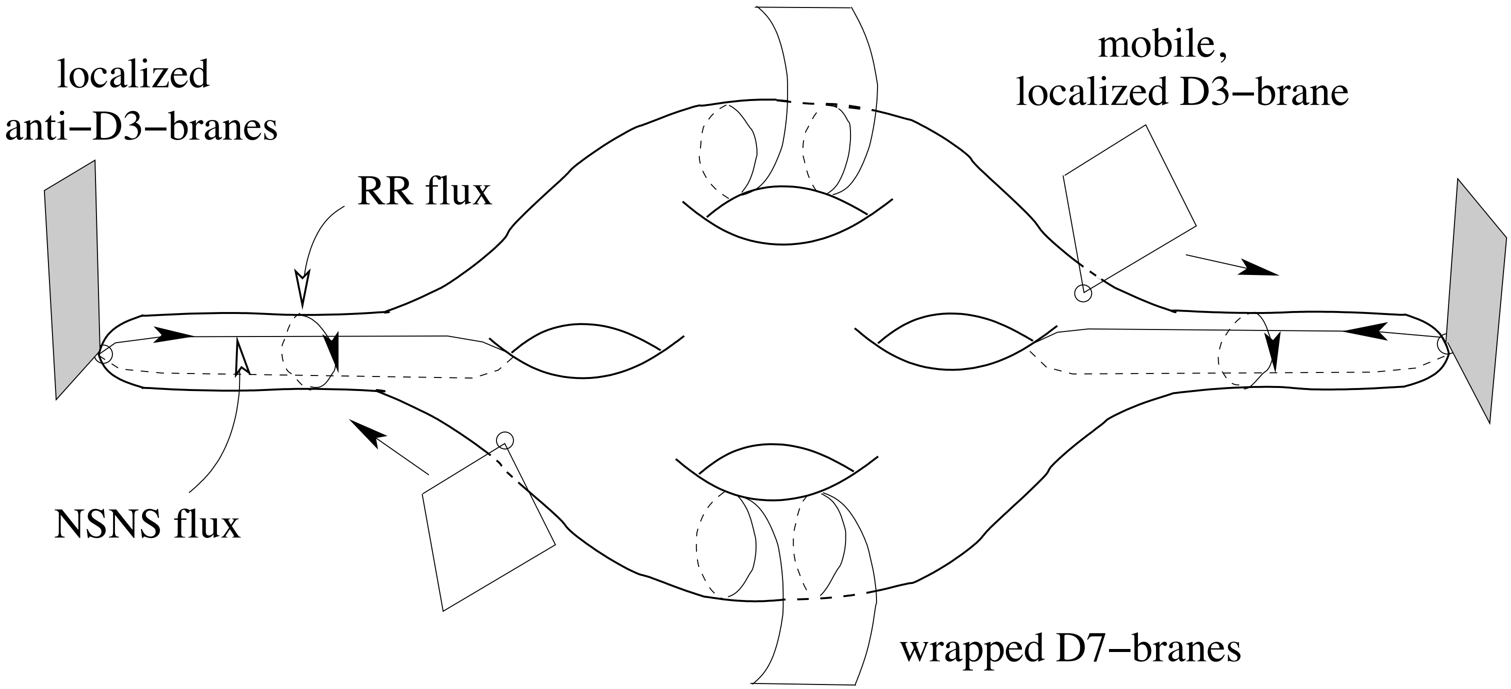
Example of added value: moduli stabilization

the scales are "yoked"
by moduli stabilization

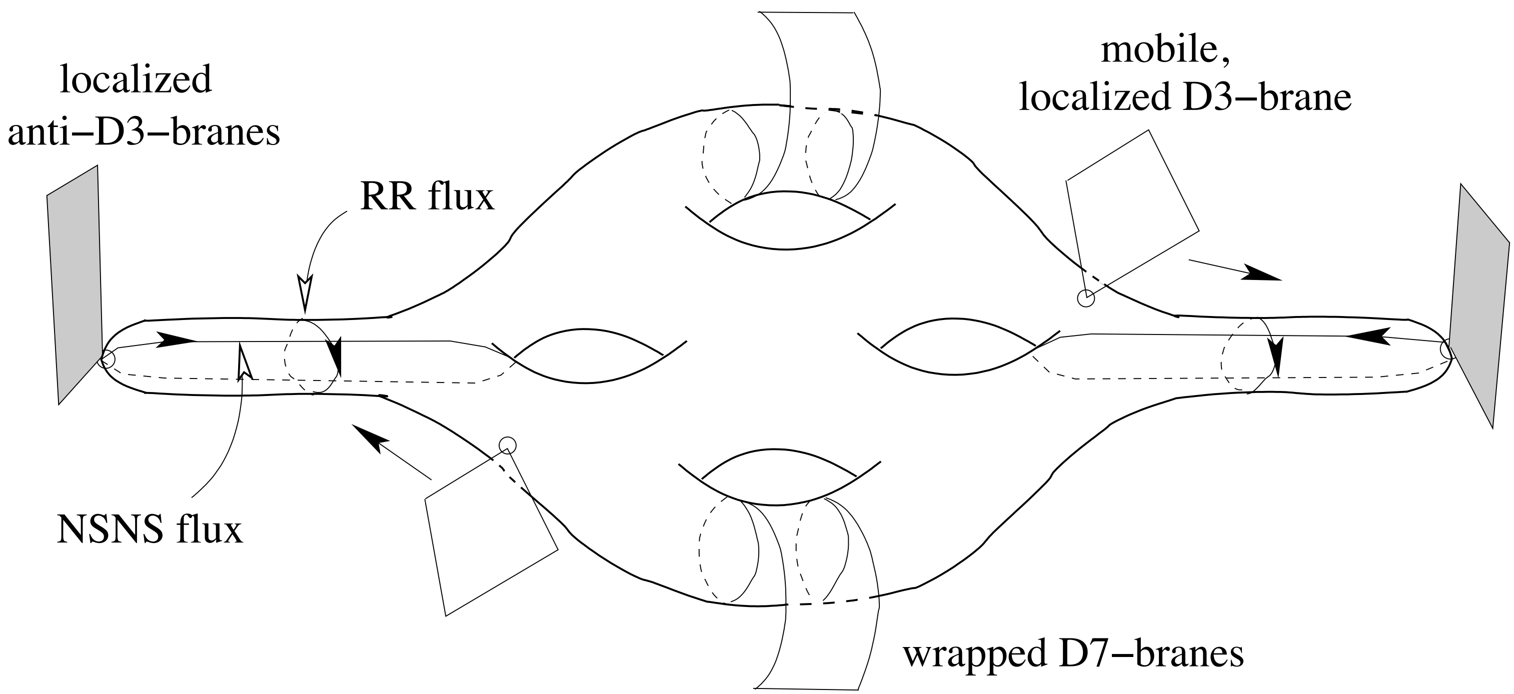


moduli stabilization gives
“added value” within a class of models

The KKLT internal space: a Calabi-Yau IIB orientifold with fluxes and warping

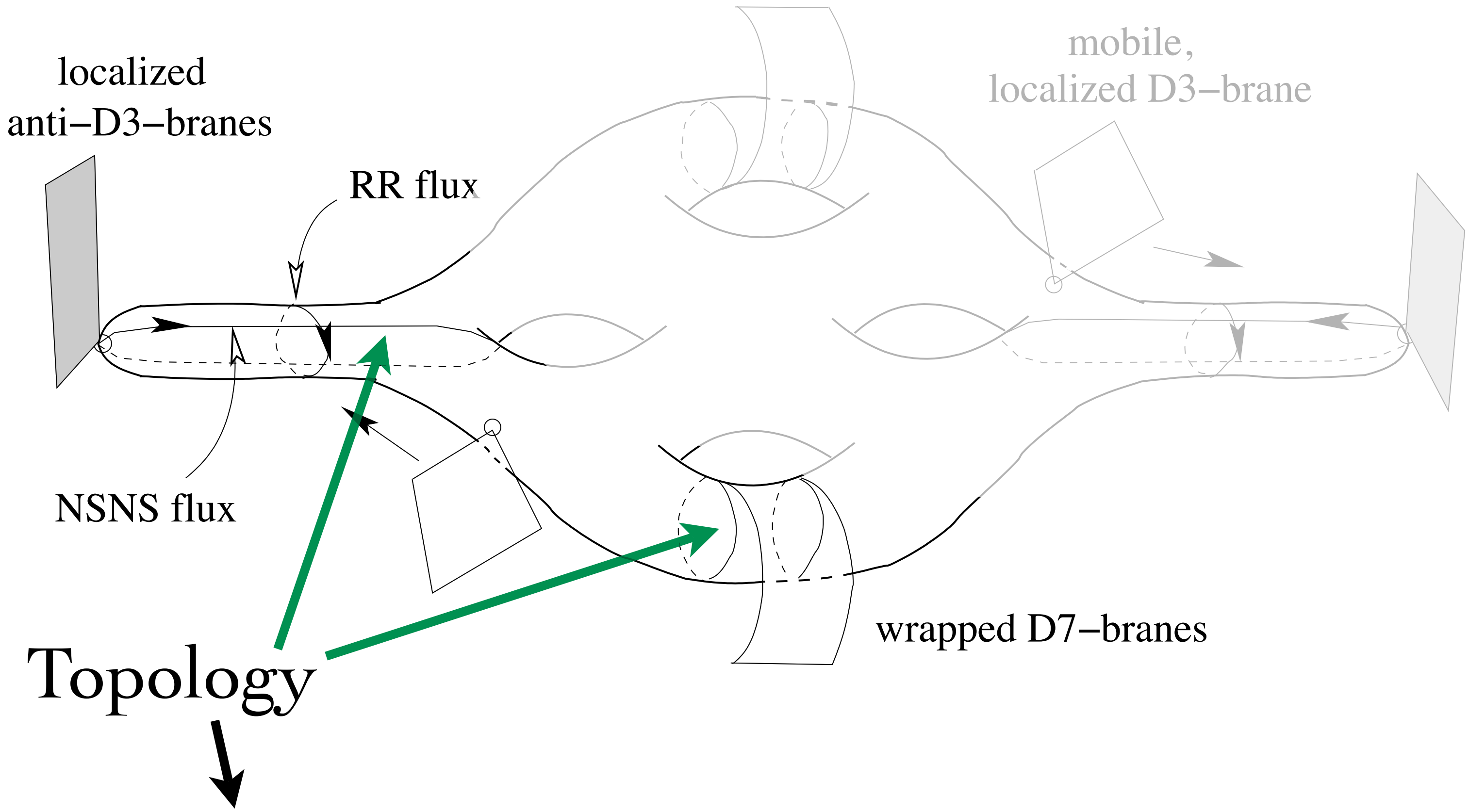


The KKLT internal space: a Calabi-Yau IIB orientifold with fluxes and warping



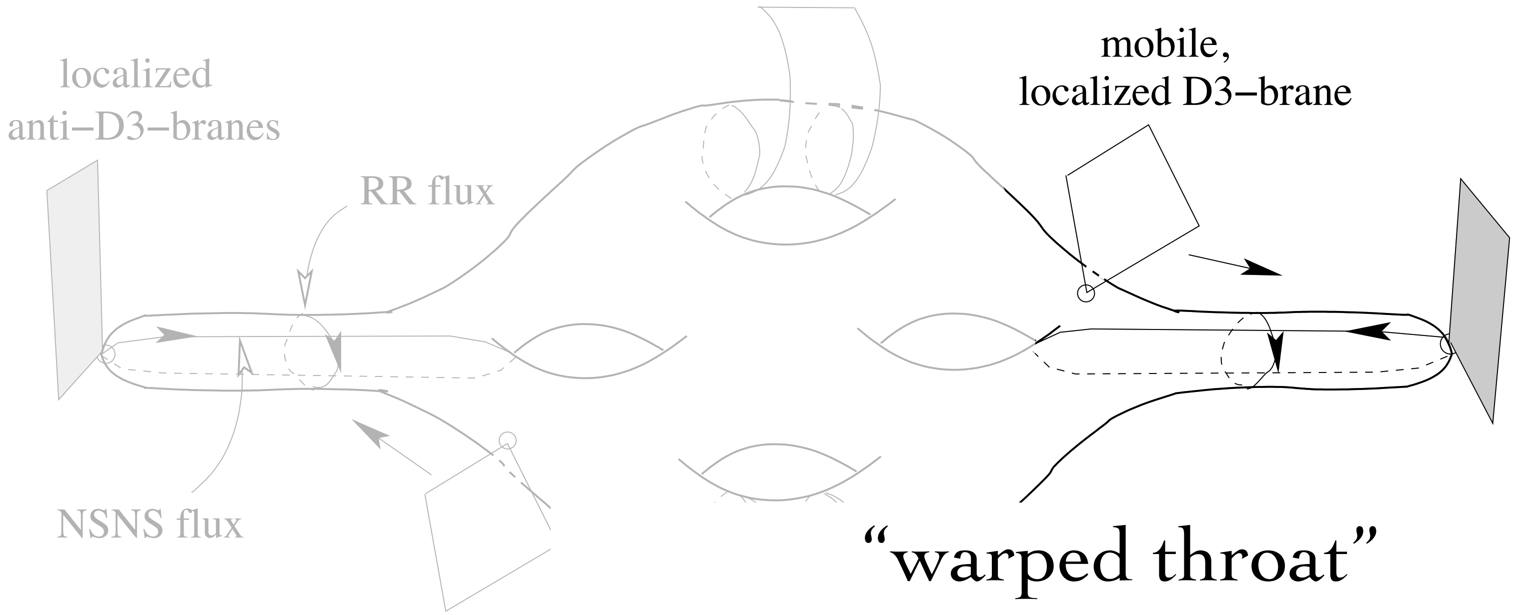
"the absence of an assumption"
relative to IIB with no fluxes, no branes

The KKLT internal space: a Calabi-Yau IIB orientifold with **fluxes** and warping



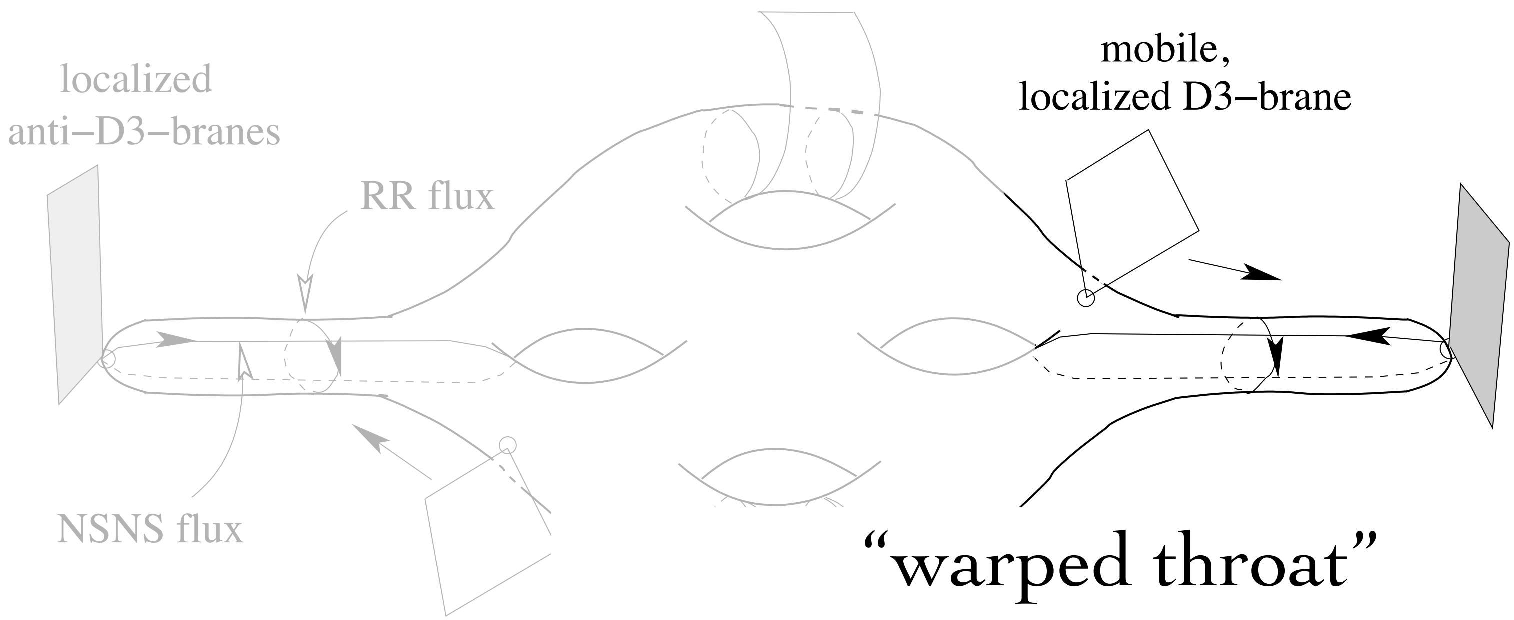
flux stabilization (vacuum selection)

The KKLT internal space: a Calabi-Yau IIB orientifold with fluxes and **warping**



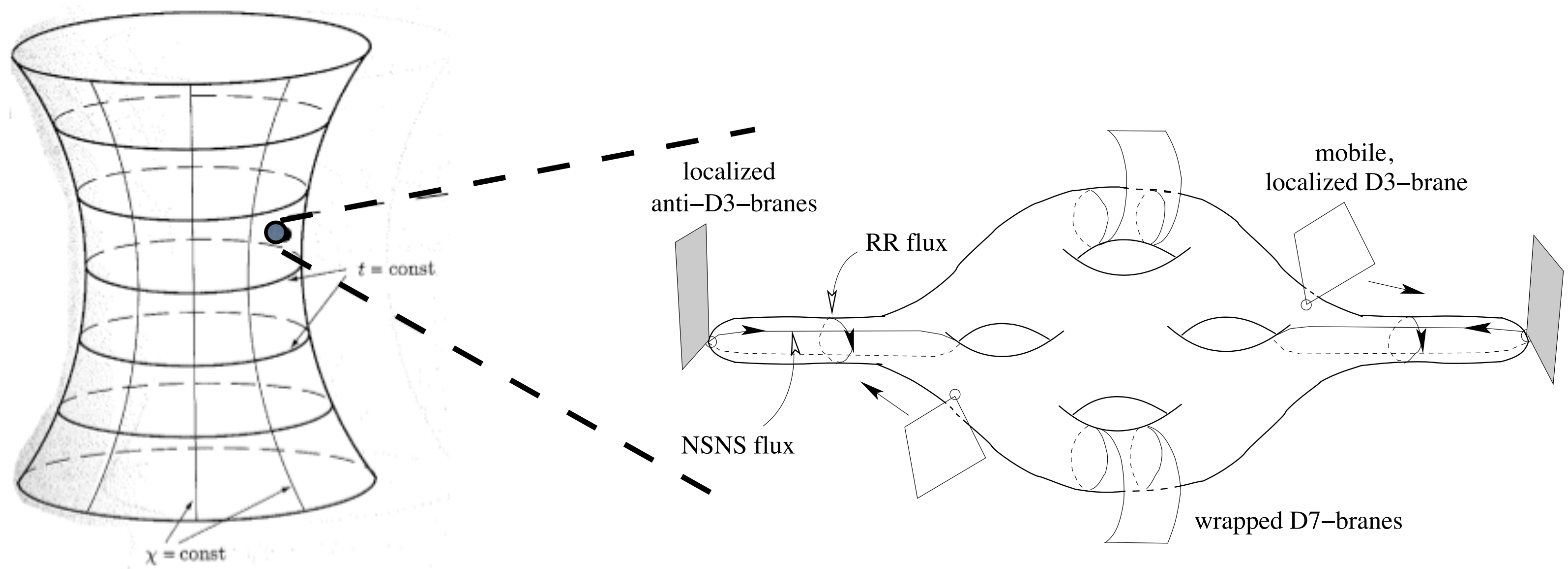
"warped throat"
i.e. Klebanov-Strassler 6d metric;
i.e. "Randall-Sundrum in 10d"

<u>The KKLT internal space: a Calabi-Yau IIB orientifold with fluxes and **warping**</u>



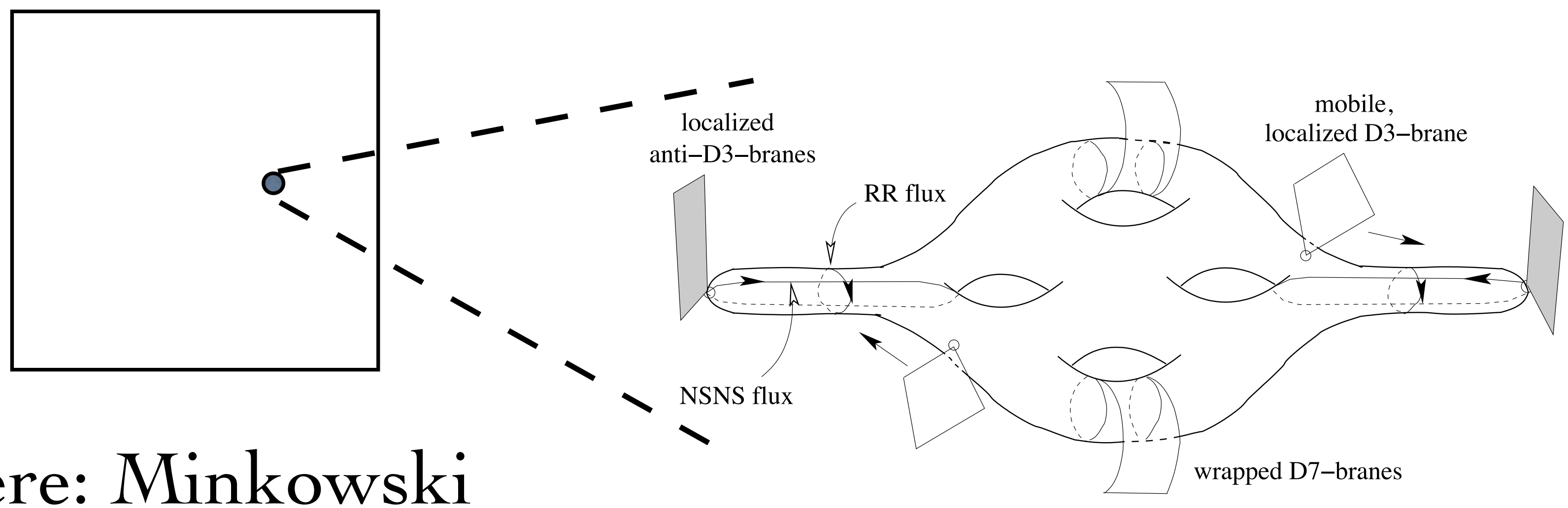
"warped throat"
often approximated
with AdS + UV cutoff

The KKLT internal space: a Calabi-Yau IIB orientifold with fluxes and warping



KKLT: external space deSitter

The KKLT internal space: a Calabi-Yau IIB orientifold with fluxes and warping



here: Minkowski external space

what is the 4d theory?

General D=4, N=1 effective theory

open and closed string moduli

$$\mathcal{L}_{\text{eff}} = \frac{1}{2\kappa^2} R - K_{\phi_i \bar{\phi}_{\bar{j}}} \partial_\mu \phi^i \partial^\mu \bar{\phi}^{\bar{j}} - \frac{1}{g^2(\phi)} \mathrm{tr}_a F^2$$

$$- V(\phi) + \text{corrections}$$

$$K_{\phi_i \bar{\phi}_{\bar{j}}} = \partial_{\phi^i} \partial_{\bar{\phi}^{\bar{j}}} K \quad \text{and} \quad \frac{1}{g^2(\phi)} = \mathrm{Re} f(\phi)$$

General D=4, N=1 effective theory

open and closed string moduli

$$\mathcal{L}_{\text{eff}} = \frac{1}{2\kappa^2}R - K_{\phi_i\bar{\phi}_{\bar{j}}}\partial_\mu\phi^i\partial^\mu\bar{\phi}^{\bar{j}} - \frac{1}{g^2(\phi)}\text{tr}_a F^2$$

$$- V(\phi) + \text{corrections}$$

closed string moduli potential: $I = (S, U_\alpha, T_i)$

$$V = e^K(K^{\bar{J}I}D_{\bar{J}}\bar{W}D_IW - 3|W|^2)$$

General D=4, N=1 effective theory

open and closed string moduli

$$\mathcal{L}_{\rm eff} = \frac{1}{2\kappa^2}R - K_{\phi_i\bar{\phi}_{\bar{j}}}\partial_\mu\phi^i\partial^\mu\bar{\phi}^{\bar{j}} - \frac{1}{g^2(\phi)}\mathrm{tr}_a F^2$$

$$- V(\phi) + \text{corrections}$$

α' and $g_{\rm s}$ corrections

Can't always think "negligible"
even when numerically small point by point in moduli space.

KKLT D=4, N=1 effective theory

closed string moduli: S, T_i, U_α

6d overall volume, function of Kähler moduli

$$K = -\ln(S+\bar{S}) - 2\ln \mathcal{V}(T_i + \bar{T}_i) + K^U$$

$$W = W_{\text{flux}} + W_{\text{np}}$$

stabilize S and U (i.e. minimize potential V with respect to S and U)

$$W = W_0 + \sum_i A_i e^{-a_i T_i}$$

KKLT D=4, N=1 effective theory

closed string moduli potential:

$$\begin{aligned} V &= (\text{terms that vanish as } W_{\rm np} \to 0) \\ &\quad + e^K (G^{\bar{\jmath}i} K_{\bar{\jmath}} K_i - 3)|W|^2 \end{aligned}$$

for tree-level K from previous slide,

$$G^{\bar{\jmath}i} K_{\bar{\jmath}} K_i = 3 \qquad \Rightarrow \qquad V(T) = 0$$

"no-scale structure"
at supergravity tree-level

KKLT D=4, N=1 effective theory

closed string moduli potential:

$$V = (\text{terms tha}\ldots$$
$$+e^{K}(\ldots$$

broken by perturbative and nonperturbative string corrections

for tree-level K fro…

$$G^{\bar{j}i}K_{\bar{j}}K_i = 3 \qquad \Rightarrow \qquad V(T) = 0$$

"no-scale structure" at supergravity tree-level

KKLT D=4, N=1 effective theory

closed string moduli potential : $(\tau_i = \mathrm{Re}\, T_i)$

$$\frac{V}{e^K} = e^{-a\tau}\left(4|A|^2 a\tau e^{-a\tau}(\tfrac{1}{3}a\tau + 1) - 4a\tau|A||W_0|\right)$$

for tree-level K from before ($G^{\bar{j}i}K_{\bar{j}}K_i = 3$)

in KKLT, no-scale structure
broken by nonperturbative superpotential

KKLT D=4, N=1 effective theory

closed string moduli potential : $(\tau_i = \mathrm{Re}\, T_i)$

$$\frac{V}{e^K} = e^{-a\tau} \left(4|A|^2 a\right.$$

In KKLT, all closed string moduli are stabilized

for tree-level K fro

in KKLT, no-scale structure
broken by nonperturbative superpotential

Some drawbacks with original KKLT

closed string moduli potential : $(\tau_i = \mathrm{Re}\, T_i)$

$$\frac{V}{e^K} = e^{-a\tau}\left(4|A|^2 a\tau e^{-a\tau}\left(\tfrac{1}{3}a\tau + 1\right) - 4a\tau|A||W_0|\right)$$

- only works for limited range of a, W_0, A
- volume slightly above string scale (no "problem", but see later)
- supersymmetry breaking "at the end" (least understood part)
- "two-step stabilization" (S, U, then T) sometimes fails (not algorithmic)

A first look at corrections: f

open and closed string moduli

$$\mathcal{L}_{\text{eff}} = \frac{1}{2\kappa^2} R - K_{\phi_i \bar{\phi}_{\bar{j}}} \partial_\mu \phi^i \partial^\mu \bar{\phi}^{\bar{j}} - \frac{1}{g^2(\phi)} \text{tr}_a F^2$$

$$- V(\phi) + \text{corrections}$$

correct

$$K_{\phi_i \bar{\phi}_{\bar{j}}} = \partial_{\phi^i} \partial_{\bar{\phi}^{\bar{j}}} K \quad \text{and} \quad \frac{1}{g^2(\phi)} = \text{Re} f(\phi)$$

A first look at corrections: f

$\mathbb{T}^2 \times \mathbb{T}^4/\mathbb{Z}_2$

$\mathbb{T}^6/(\mathbb{Z}_2 \times \mathbb{Z}_2)$

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

threshold corrections

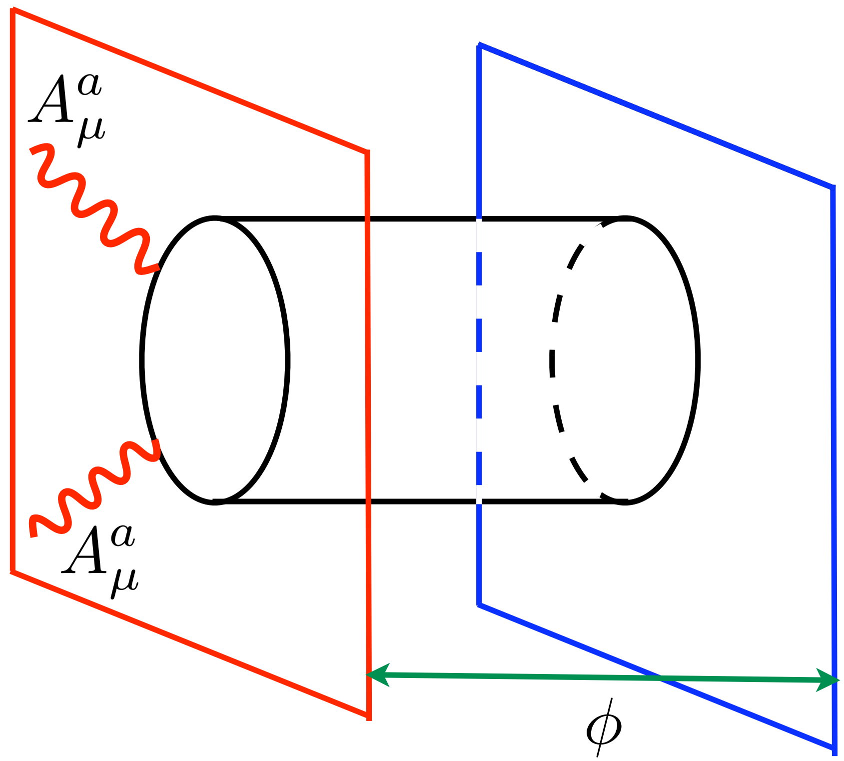
$$\left(\frac{1}{g^2}\right)^{1-\text{loop}} = \beta^{\mathcal{N}=2} \ln \frac{M_{\text{string}}}{\mu} + \Delta(\phi, U)$$

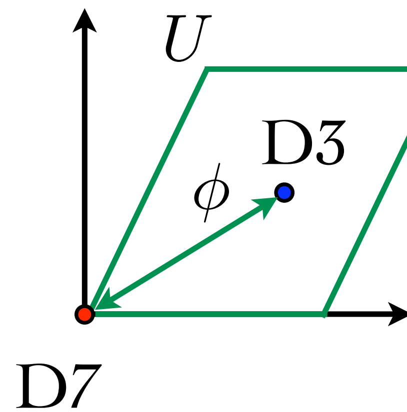
correct

$$K_{\phi_i \bar{\phi}_{\bar{j}}} = \partial_{\phi^i} \partial_{\bar{\phi}^{\bar{j}}} K \quad \text{and} \quad \frac{1}{g^2(\phi)} = \text{Re} f(\phi)$$

A first look at corrections: f

M.B., Haack, Kors '04



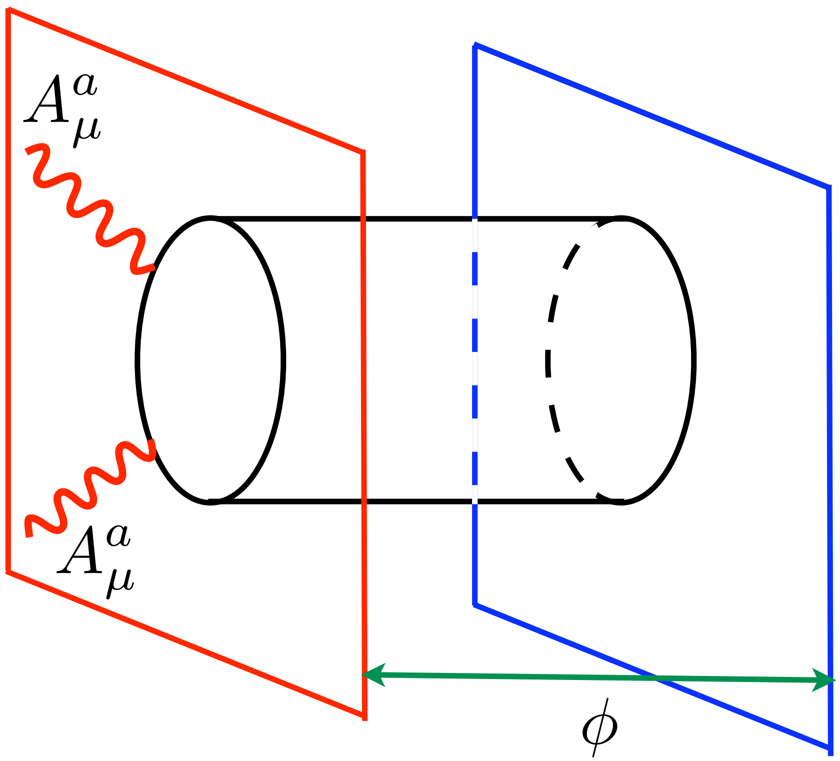


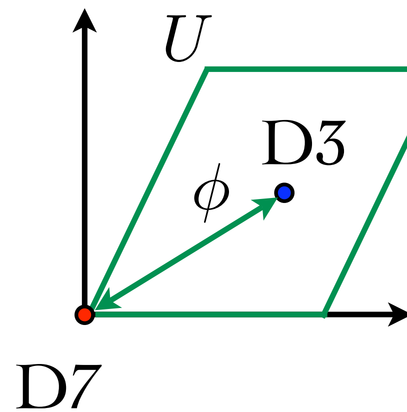
$$\Delta(\phi, U) = -\frac{1}{2} \ln \left| \frac{\vartheta_1(\phi/2\pi, U)}{\eta(U)} \right|^2 + \frac{(\mathrm{Im}\phi)^2}{4\pi\, \mathrm{Im} U}$$

$$f^{1-\mathrm{loop}} = -2 \ln \vartheta_1(\phi/2\pi, U) + \dots$$

A first look at corrections: f

M.B., Haack, Kors '04



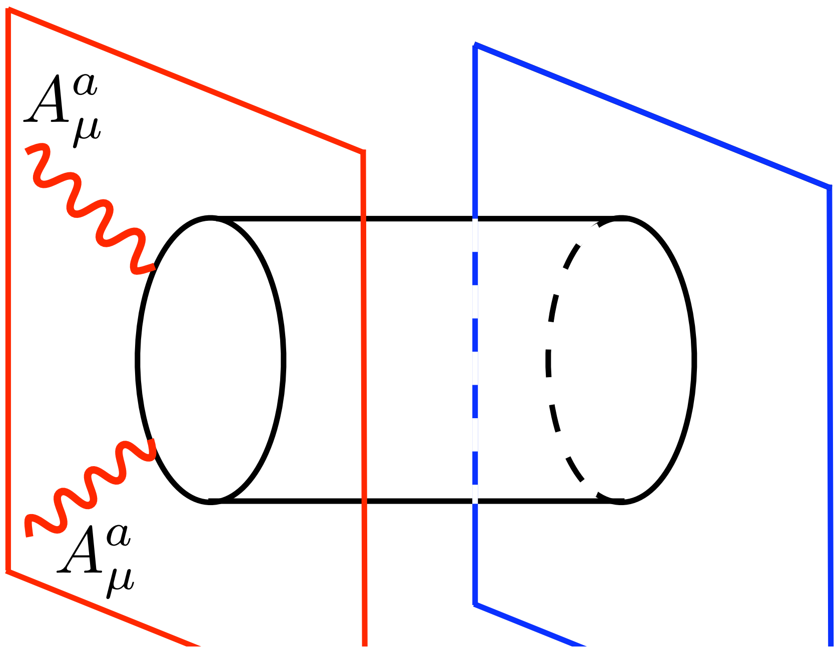


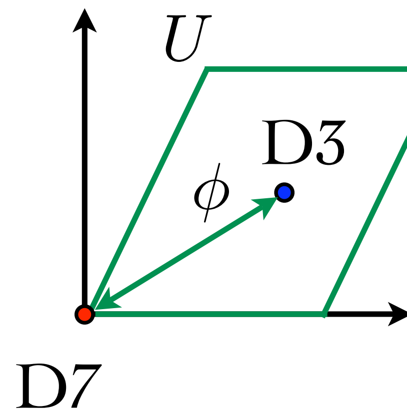
$$\ln|z|^2 = \ln z + \ln \bar{z} = \tfrac{1}{2}\mathrm{Re}\ln z$$

$$\Delta(\phi, U) = -\frac{1}{2}\ln\left|\frac{\vartheta_1(\phi/2\pi, U)}{\eta(U)}\right|^2 + \frac{(\mathrm{Im}\phi)^2}{4\pi\,\mathrm{Im}U}$$

$$f^{1-\mathrm{loop}} = -2\ln\vartheta_1(\phi/2\pi, U) + \ldots$$

A first look at corrections: f





where could this play a role in, say, KKLT?

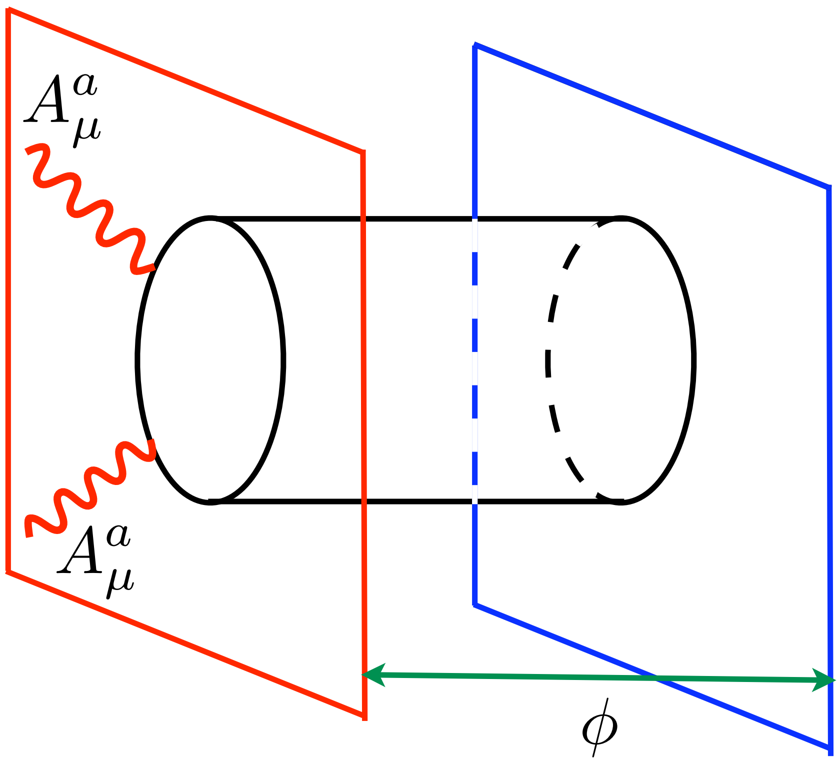
Ganor '04

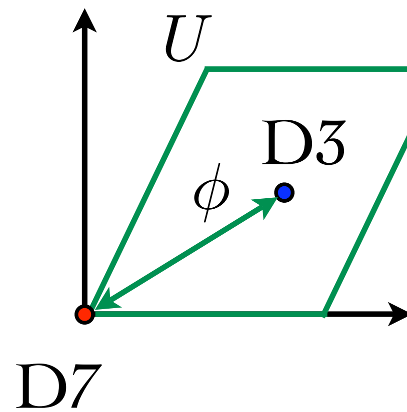
$$W_{\rm np} = Ae^{-af} = Ae^{-a(f^{\rm tree}+f^{\rm 1-loop}+\ldots)}$$

$$= \underbrace{A\cdot(\vartheta_1(\phi/2\pi,U)^{2a}\cdots)}_{\tilde{A}(\phi,U)}\,e^{-a(f^{\rm tree}+\ldots)}$$

$$a \sim 1/N_{\rm D7}$$

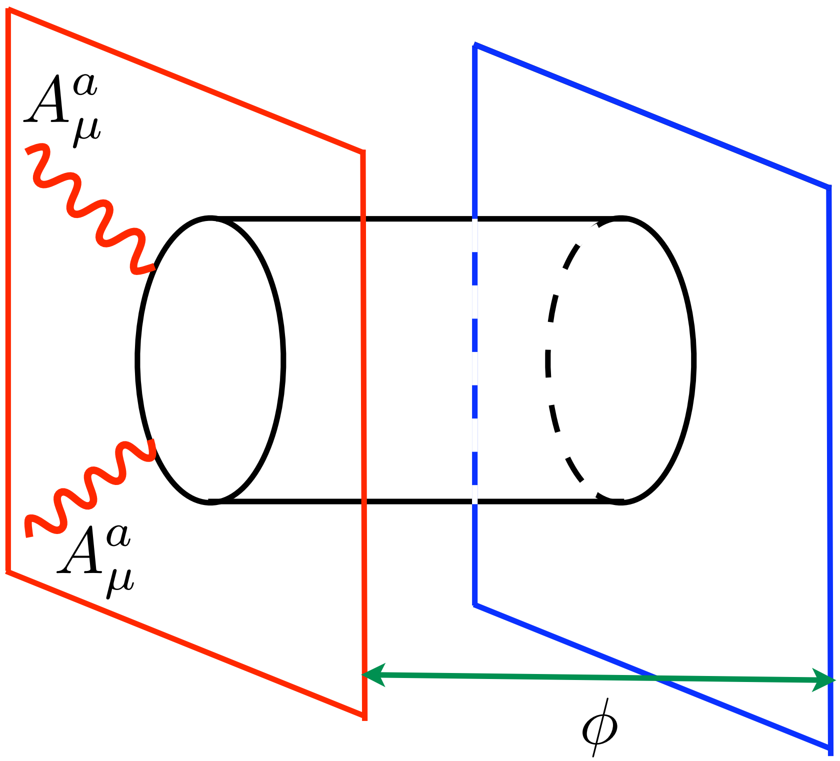
A first look at corrections: f

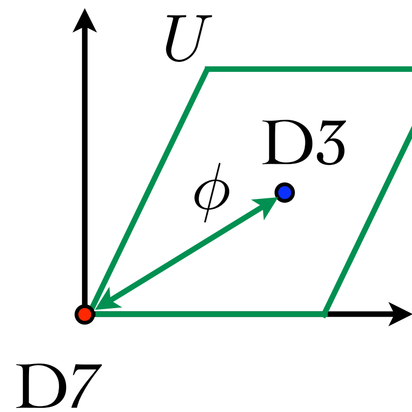




Moral: these are string loop corrections, but without them, W_{np} doesn't depend on D3-brane scalar ϕ at all. So they are not "negligible" in any real sense.

A first look at corrections: f

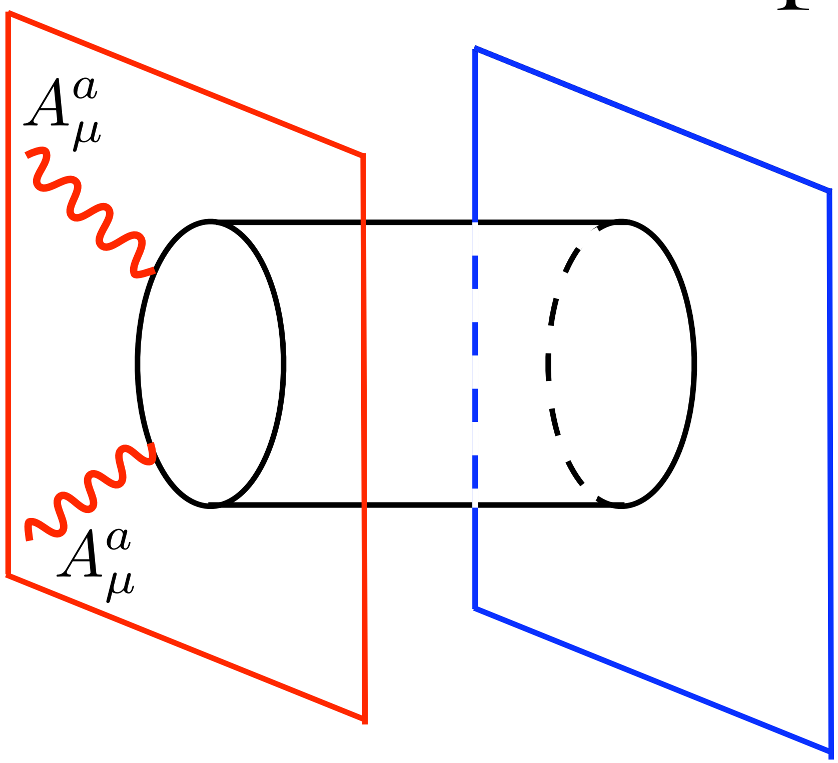




Moral: these are string loop corrections, but without them, W_{np} doesn't depend on D3-brane scalar ϕ at all. So th "negligible" in any real s

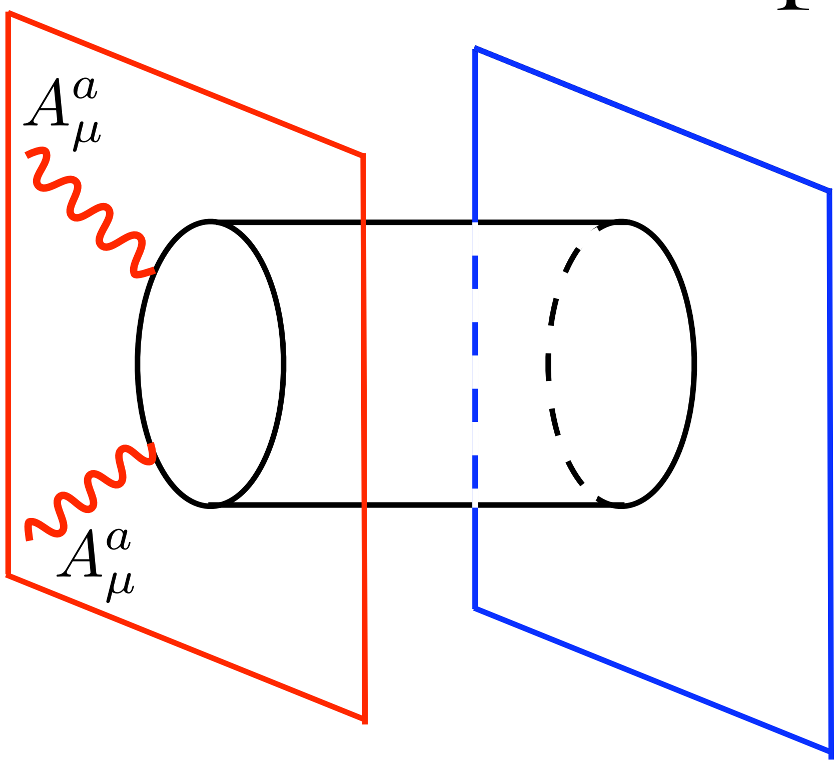
cf. brane inflation

Other progress



These were "not completely twisted" strings.
For branes at right angles, that is the *only f* correction that gives moduli dependence.

Other progress



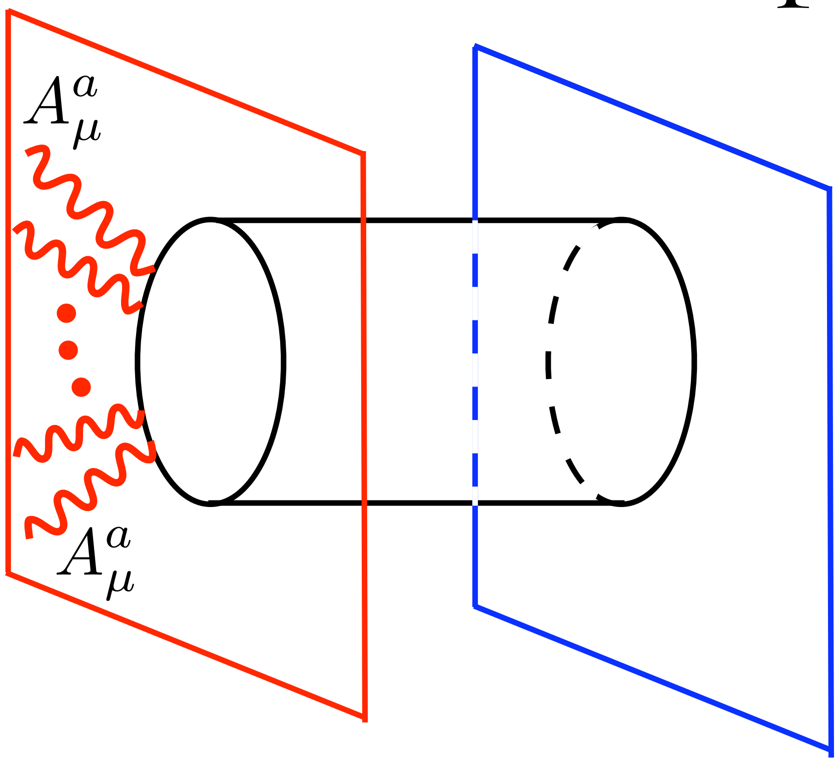
Branes at angles:
"Completely twisted"
strings give moduli
dependence too

Lust, Stieberger '03

$$\int_0^\infty d\ell\, \frac{\vartheta_1'(ia)}{\vartheta_1(ia)} = -\frac{\pi}{2} \ln\left[e^{-2i\gamma a} \frac{\Gamma(1-ia)}{\Gamma(1+ia)}\right]$$

(some fine print here)

Other progress



Many insertions:
need more powerful results

Stieberger, Taylor '02

$$\int \prod_{i=1}^{N} d^2 z_i \, G^{\mathrm{F}}_{\vec{\alpha}}(z_{12}) \cdots G^{\mathrm{F}}_{\vec{\alpha}}(z_{N1}) = -\frac{(2\tau_2)^N}{(N-1)!} \frac{\partial^N}{\partial z^N} \ln \vartheta_{\vec{\alpha}}(0,\tau)$$

fermion propagator

A second look at corrections: *K*

open and closed string moduli

$$\mathcal{L}_{\rm eff} = \frac{1}{2\kappa^2} R - K_{\phi_i \bar{\phi}_{\bar{j}}} \partial_\mu \phi^i \partial^\mu \bar{\phi}^{\bar{j}} - \frac{1}{g^2(\phi)} \mathrm{tr}_a\, F^2$$

$$- V(\phi) + \text{corrections}$$

$$K_{\phi_i \bar{\phi}_{\bar{j}}} = \partial_{\phi^i} \partial_{\bar{\phi}^{\bar{j}}} K \quad \text{and} \quad \frac{1}{g^2(\phi)} = \mathrm{Re} f(\phi)$$

correct

did before

A second look at corrections: K

To make it more concrete, let's consider a scenario where corrections to the Kähler potential is supposed to make a difference

$$K_{\phi_i \bar{\phi}_{\bar{j}}} = \partial_{\phi^i} \partial_{\bar{\phi}^{\bar{j}}} K \quad \text{and} \quad \frac{1}{g^2(\phi)} = \text{Re} f(\phi)$$

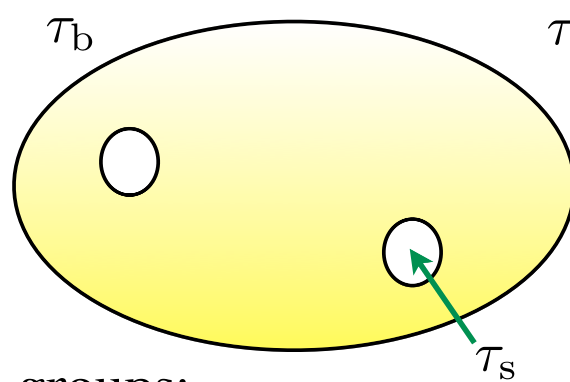
correct

did before

The Large Volume Scenario (LVS)

Balasubramanian, Berglund, Conlon, Quevedo '05

Variant of KKLT with "Swiss cheese" Calabi-Yau and α' correction:



split Kähler moduli into two groups:

$$\{T_i\} \rightarrow \{T_{\rm b}\}, \{T_{\rm s}\}$$

Volume of special "Swiss cheese" Calabi-Yau →

$$\mathcal{V} = \tau_{\rm b}^{3/2} - f(\tau_{\rm s}) \qquad (\tau_i = \mathrm{Re}\, T_i)$$

$$K = K_{\rm KKLT} + \xi \frac{S_1^{3/2}}{\mathcal{V}}$$

$$W = W_{\rm KKLT}$$

← α' (higher derivative) correction

Becker, Becker, Haack , Louis '02

The Large Volume Scenario (LVS)

Balasubramanian, Berglund, Conlon, Quevedo '05

Truncation problem: it typically makes no sense to attempt to "improve" any leading-order string model by string/quantum corrections

LVS is one case where this intuition may fail (under investigation!)

$$\{T_i\} \rightarrow \{T_\mathrm{b}\}, \{T_\mathrm{s}\}$$

Volume of special "Swiss cheese" Calabi-Yau

$$\mathcal{V} = \tau_\mathrm{b}^{3/2} - f(\tau_\mathrm{s}) \qquad (\tau_i = \mathrm{Re}\, T_i)$$

$$K = K_\mathrm{KKLT} + \xi \frac{S_1^{3/2}}{\mathcal{V}}$$

$$W = W_\mathrm{KKLT}$$

α' (higher derivative) correction

Becker, Becker, Haack , Louis '02

LVS moduli stabilization

change variables $(\tau_{\rm b}, \tau_{\rm s}) \to (\mathcal{V}, \tau_{\rm s})$

$$X = A e^{-a\tau_{\rm s}}$$

$$V = (\ldots)\frac{X^2}{\mathcal{V}} + (\ldots)\frac{X}{\mathcal{V}^2} + (\ldots)\frac{\xi}{\mathcal{V}^3}$$

$$\frac{\partial V}{\partial \mathcal{V}} = 0 \quad \Rightarrow \quad \mathcal{V} = \frac{f(\tau_{\rm s})}{X}$$

$$(\tau_i = {\rm Re}\, T_i)$$

$$\frac{\partial V}{\partial \tau_{\rm s}} = 0 \quad \Rightarrow \quad X = \frac{g(\tau_{\rm s})}{\mathcal{V}}$$

$$\Rightarrow \quad f(\tau_{\rm s}) = g(\tau_{\rm s})$$

$$\overset{a\tau_{\rm s} \gg 1}{\Longrightarrow} \quad \tau_{\rm s} \sim \xi^{2/3}$$

$$\Rightarrow \quad \mathcal{V} \sim e^{a\tau_{\rm s}}$$

dial: $\mathcal{V} \sim 10^{15} \ell_{\rm s}^6$

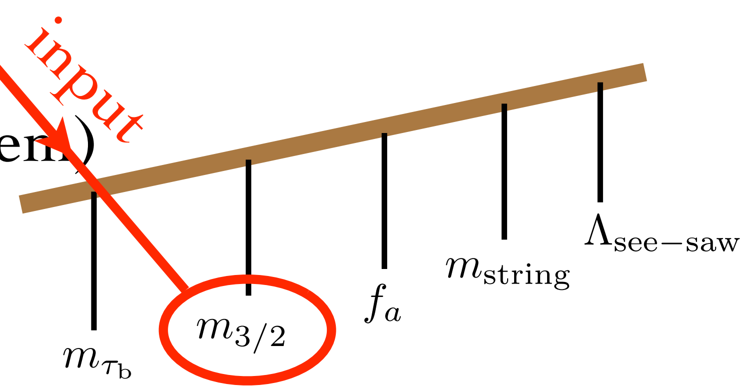
Why $\mathcal{V} \sim 10^{15} \ell_s^6$?

Conlon, Quevedo, Suruliz '05

1. Why is big good?
   - α' (inverse volume) expansion under control
   - "two-step" integrating out becomes algorithmic
   - matter fields: $K(\phi, \bar{\phi}) \sim \mathcal{V}^p k(\phi, \bar{\phi})$
   - soft supersymmetry breaking terms: simplifications

2. Why $\mathcal{V} \sim 10^{15} \ell_s^6$?
   - TeV scale supersymmetry
   - QCD axion (strong CP problem)
   - neutrino masses

the scales are "yoked"



Sample soft terms: gaugino masses

Conlon, Abdussalam, Quevedo, Suruliz '06

Assume MSSM

$$\begin{aligned} M_a &= \frac{1}{2\,\mathrm{Re} f_a} \sum_I F^I \partial_I f_a \\ F^{\tau_s} &= e^{K/2} (G^{\bar{s}s} \partial_{\bar{s}} \bar{W} + (G^{\bar{s}s} K_{\bar{s}} + G^{\bar{b}s} K_{\bar{b}}) \bar{W}) \\ &= 2\tau_s e^{K/2} \bar{W}_0 \left(\left(1 - \frac{3}{4a\tau_s} \right) - 1 + \ldots \right) \\ |M_s| &\sim \frac{m_{3/2}}{\ln(M_P/m_{3/2})} \left(1 + \frac{(\ldots)}{\ln(M_P/m_{3/2})} + \ldots \right) \end{aligned}$$

Gaugino masses suppressed by factor of 30 compared to gravitino mass

Consistency conditions for LVS

M.B., Haack, Pajer '07 + newer
Cicoli, Conlon, Quevedo '08 (May)

$$\Delta K_{\alpha'} : \Delta K_{g_s} \quad \sim \quad \alpha'^3 \ : \ g_s^2 \alpha'^2$$

dimensional analysis:

$$\Delta K_{\alpha'} \quad \sim \quad g_s^{-3/2} \mathcal{V}^{-1}$$
$$\Delta K_{g_s} \quad \sim \quad g_s \mathcal{V}^{-2/3}$$

cancellation (shown in detail in paper):

$$\Delta V_{\alpha'} \quad \sim \quad g_s^{-1/2} \mathcal{V}^{-3}$$
$$\Delta V_{g_s} \quad \sim \quad g_s \mathcal{V}^{-3}$$

should consider D-brane corrections in LVS!

D-Brane Corrections to Kähler potential

Problem: D-Brane corrections to Kähler potential not known for general Calabi-Yau orientifolds, much less with fluxes and warping.

Proposed solution: Estimate at least scaling behavior from known corrections in simpler models: $\mathcal{N} = 1$ toroidal IIB orientifolds with arbitrary D3 and D7 brane positions.

Problem: in early 2005, those were not known either.

D-Brane Corrections to Kähler potential

M.B., Haack, Körs, '05

Consider Type IIB N=2 or 1 toroidal orientifolds
with D3- and D7-branes

Ex:

$$\mathbb{T}^2 \times \mathbb{T}^4/\mathbb{Z}_2$$

$$\mathbb{T}^6/(\mathbb{Z}_2 \times \mathbb{Z}_2)$$

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

tree-level Kähler metric for brane scalars?

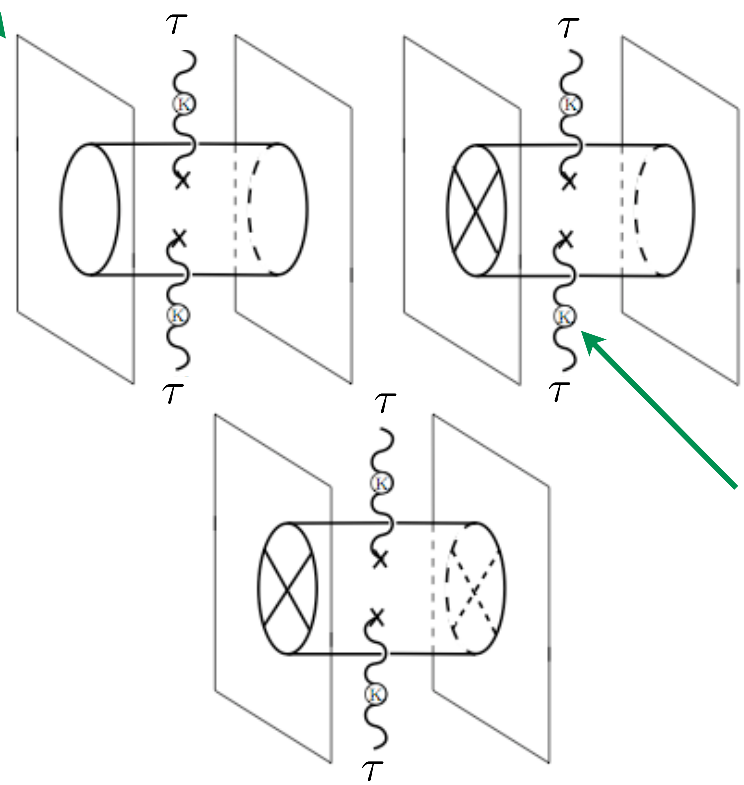
D-Brane Corrections to Kähler potential

M.B., Haack, Körs, ‘05

brane at arbitrary position ϕ

$\tau = \mathrm{Re}\, T$

$$\langle \tau \, \tau \rangle =$$



“Kähler adapted vertex operators”

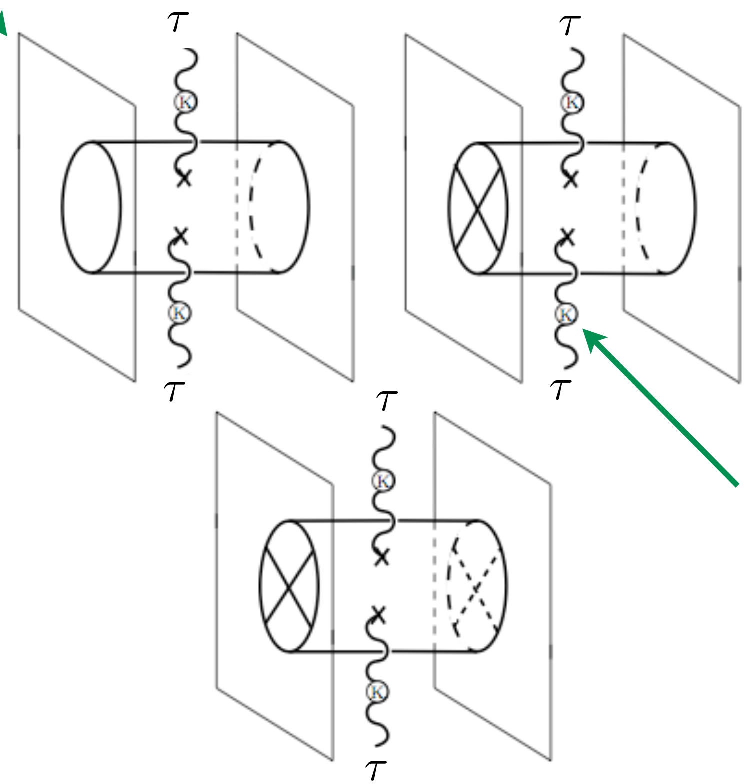
D-Brane Corrections to Kähler potential

brane at arbitrary position ϕ

M.B., Haack, Körs, '05

$\tau = \mathrm{Re}\, T$

$\langle \tau \tau \rangle =$

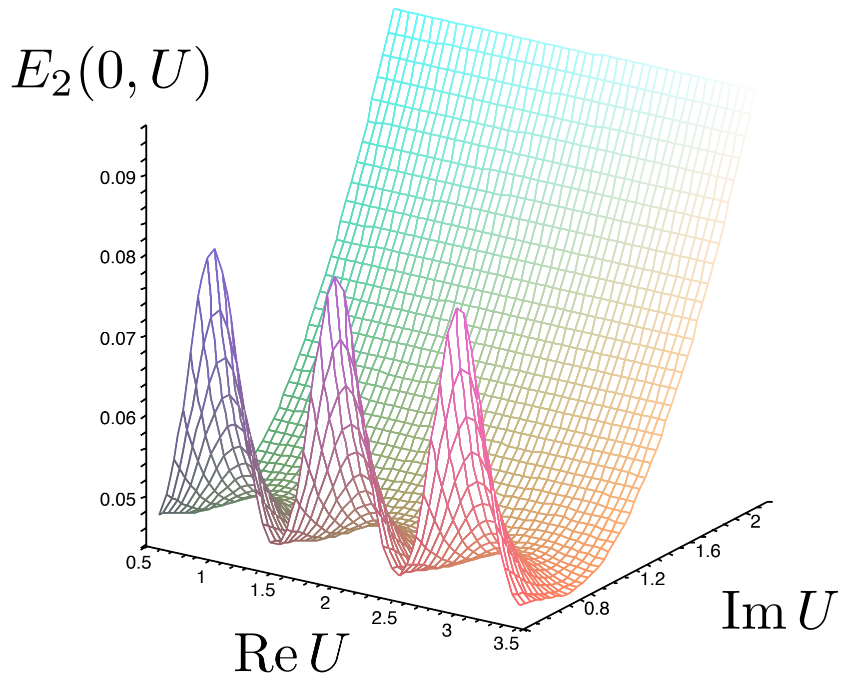


"Kähler adapted vertex operators"

$$E_2(\phi, U) = \sum_{(n,m)=(0,0)} \frac{\mathrm{Re}(U)^2}{|n+mU|^4} \exp\left(2\pi i \frac{\phi(n+m\bar{U}) + \bar{\phi}(n+mU)}{U+\bar{U}}\right)$$

Generalized nonholomorphic Eisenstein series

M.B., Haack, Körs, '05



$$E_2(\phi, U) = \sum_{(n,m)=(0,0)} \frac{\mathrm{Re}(U)^2}{|n+mU|^4} \exp\left(2\pi i \frac{\phi(n+m\bar{U}) + \bar{\phi}(n+mU)}{U+\bar{U}}\right)$$

D-Brane Corrections to Kähler potential

M.B., Haack, Körs, '05

"integrate" one-loop corrected Kähler metric to get one-loop corrected Kähler potential:

sum over images of $E_2(\phi_i, U)$

$$K = -\ln\left((S+\bar{S})(T+\bar{T})(U+\bar{U})\right) - \ln\left(1 - \frac{1}{8\pi}\sum_i \frac{N_i(\phi_i+\bar{\phi}_i)^2}{(T+\bar{T})(U+\bar{U})} - \frac{1}{128\pi^6}\sum_i \frac{\mathcal{E}_2(\phi_i, U)}{(S+\bar{S})(T+\bar{T})}\right)$$

$$E_2(\phi, U) = \sum_{(n,m)=(0,0)} \frac{\mathrm{Re}(U)^2}{|n+mU|^4} \exp\left(2\pi i \frac{\phi(n+m\bar{U}) + \bar{\phi}(n+mU)}{U+\bar{U}}\right)$$

Aside: "Prepotential puzzle"

M.B., Haack, Körs, '05

we "integrated" $K_{T\bar{T}} \to K$

Q: what about "integrability conditions" due to other Kähler metric components, like $K_{\phi\bar{\phi}}$?

sum over images of $E_2(\phi_i, U)$

$$K = -\ln\left((S+\bar{S})(T+\bar{T})(U+\bar{U})\right) - \ln\left(1 - \frac{1}{8\pi}\sum_i \frac{N_i(\phi_i+\bar{\phi}_i)^2}{(T+\bar{T})(U+\bar{U})} - \frac{1}{128\pi^6}\sum_i \frac{\mathcal{E}_2(\phi_i, U)}{(S+\bar{S})(T+\bar{T})}\right)$$

...
M.B., Haack, Körs, '04
...

compare earlier results:

e.g. for $N = 2$ case, gauge coupling correction $\sim \ln|\vartheta_1(\phi, U)|^2$ is related to $K_{\phi\bar{\phi}}$: both come from prepotential

$$\Delta \frac{1}{g^2_{\rm YM}} \sim \ln|\vartheta_1(\phi, U)|^2 + \ldots$$

Aside: "Prepotential puzzle"

M.B., Haack, Körs, '05

$$K = -\ln\big((S+\bar{S})(T+\bar{T})(U+\bar{U})\big)$$
$$-\ln\left(1-\frac{1}{8\pi}\sum_i \frac{N_i(\phi_i+\bar{\phi}_i)^2}{(T+\bar{T})(U+\bar{U})} - \frac{1}{128\pi^6}\sum_i \frac{\mathcal{E}_2(\phi_i,U)}{(S+\bar{S})(T+\bar{T})}\right)$$

so concrete question is: are we going to get something $\sim \ln|\vartheta_1(\phi,U)|^2$ if we differentiate $\partial_\phi \partial_{\bar{\phi}}$?

Aside: "Prepotential puzzle"

M.B., Haack, Körs, '05
...
Benakli, Goodsell '08 (May 13)

$$
\begin{aligned}
K \quad = \quad & -\ln\big((S+\bar{S})(T+\bar{T})(U+\bar{U})\big) \\
& -\ln\left(1-\frac{1}{8\pi}\sum_i \frac{N_i(\phi_i+\bar{\phi}_i)^2}{(T+\bar{T})(U+\bar{U})}-\frac{1}{128\pi^6}\sum_i \frac{\mathcal{E}_2(\phi_i,U)}{(S+\bar{S})(T+\bar{T})}\right)
\end{aligned}
$$

Saved by identity:

$$\partial_\phi \partial_{\bar{\phi}} E_2(\phi,U) = -\frac{2\pi^2}{U+\bar{U}} E_1(\phi,U)$$

$$E_1(\phi,U) \sim \ln|\vartheta_1(\phi,U)|^2 + \dots$$

String Corrections to K

M.B., Haack, Körs, '05

$$K = -\ln\big((S+\bar{S})(T+\bar{T})(U+\bar{U})\big)$$
$$-\ln\left(1 - \frac{1}{8\pi}\sum_i \frac{N_i(\phi_i+\bar{\phi}_i)^2}{(T+\bar{T})(U+\bar{U})} - \frac{1}{128\pi^6}\sum_i \frac{\mathcal{E}_2(\phi_i,U)}{(S+\bar{S})(T+\bar{T})}\right)$$

Saved by identity:

$$\partial_\phi \partial_{\bar{\phi}} E_2(\phi,U) = -\frac{2\pi^2}{U+\bar{U}} E_1(\phi,U)$$

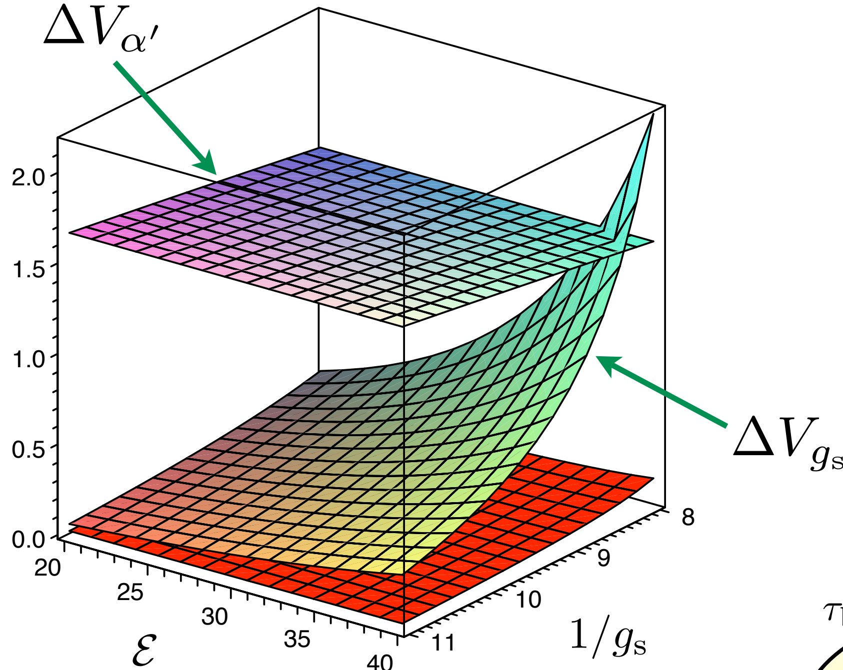
$$E_1(\phi,U) \sim \ln|\vartheta_1(\phi,U)|^2 + \ldots$$

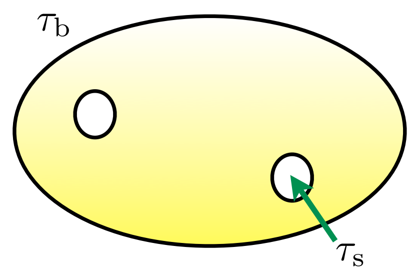
Above K consistent with all Kähler metric corrections

D-Brane Corrections to Kähler potential

M.B., Haack, Körs, '05

use toroidal result for scaling estimates:





for "Swiss cheese" Calabi-Yaus, loop corrections negligible

...can we trust these estimates?

D-brane corrections in flux compactifications?

As we saw before: gauge threshold (loop) corrections?

$$f_{\mathrm{D7}} = T + f^{(1)}(\phi, U) \quad \Rightarrow \quad W_{\mathrm{np}} = \underbrace{e^{-a f^{(1)}(\phi,U)}}_{A(\phi,U)} e^{-aT}$$

Originally: constant

D-brane corrections in flux compactifications?

Dixon, Kaplunovsky, Louis '91

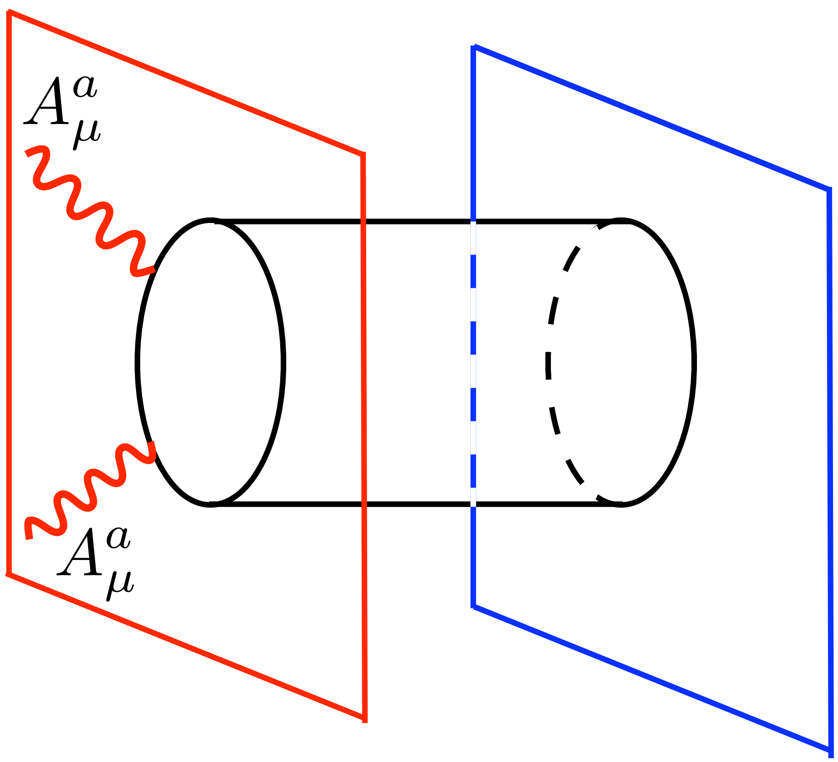
...

M.B., Haack, Körs '04

But $$E_1(\phi, U) \sim \ln|\vartheta_1(\phi, U)|^2 + \ldots$$

eigenfunction of Laplacian on torus
transverse to D7-branes – what is going on?

D-brane corrections in flux compactifications?



closed string exchange?

D-brane corrections in flux compactifications?

M.B., Haack, Körs '04
Giddings, Maharana '05
Baumann, Dymarsky, Klebanov, Maldacena, McAllister, Murugan '06
Forcella, Garcia-Extebarrieta, Uranga '08 (June)

calculate D-brane loop corrections by supergravity?
gauge coupling corrections ~ eigenfunction of Laplacian
– claim that this works by **open/closed duality**

- generalize to warped deformed conifold (!) with general holomorphic D7-brane embedding specified by integers p_i

$$A = A_0 \left(\frac{\mu^P - \prod_{i=1}^4 w_i^{p_i}}{\mu^P} \right)^{1/N_{\rm D7}} \qquad P = \sum_{i=1}^{4} p_i$$

e.g. Kuperstein embedding

D-brane corrections in flux compactifications?

M.B., Haack, Körs '04
Giddings, Maharana '05
Baumann, Dymarsky, Klebanov, Maldacena, McAllister, Murugan '06
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calculate D-brane loop corrections by supergravity?
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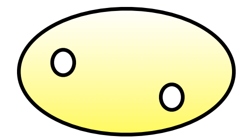
– claim that this works by **open/closed duality**

- generalize to warped deformed conifold (!) with general holomorphic D7-brane embedding specified by integers p_i

much work left to do!

Summary



- Variants of KKLT, like LVS, can be surprisingly controllable

- Checks must be performed – whole classes can disappear

- Existing results, if correct, already give generic statements about effective action that seem interesting for phenomenology

- With more details, would be more interesting...

- Development about loop corrections in very general backgrounds interesting in its own right

Work in progress

- More checks of “Green’s function method” (closed string alternative calculation)

- Stieberger-Taylor formula generalized to “completely twisted strings”, which give additional moduli dependence for branes at angles

$$\int \prod_{i=1}^{N} d^2 z_i \, G^{\mathrm{F}}_{\vec{\alpha}}(z_{12}) \cdots G^{\mathrm{F}}_{\vec{\alpha}}(z_{N1}) = -\frac{(2\tau_2)^N}{(N-1)!} \frac{\partial^N}{\partial z^N} \ln \vartheta_{\vec{\alpha}}(0,\tau)$$

fermion propagator