Open Office (Linux)

A String Manifesto

Marcus Berg
CoPS

M.B., Haack, Pajer '07
M.B., Haack, Körs '05, '04

Open Office (Linux)

A String Manifesto

Marcus Berg
CoPS

- Summary of current state of affairs
- Statement about future plans
- Based on *opinion* (but strongly held)
- Aim for future influence

Talk posted on website `cops.physto.se/~mberg`

Outline

- Selective history of string theory
- Current research in string theory (very brief)
- Current research in string phenomenology

  details: VR-foass lecture series!
- My research on “KKLT-like orientifolds”
- Future directions / points of contact

Selective history of string theory

1968 Veneziano

1968-1973 Early history

“The Birth of String Theory”, mini-conference
GGI Florence, May 18-19 2007
`http://theory.fi.infn.it/colomo/string-birth/`

1980s Early exploration of string perturbation theory:
thermodynamics, ultrahigh energy, heavy states
Ex: Sundborg thesis: “Strings Hot Fast and Heavy”

Early attempts at phenomenology
Ex: “Rank of gauge group must be < 23” (... or not)
(see intro to Kachru, McGreevy, Svrcek '06)

Selective history of string theory

Sagnotti '87, ...

1980s (cont'd) Orientifold models, “half-SUSY” (not much attention)

Strong statements

1990s Early explorations of nonperturbative string theory

Dualities

D-Branes ..., Polchinski '95

AdS/CFT ..., Maldacena '97

Even stronger statements

2000s Putting things together: more general backgrounds

Ex. “strongly time-dependent backgrounds”

(promising for cosmological models)

Balasubramanian, Hassan et al '02

Less strong statements (still occasionally outrageous)

Current research in string theory

Amount of supersymmetry

N=0	N=1	N=2, N=4, N=8
AdS/QCD	Heterotic models	Supergravity solutions
“Applied AdS/CFT”	Sasaki-Einstein/Quivers	Topological strings
String pheno	SQCD in AdS/CFT	M-theory / Matrix models
String cosmo	String instantons	Topological M-theory
KKLT	Intersecting branes/MSSM	Spin chains
	Nongeometric backgrounds	

String Phenomenology I: Soft Supersymmetry Breaking

$D=4$, $N=1$ effective quantum field theory (supergravity)

Kähler potential K, superpotential W, gauge kinetic function f

…

“hidden sector” = “moduli”

$$\begin{aligned} W &= \hat{W}(\Phi) + \mu(\Phi) H_1 H_2 + \frac{1}{6} Y_{\alpha\beta\gamma}(\Phi) C^\alpha C^\beta C^\gamma + \dots \\ K &= \hat{K}(\Phi,\bar{\Phi}) + \tilde{K}_{\alpha\beta}(\Phi,\bar{\Phi}) C^\alpha C^\beta + (Z(\Phi,\bar{\Phi}) H_1 H_2 + \text{h.c.}) + \dots \\ f_a &= f_a(\Phi) \end{aligned}$$

particle physics

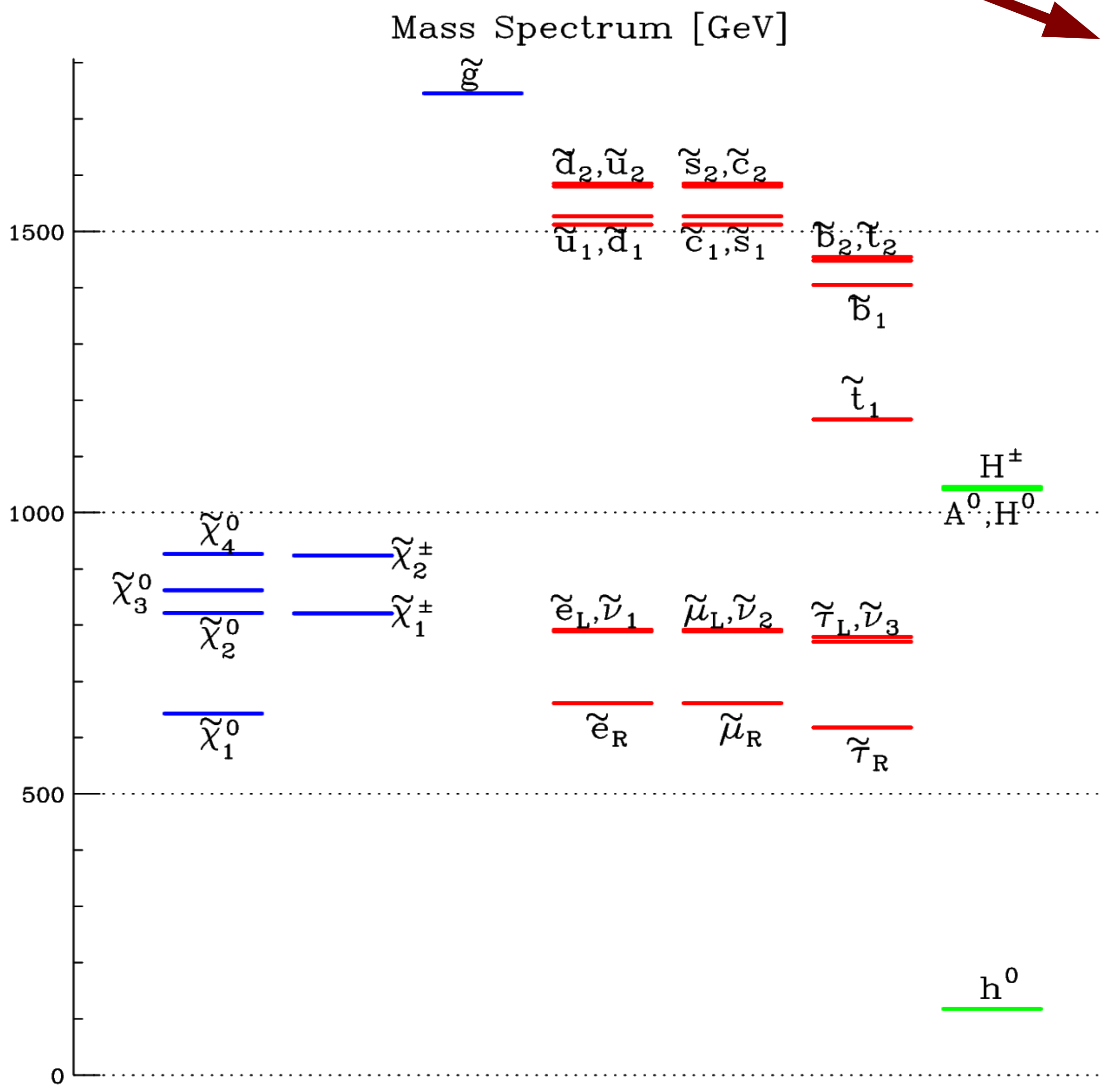
break supersymmetry spontaneously:

$$F^I = e^{\hat{K}/2} \hat{K}^{\bar{I}J} D_{\bar{J}} \bar{\hat{W}}$$

cosmology

String Phenomenology II: Low Energy Spectrum

Example: LVS (dilute flux, C)

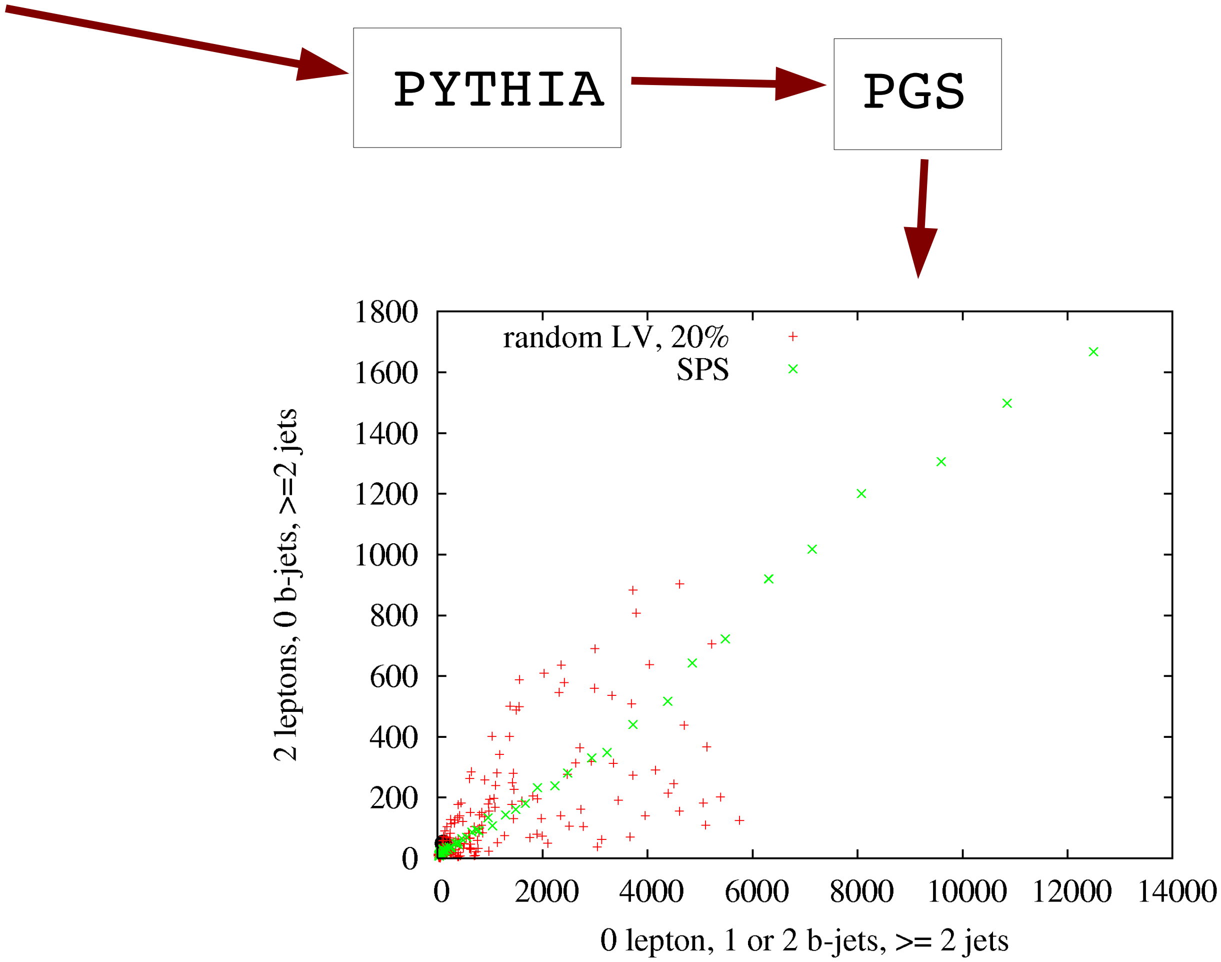


SoftSUSY

future discussions

String Phenomenology III: LHC observables

Kane, Kumar, Shao '06
Conlon, Kom, Suruliz, Allanach, Quevedo '07



future discussions

How sure are we about these 'clouds'?

String Cosmology I: Soft Supersymmetry Breaking

$D{=}4$, $N{=}1$ effective supergravity

Kähler potential K, superpotential W, gauge kinetic function f

...

$$
\begin{aligned}
W &= \hat{W}(\Phi) + \mu(\Phi) H_1 H_2 + \frac{1}{6} Y_{\alpha\beta\gamma}(\Phi) C^\alpha C^\beta C^\gamma + \ldots \\
K &= \hat{K}(\Phi, \bar{\Phi}) + \tilde{K}_{\alpha\beta}(\Phi, \bar{\Phi}) C^\alpha C^\beta + (Z(\Phi, \bar{\Phi}) H_1 H_2 + \text{h.c.}) + \ldots \\
f_a &= f_a(\Phi)
\end{aligned}
$$

Inflaton one of these

particle

break supersymmetry spontaneously:

$$F^I = e^{\hat{K}/2} \hat{K}^{\bar{I}J} D_{\bar{J}} \bar{\hat{W}}$$

cosmology

String Cosmology II: Dark energy

- Some ideas
- None really attractive
- In the following, will *parameterize*, not explain

future discussions

(not much more later)

String Cosmology III: Inflation

Sep 2007

Searching for Inflation in Simple String Theory Models: An Astrophysical Perspective

Mark P. Hertzberg[1*], Max Tegmark[1], Shamit Kachru[2], Jessie Shelton[1,3], and Onur Özcan[1]
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[2] *Dept. of Physics and SLAC, Stanford University, Stanford, CA 94305, USA and*
[3] *Dept. of Physics and Astronomy, Rutgers University, Piscataway, NJ 08855, USA*

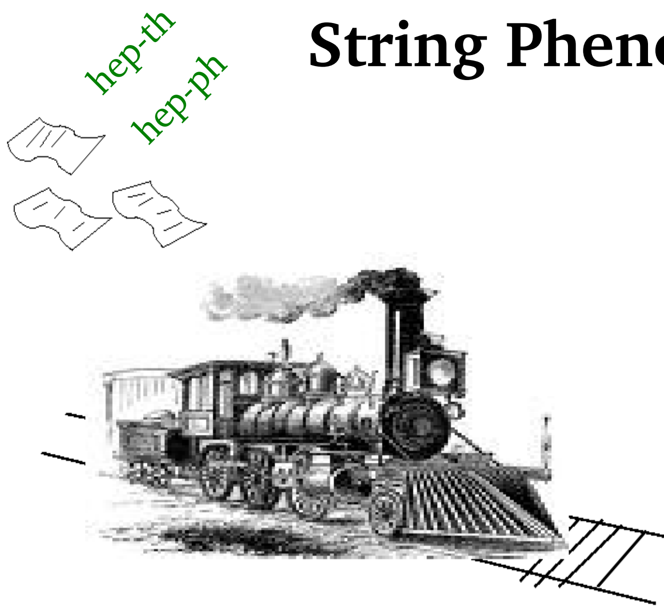
Attempts to connect string theory with astrophysical observation are hampered by a jargon barrier, where an intimidating profusion of orientifolds, Kähler potentials, *etc.* dissuades cosmologists from attempting to work out the astrophysical observables of specific string theory solutions from the recent literature. We attempt to help bridge this gap by giving a pedagogical exposition with detailed examples, aimed at astrophysicists and high energy theorists alike, of how to compute predictions for familiar cosmological parameters when starting with a 10-dimensional string theory action. This is done by investigating inflation in string theory, since inflation is the dominant

Generic "moduli": denote by Φ

Observable parameters: $n_{\rm s}(\Phi),\ r(\Phi),\ldots$
computable analytical functions of moduli
(though difficult)

(more later)

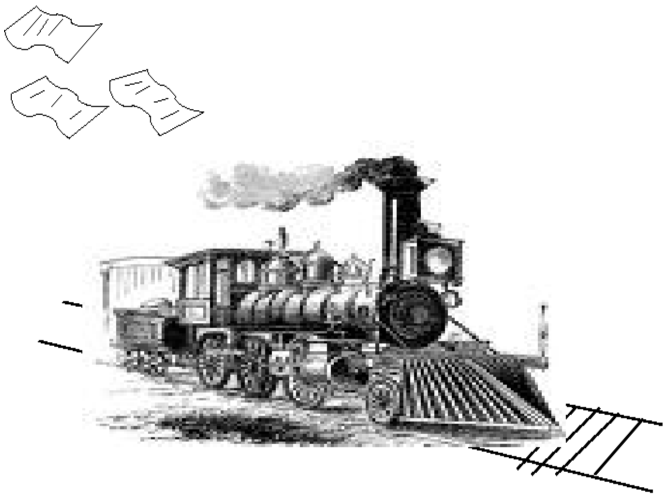
String Phenomenology: Pessimism vs. Optimism



"string-inspired scenarios"

?

String Phenomenology: Pessimism vs. Optimism

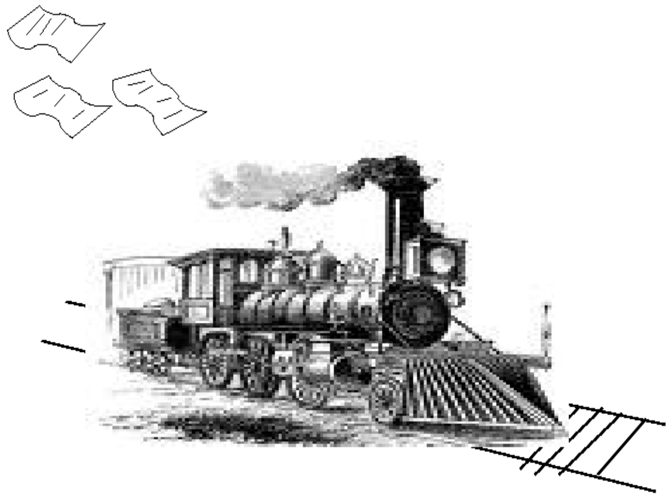


“string-inspired scenarios”

“match to experiment”

Go on to match
more experimental data

String Phenomenology: Pessimism vs. Optimism



"string-inspired scenarios"

Supersymmetry breaking?
Instability? (any direction in moduli space!)
Higher-derivative / quantum corrections?
Nonperturbative effects?

Montparnasse 1895

?

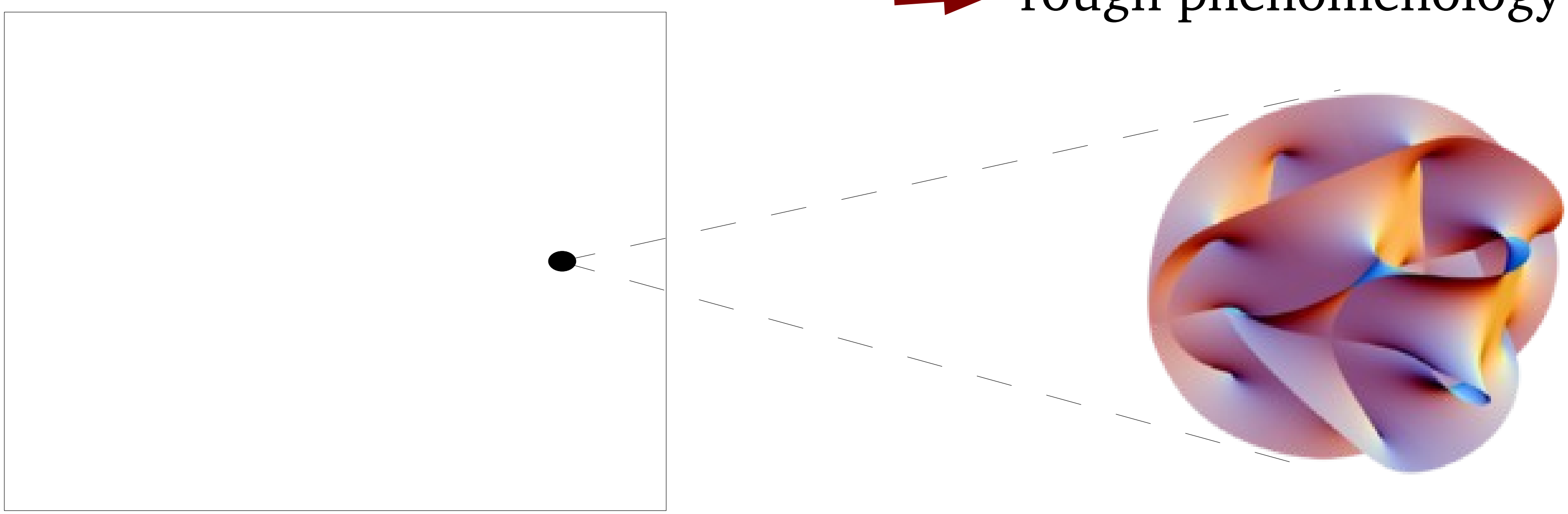
INCONSISTENCY
(examples later)

here: code for "concrete model"

Old-fashioned compactification

Candelas, Horowitz, Strominger, Witten '85
...

Topological properties
→ rough phenomenology in 4D

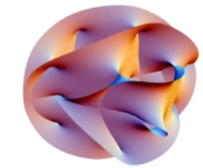


4D Minkowski space

Calabi-Yau manifold (N=1 SUSY)

Candelas, de la Ossa, He, Szendroi '07

Some issues with old-fashioned compactifications



- Tend to lose control when supersymmetry is broken

- The *moduli problem*: no "stabilization"
  (Want potential energy for moduli, but supersymmetry
  prevents it) ... maybe we can ignore this? (later)

- No cosmological constant

- Usually only "rough" phenomenology
  (need details to address e.g. flavor problem)

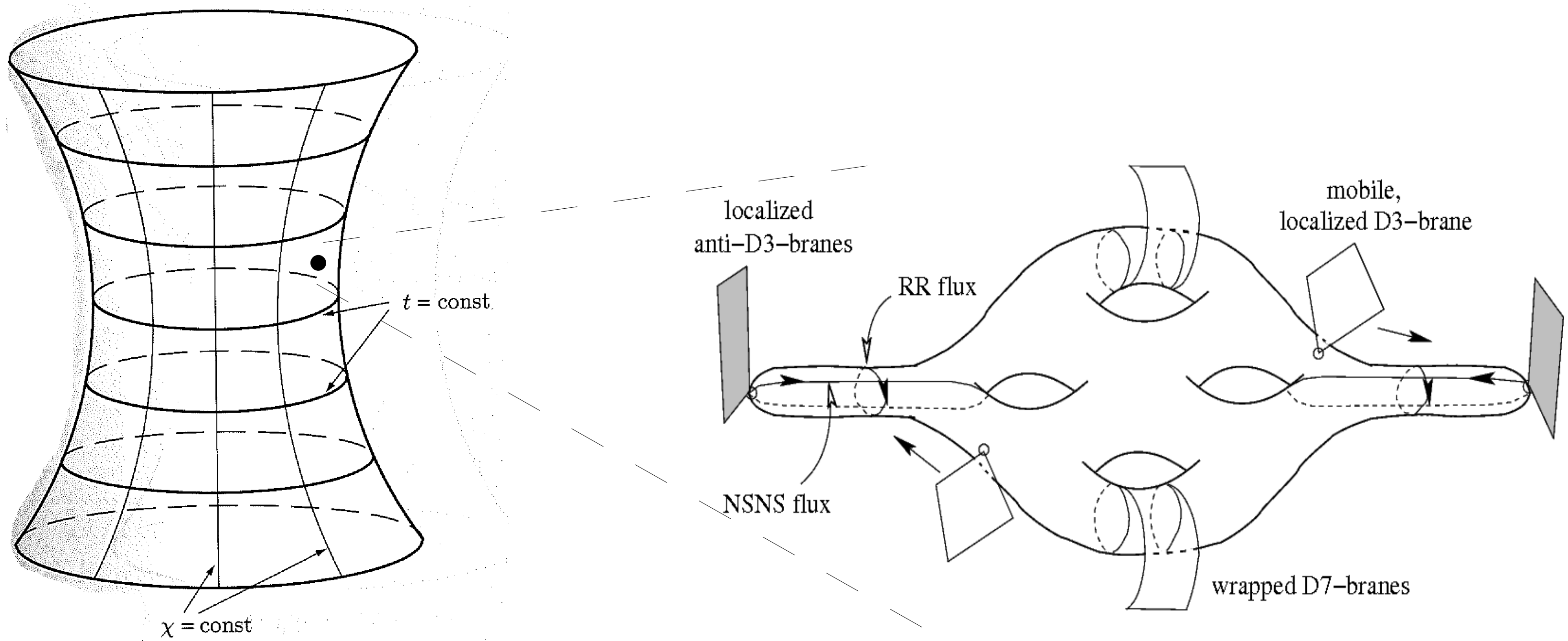
- No known Calabi-Yau metric! (only topological information)

- Explicit models can be ruled out! (if taken literally)
  (Ex. quintic gives 100 visible generations)

Uniqueness?

Warped compactification with D-branes

Giddings, Kachru, Polchinski '01
Kachru, Kallosh, Linde, Trivedi '03



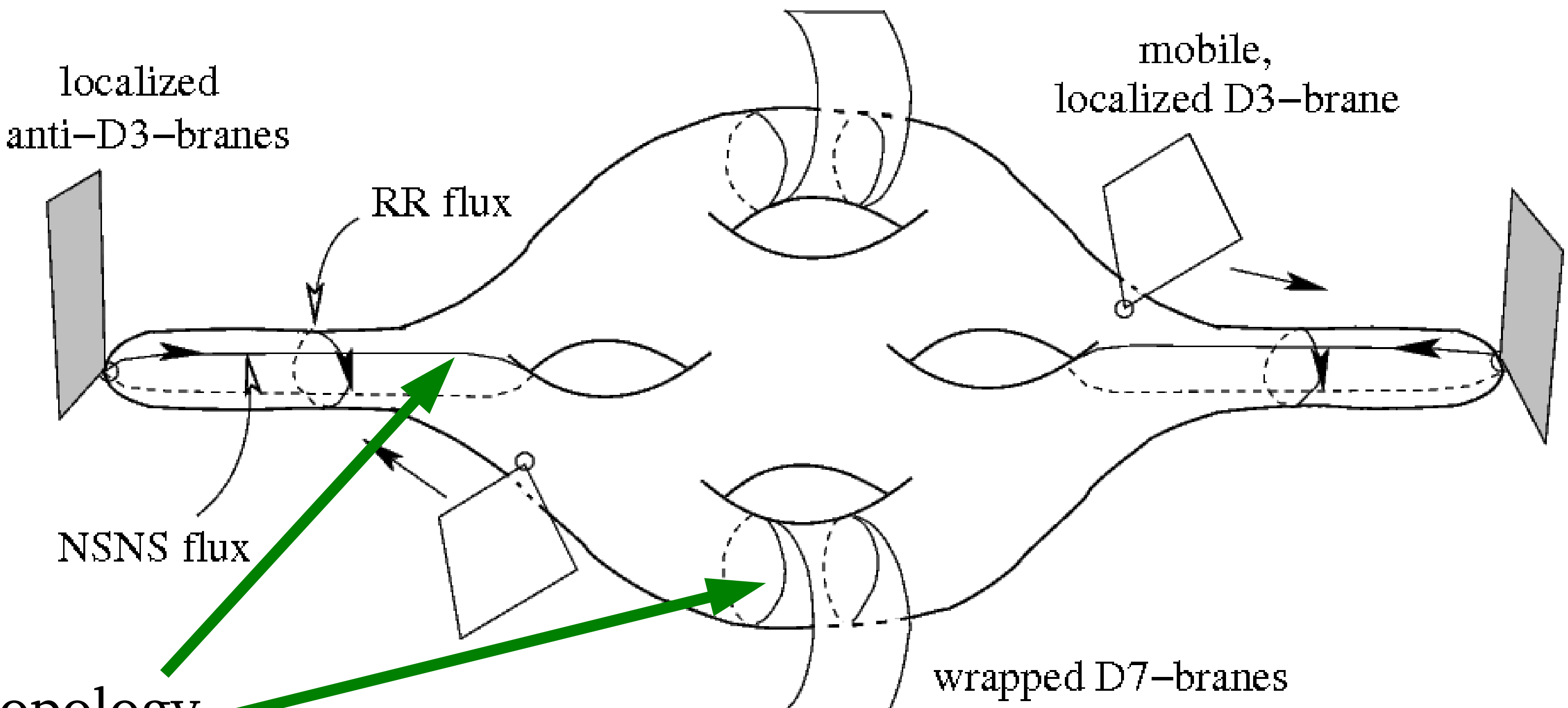
deSitter

Topology → stabilization (vacuum selection)

Curvature → dynamics (e.g. inflation)

The KKLT 6D internal space:
a Calabi-Yau orientifold with fluxes and warping

Giddings, Kachru, Polchinski '01
Kachru, Kallosh, Linde, Trivedi '03



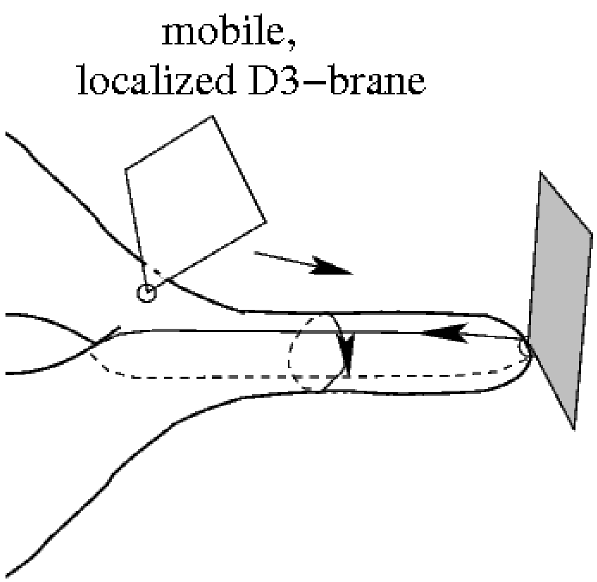
Topology

stabilization (vacuum selection) – more explicit a few slides later

The KKLT 6D internal space:
a Calabi-Yau orientifold with fluxes and warping

Giddings, Kachru, Polchinski '01
Kachru, Kallosh, Linde, Trivedi '03

“warped throats” (originally conceived as Randall-Sundrum type scenarios)
but: RS was 1D, this is 6D



Klebanov, Strassler '00

Explicit “warped throat” noncompact 6D Calabi-Yau metric!
Can consider dynamics in extra dimensions, e.g. D-brane inflation.

The KKLT 6D internal space:

a Calabi-Yau orientifold with fluxes and warping

Giddings, Kachru, Polchinski '01
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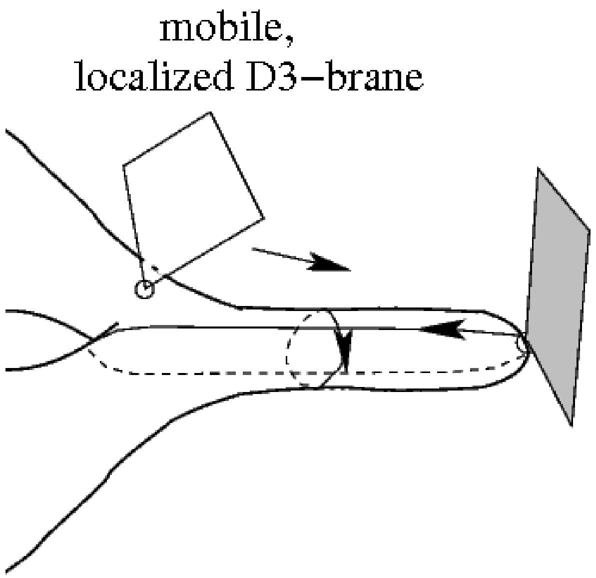


Kachru, Kallosh, Linde, Maldacena, McAllister, Trivedi '03

Simplest approximation to “warped throat”:
D3-brane moving in AdS_5.

Effective quantum field theory from string theory

(many exceptions and caveats here)

eg. Green-Schwartz-Witten

"Old" string perturbation theory: very rigid double expansion

- $E^2\alpha'$ expansion (energy vs. string length) "all or nothing!"
- g_s (string coupling) expansion = loop expansion
- String length $\sim$ Planck scale
- GUT unification

eg. Giddings, Kachru, Polchinski '01

"New" string perturbation theory: more flexible

- N_F flux quanta – new parameter (labels vacua)
- N_D number of D-branes – new parameter (cf. 1/N expansion)
- Include some nonperturbative effects (estimates, e.g. A)
- String length only restricted by phenomenology
- Often nonstandard gauge unification

In both cases, can only rarely *truncate* perturbation theory
(but only then is it really interesting)

KKLT $D=4$, $N=1$ effective theory: vacuum selection

Moduli Φ from earlier : break up into S, T, U

$$
\begin{aligned}
K &= -\ln(S+\bar{S}) - 2\ln\mathcal{V}(T_i+\bar{T}_i) + K^U \\
W &= W_{\text{flux}} + W_{\text{np}}
\end{aligned}
$$

6D overall volume
as function of parameters T
("Kähler moduli")

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

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

Now stabilize Kähler moduli T

Stabilize Kähler moduli in KKLT

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

Cremmer, Ferrara, Kounnas, Nanopoulos '83

For K given on previous slide (*leading order*), it so happens that

$$G^{\bar{\jmath} i} K_{\bar{\jmath}} K_i = 3$$

so potential vanishes, T is not stabilized ("no-scale model")

Details: e.g appendix of M.B., Haack, Pajer '07

Beyond leading order: broken by all kinds of corrections

In KKLT, by nonperturbative corrections to W

Stabilize Kähler moduli in KKLT

$$V = (\text{terms that} \to 0 \text{ as } W_{\rm np} \to 0) + e^K (G^{\bar{j}i} K_{\bar{j}} K_i - 3)|W|^2$$

Point: In KKLT, all moduli are stabilized.
This also means parameters in the effective theory are all connected. We will see an example of this.

Beyond leading order: broken by all kinds of corrections
In KKLT, by nonperturbative corrections to *W*

Technical work left to compute
KKLT effective action parameters from string theory

- Ramond-Ramond fluxes in string perturbation theory
- Supersymmetry breaking in string theory
- Nonperturbative superpotentials
- “Uplift” details (scale of inflation? dark energy?)
- Putting it all together

many different issues,
e.g. “tadpole problem”

Truly “top-down” approach

One lesson made explicit by KKLT program

Moduli stabilization is not an afterthought! ("add later...")

Example: compute soft supersymmetry breaking terms M, m, A, ...
from flux superpotential alone

stabilize T → restores supersymmetry!
(M, m, A, ... $= 0$)

String phenomenology needs moduli stabilization

Some drawbacks with original KKLT

real part of Kähler moduli

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

balance
to stabilize

- only works for limited range of *a, W, A*
- volume not stabilized big (not really a "problem", but see later)
- supersymmetry breaking "at the end" (least understood part)
- "two-step stabilization" sometimes fails (i.e. not algorithmic)

The “Large-Volume Scenario” (LVS)

Balasubramanian, Berglund, Conlon, Quevedo '05
Conlon, Quevedo, Suruliz '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!)

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

$$\mathcal{V} = \tau_{\rm b}^{3/2} - f(\tau_{\rm s})$$

special Calabi-Yau

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

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

α'
(higher-derivative correction)

LVS Kähler moduli stabilization

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

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

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

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

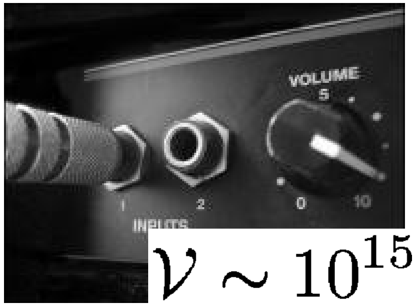
$$\frac{\partial V}{\partial \tau_{\rm s}} = 0 \quad \Rightarrow \quad X = \frac{g(\tau_{\rm s})}{\mathcal{V}}$$

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

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

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

dial volume!



$\mathcal{V} \sim 10^{15}$

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

Why is big good?

Conlon, Quevedo, Suruliz '05

- 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

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

- TeV supersymmetry
- QCD axion (strong CP problem)
- neutrino masses

connections

Sample calculation: Gaugino Masses From LVS

Conlon, Abdussalam, Quevedo, Suruliz '06

Assume MSSM

$$M_a = \frac{1}{2\,\mathrm{Re}\,f_a}\sum_I F^I \partial_I f_a$$

$$F^{\tau_s} = e^{K/2}(G^{\bar{s}s}\partial_{\bar{s}}\bar{W} + (G^{\bar{s}s}K_{\bar{s}} + G^{\bar{b}s}K_{\bar{b}})\bar{W})$$

$$= 2\tau_s e^{K/2}\bar{W}_0\left(\left(1-\frac{3}{4a\tau_s}\right)-1+\ldots\right)$$

$$|M_s| \sim \frac{m_{3/2}}{\ln(1/m_{3/2})}\left(1+\frac{(\ldots)}{\ln(1/m_{3/2})}+\ldots\right)$$

Gaugino masses suppressed by ~ 30 compared to gravitino mass.

"Mirror mediation"

“Mirror Mediation” in LVS

Conlon '07 (Oct 9)

- Flavor structure from only one kind of modulus (here *U*)

$$m^2_{\alpha\beta} = m^2\delta_{\alpha\beta} + \frac{f(U)}{M} X_{\alpha\beta} + \mathcal{O}\left(\frac{1}{M^2}\right)$$

mass threshold

- New nonrenormalizable couplings at each mass threshold *M* (typical)

- Hard to compute *f(U)*, but not unthinkable

LVS and dark matter?

Conlon, Quevedo '07

- compute *leading-order* couplings, masses and lifetimes

	Light modulus χ		Heavy Modulus Φ	
Mass	$\sim m_{3/2}\left(\frac{m_{3/2}}{M_P}\right)^{\frac{1}{2}} \sim 2\text{MeV}$		$2\, m_{3/2} \ln(M_p/M_{3/2}) \sim 1200\text{TeV}$	
Matter Couplings	M_P^{-1}	(electrons)	m_s^{-1}	
	$\left(M_P \ln\left(\frac{M_P}{m_{3/2}}\right)\right)^{-1}$	(photons)		
Decay Modes				
$\gamma\gamma$	Br ~ 0.025,	$\tau \sim 6.5 \times 10^{25}$s	Br $\sim \mathcal{O}(1)$,	$\tau \sim 10^{-17}$s
e^+e^-	Br ~ 0.975,	$\tau \sim 1.7 \times 10^{24}$s	Br $\sim \mathcal{O}(1)$,	$\tau \sim 10^{-17}$s
$q\bar{q}$	inaccessible		Br $\sim \mathcal{O}(1)$,	$\tau \sim 10^{-17}$s
$\psi_{3/2}\psi_{3/2}$	inaccessible		Br $\sim 10^{-30}$,	$\tau \sim 10^{13}$s

Table 1: The properties of the two moduli and their decay modes. The lifetimes quoted are for sample masses of $m_\Phi = 1200$TeV and $m_\chi = 2$MeV, with a string scale of $m_s = 10^{11}$GeV and a gravitino mass of 20 TeV. The scale of soft terms here is $m_{3/2}/\ln(M_P/m_{3/2}) \sim 500$GeV.

LVS = very practical, explicit model. Too good to be true?

ignored in LVS

Consistency Conditions:

String Length vs. D-Brane Loop Corrections

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

dimensional analysis:

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

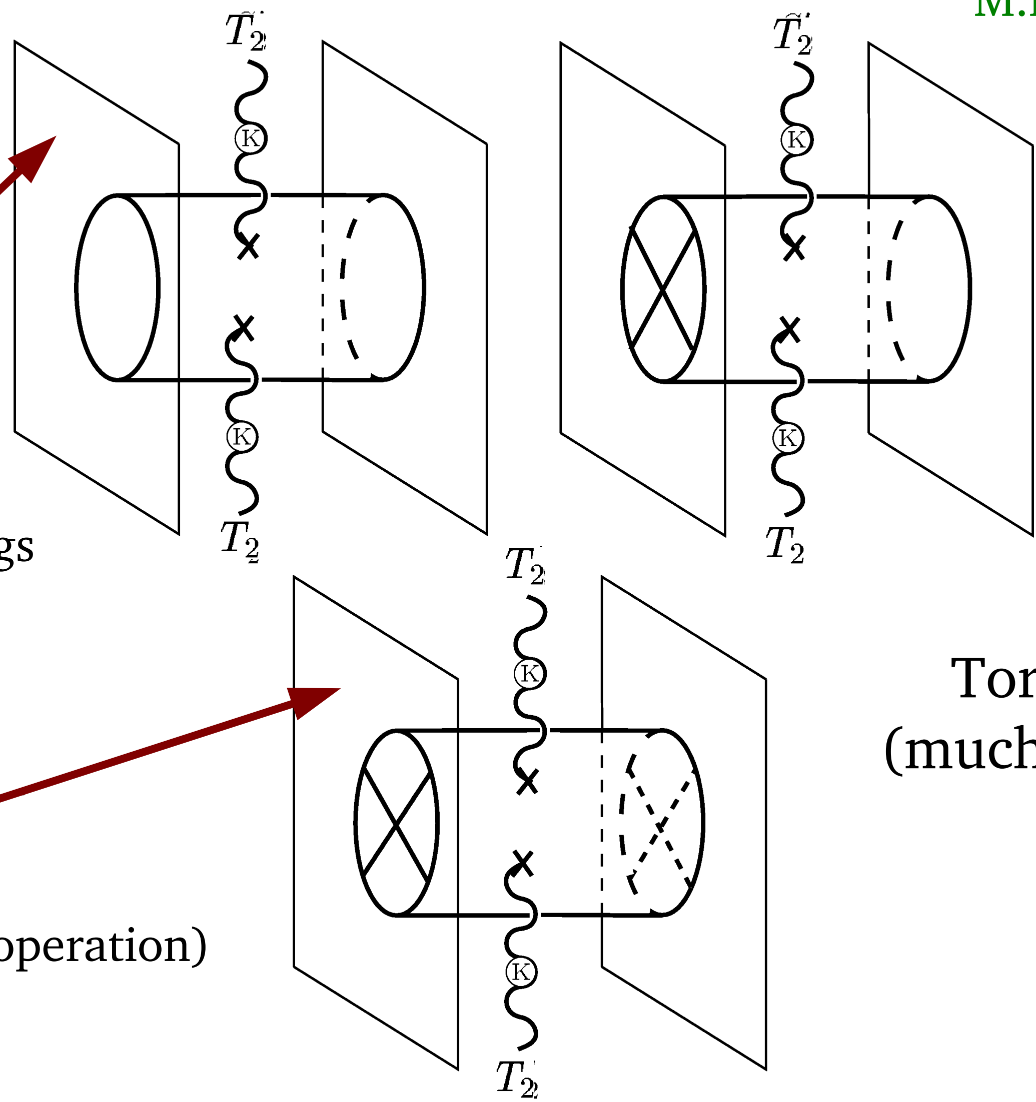
Cancellation in scalar potential (to be shown):

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

should consider D-brane corrections in LVS!

D-Brane Corrections to Kähler potential

M.B., Haack, Körs '05



D-brane
(where open strings
can end)

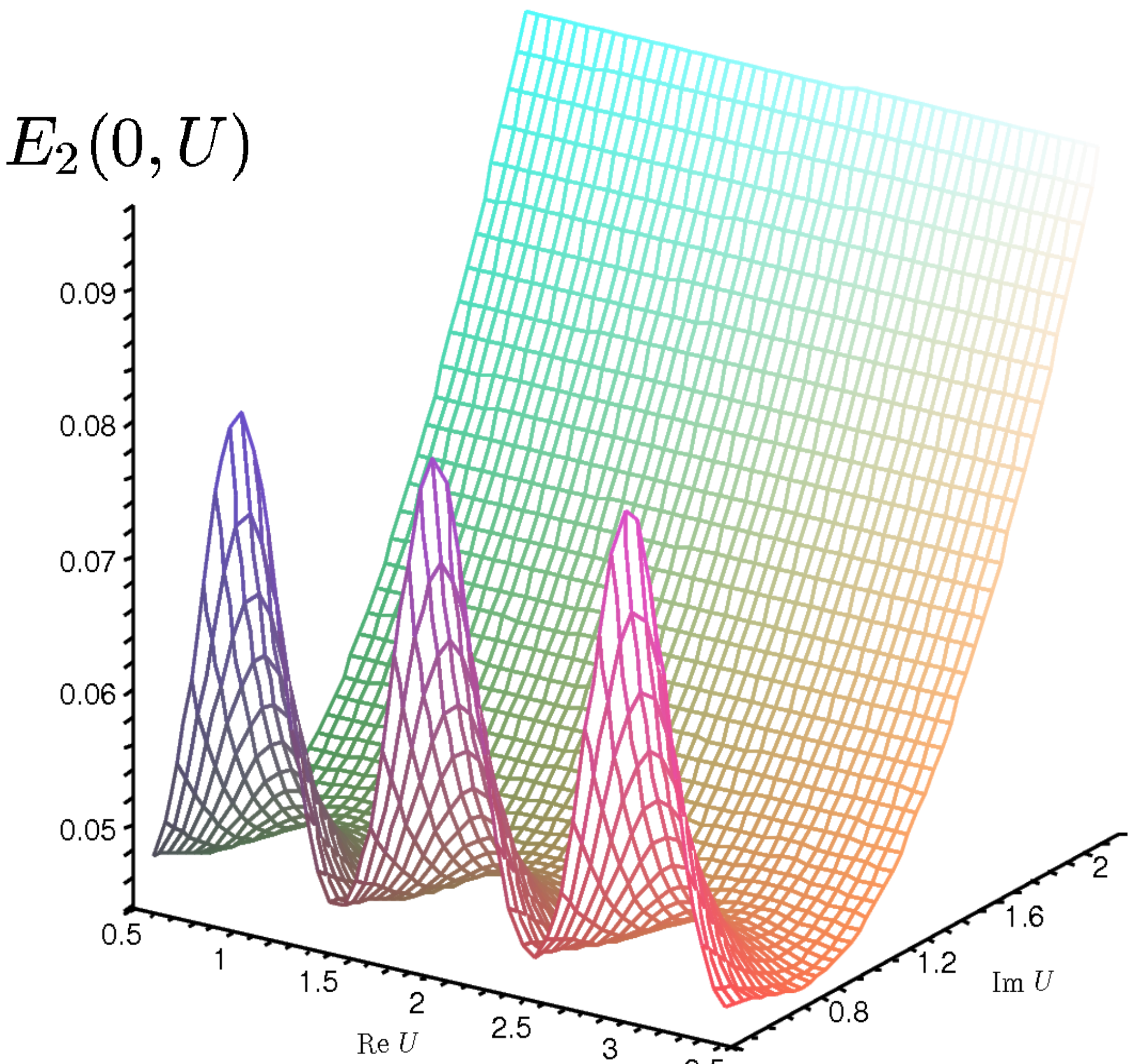
Orientifold plane
(fixed plane of
worldsheet parity operation)

Toroidal orientifold
(much simpler than LVS)

Final answer:

s=2 case of $$E_s(\phi, U) = {\sum_{m,n}}' \frac{U_2^s}{|n+mU|^{2s}} e^{2\pi i \frac{\phi(n+m\bar{U}) - \bar{\phi}(n+mU)}{U+\bar{U}}}$$

De-mystifying generalized holomorphic Eisenstein series



(This is *f(U)* that appears in loop correction to Kähler potential)

Integrate loop-corrected Kähler metric to get Kähler potential

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

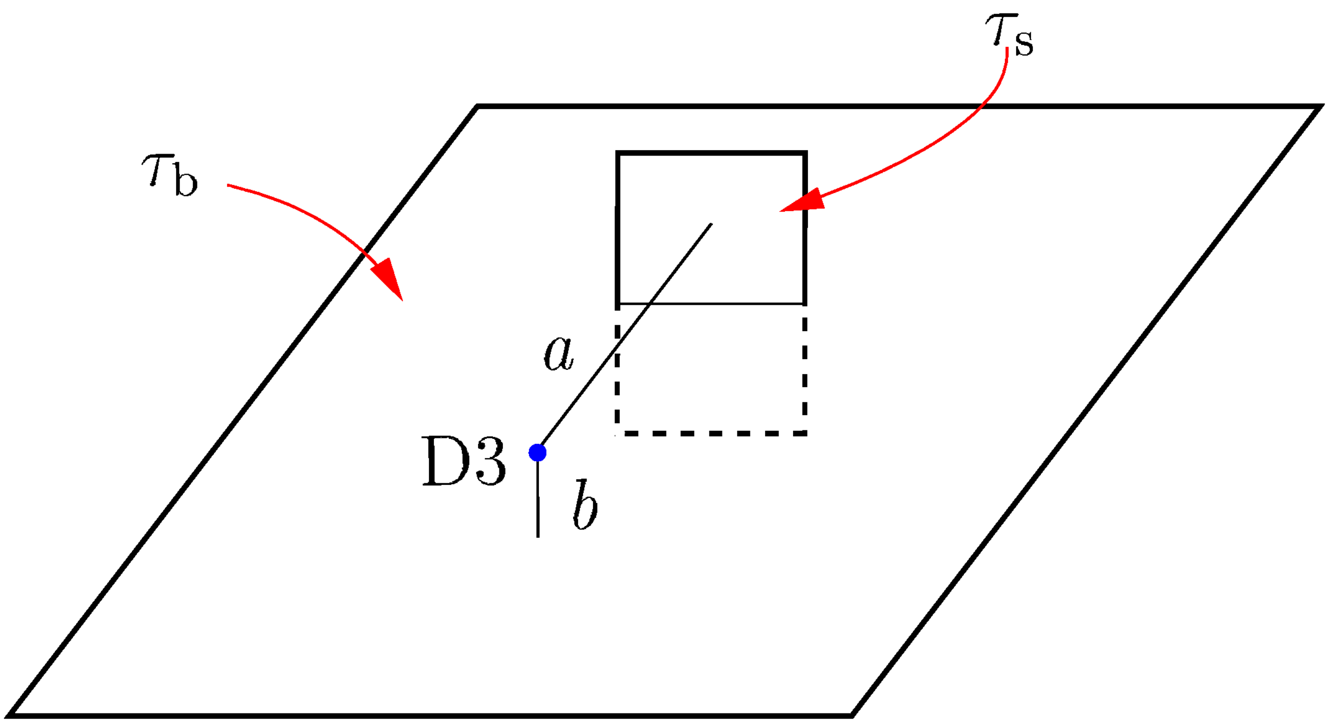
this is what we did on previous 2 slides

for experts:

"Kähler puzzle": OK for *T*, but what about the D3-brane scalar, is this consistent with D7-brane gauge coupling loop corrections?

In other words, we are integrating a PDE – are the integrability conditions due to *other* loop corrections satisfied? (Answer at the end)

Generalizing to LVS (here: contribution from KK states)



M.B., Haack, Pajer '07

Based on results in toroidal orientifolds,
guess the important aspects of results in LVS
(obviously, much work left to do here!)

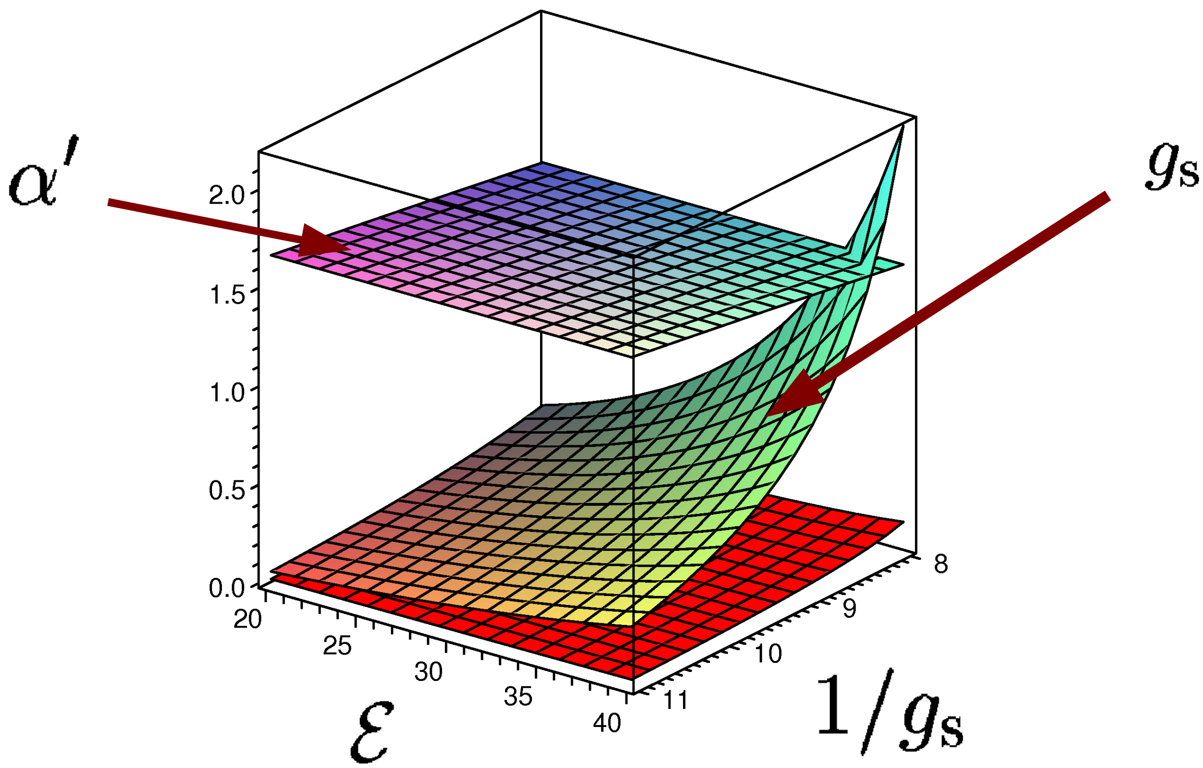
LVS + Loop Corrections (specific model)

$$
\begin{aligned}
K &= -\ln(2S_1) - 2\ln\mathcal{V} + K^U \\
&\quad -\tilde{\xi}\frac{S_1^{3/2}}{\mathcal{V}} + \frac{\sqrt{\tau_{\mathrm{b}}}\mathcal{E}_{\mathrm{b}}^{(\mathrm{K})}}{S_1\mathcal{V}} + \frac{\sqrt{\tau_{\mathrm{s}}}\mathcal{E}_{\mathrm{s}}^{(\mathrm{K})}}{S_1\mathcal{V}}
\end{aligned}
$$

$$
V_3 = \frac{3e^{K^U}|W_0|^2}{8\mathcal{V}^3}\left(S_1^{1/2}\tilde{\xi} + \frac{4(\mathcal{E}_{\mathrm{s}}^{(\mathrm{K})})^2\sqrt{\tau_{\mathrm{s}}}}{S_1^2(\sqrt{2}S_1\tau_{\mathrm{s}} - 3\mathcal{E}_{\mathrm{s}}^{(\mathrm{K})})}\right)
$$

- Some magical cancellations (“extended no-scale”)
- Can now minimize full, corrected potential
- Perturbative term depends on more moduli now

Scalar Potential *V* with String Loop Corrections



For *this type* of Calabi-Yau, loop corrections *can* be neglected (in *V*)

Generalization to KKLT, LVS?
Ex: loop-corrected nonperturbative superpotential

M.B., Haack, Körs '04
Giddings, Maharana '05
Baumann, Dymarsky, Klebanov, Maldacena, McAllister, Murugan '06

$$\Delta\left(\frac{1}{g^2}\right) \sim \frac{1}{8\pi^2}\ln\left|\vartheta_1(\phi,U)\right|^2 + \ldots$$

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

$$W = \exp(-\rho - \frac{1}{8\pi^2}\ln\vartheta_1(\phi,U) + \frac{1}{\pi^2}\ln\eta(U))$$

Gauge coupling correction $\sim$ potential for D3-brane scalars (inflaton)

Generalization to KKLT, LVS?
Ex: loop-corrected nonperturbative superpotential

M.B., Haack, Körs '04
Giddings, Maharana '05
Baumann, Dymarsky, Klebanov, Maldacena, McAllister, Murugan '06

$$\Delta\left(\frac{1}{g^2}\right) \sim \frac{1}{8\pi^2} \ln|\vartheta_1(\phi, U)|^2 + \ldots$$

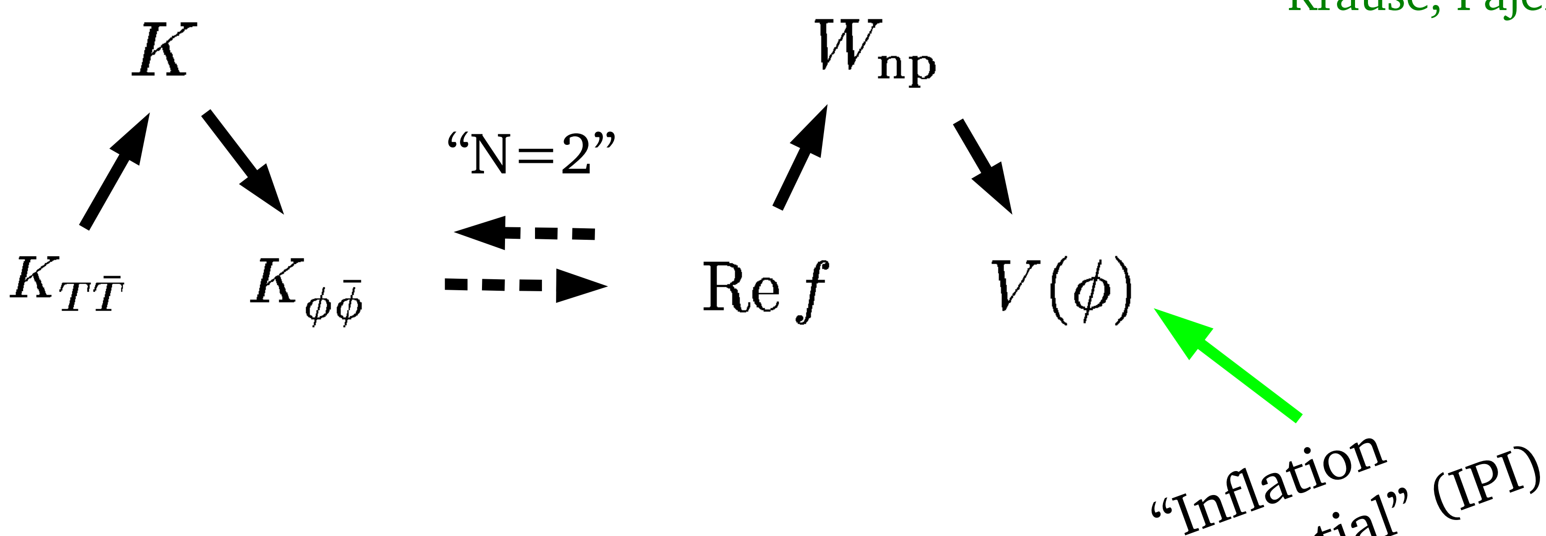
Realization: this is also the scalar propagator on a 2-torus transverse to the D7-branes!

"Green's function method":
integrate propagator over 4-cycle wrapped by D7-branes,
was applied to warped throat metrics
(curiously: AdS/CFT intuition useful!)

D3-brane potentials:

MSSM flavor structure <-> inflaton potential?

Baumann, Dymarsky, Klebanov, McAllister '07
Krause, Pajer '07



Dependence on S, T_i, U_α, ϕ

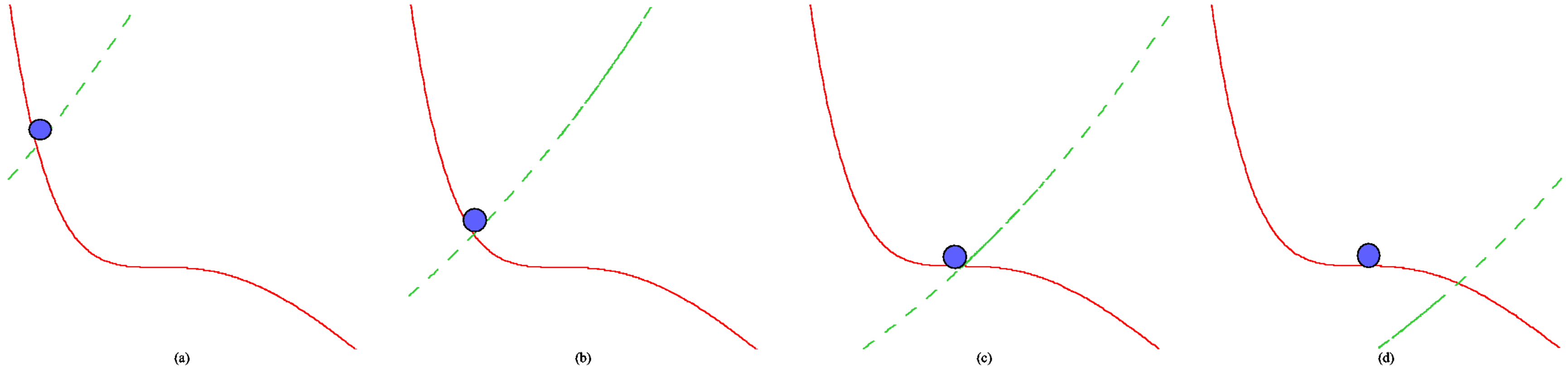
Relate particle physics (e.g. gaugino masses) and cosmology (e.g. inflation)!

Many technical aspects to be sorted out... (e.g. twisted strings)

Inflection point inflation

..., Itzhaki, Kovetz '07 (Aug)

In the only class of models where the D3-brane potential is currently known, the inflaton is massless!



Work in progress – but shows one aspect of string models: maybe not unique, but very restrictive!

for experts:

Resolution of Kähler puzzle

(gauge coupling vs. Kähler metric integrability)

M.B., Haack, Körs '05

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

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

Fits with gauge coupling corrections

Summary

- Much work left to achieve safe and interesting *stabilized* models
- LVS is promising: LHC phenomenology, dark matter, etc.

  details: VR-foass lecture series!
- Our LVS consistency check ("jumping through loops") OK
- LVS won't work for generic (?) Calabi-Yaus --- but maybe cousin?
- D-brane inflation: progress on computing potentials

  (work in progress w. M. Haack)

Future directions

- Instead of LVS: purely perturbative stabilization? M.B., Haack, Körs '05
- "Bottom-up": Effective action analysis: BMSSM Dine, Seiberg, Thomas '07
- "Top-down":Further study of effective action as function of moduli details: VR-foass lecture series!
- "Green function method"? Much more general models
- D-Brane inflation: IPI, what next? Hertzberg, Tegmark, Kachru et al '07
- Inflation and the renormalization group? (w. M. Haack)
- Strong time dependence? cf. Balasubramanian, Hassan et al '02
- Dark energy models? (Journal club w. S. Hofmann at Nordita)