D-terms and F-terms form D7-brane fluxes

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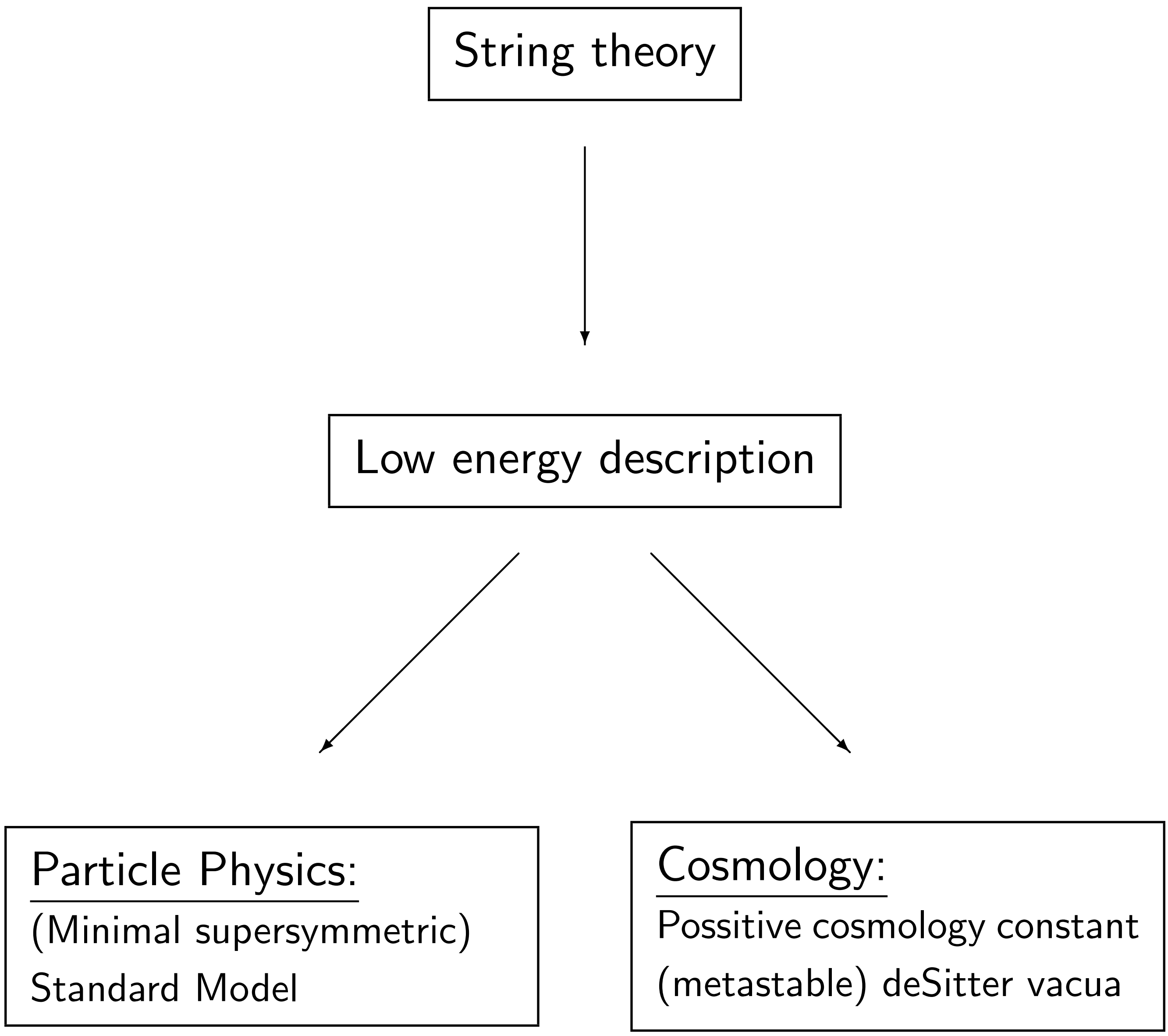
String Phenomenology – June 2005

Motivation


String theory
Low energy description
Particle Physics:
(Minimal supersymmetric)
Standard Model
Cosmology:
Possitive cosmology constant
(metastable) deSitter vacua

Motivation

- D-brane scenarios in Type II string theories

  see Angel Uranga's talk

- In the following: Focus on low energy effective action of D7-brane in Calabi-Yau orientifold compactifications

  Lüst, Reffert, Stieberger; Cámara, Ibáñez, Uranga; Louis, HJ

  - Standard model on D7-branes

    Lüst, Reffert, Stieberger; Cámara, Ibáñez, Uranga; Ibáñez

  - Hidden sector on D7-branes

    Kachru, Kallosh, Linde, Trivedi; Denef, Douglas, Florea; Görlich, Kachru, Tripathy, Trivedi

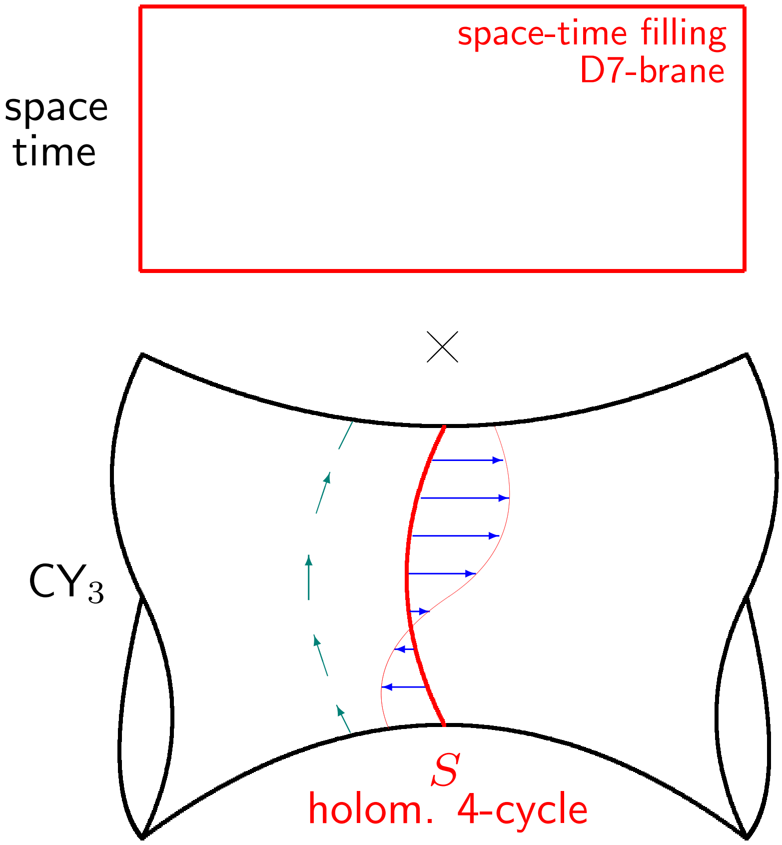
  - Internal D7-brane fluxes to generate metastable deSitter vacua

    Burgess, Kallosh, Quevedo

  - Discuss flux-induced D- and F-terms of D7-brane fluxes

    Lüst, Mayr, Reffert, Stieberger; Berglund, Mayr; Louis, HJ

D7-brane spectrum



- Massless bosonic & fermionic spectrum yields:

$\mathcal{N}=1$ multiplets	fields	multiplicity
vector	(A_μ, λ)	1
chiral	(ζ^A, χ^A)	$h^{2,0}(S)$
chiral	(a_I, χ_I)	$h^{0,1}(S)$

- Stack of N D7-branes:
  Multiplets transform in the adjoint of $U(N)$

Bulk: Type IIB Calabi-Yau orientifold

- Consistency: D-branes require negativ tension objects

Brane world scenarios D3/D7-branes	cancel → Tadpoles	Orientifold planes O3/O7-planes

- IIB Calabi-Yau orientifolds: Mod out $\mathbb{Z}_2$ action $\mathcal{O}$.
  For O3/O7-planes:

$$\mathrm{H}^{p,q}(CY_3) = \mathrm{H}_+^{p,q}(\mathrm{CY}_3) \oplus \mathrm{H}_-^{p,q}(\mathrm{CY}_3)$$

$$J \in \mathrm{H}_+^{1,1}(\mathrm{CY}_3) \qquad \Omega \in \mathrm{H}_-^{3,0}(\mathrm{CY}_3)$$

Acharya, Aganagic, Hori, Vafa; Brunner, Hori

- Low energy effective theory on $\mathrm{CY}_3/\mathcal{O}$

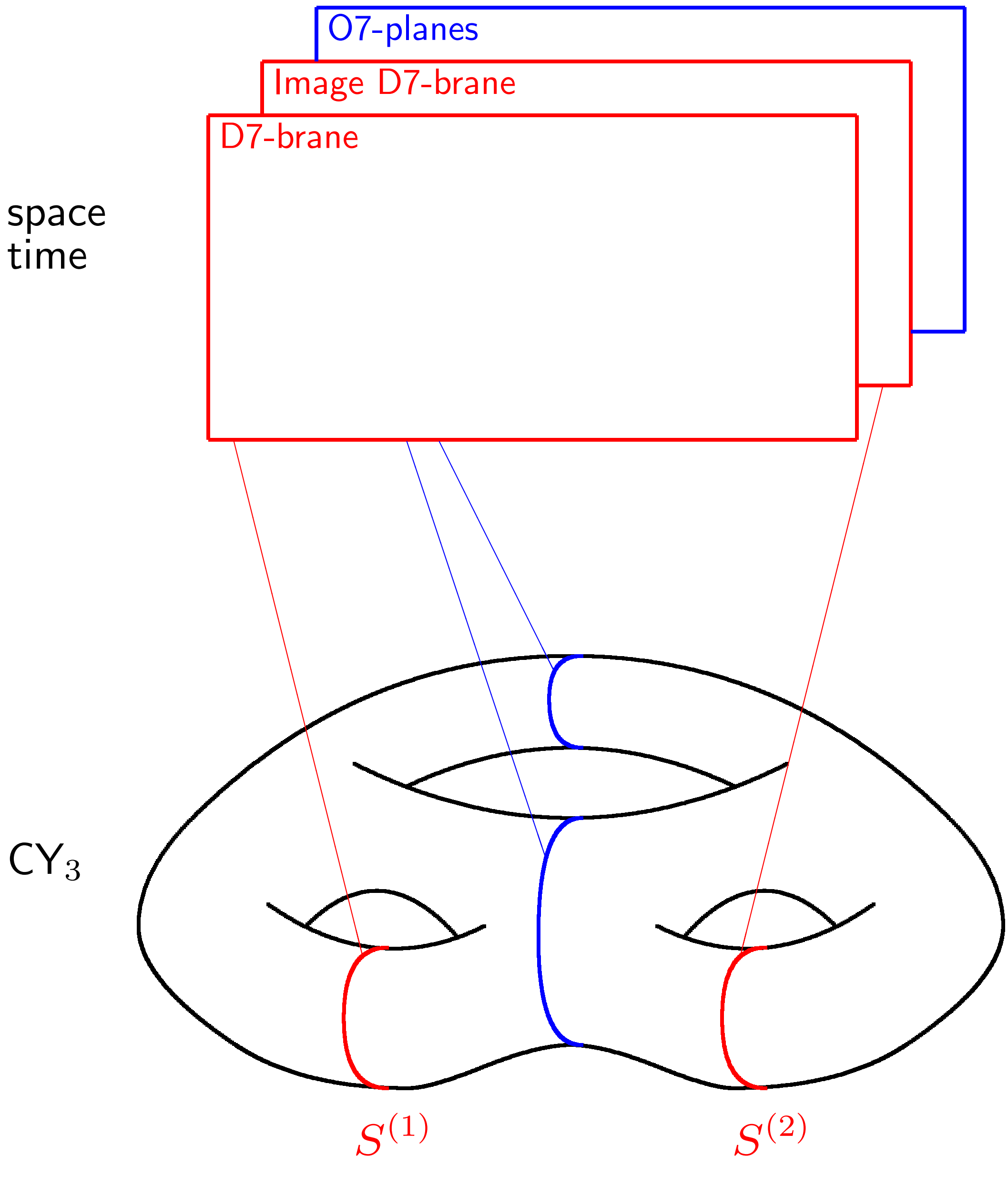
Type IIB on CY_3 $D = 4$, $\mathcal{N} = 2$ SUGRA	$\mathcal{O}$ inv. → spectrum	Type IIB on $\mathrm{CY}_3/\mathcal{O}$ $D = 4$, $\mathcal{N} = 1$ SUGRA

D'Auria, Ferrara, Trigiante; Grimm, Louis

- $D = 4$, $\mathcal{N} = 1$ bulk Calabi-Yau orientifold spectrum

multiplet	multiplicity	4D-fields	10D-fields
gravity	1	$g_{\mu\nu}$	g_{MN}
vector	$h_+^{2,1}$	$V^{\hat{\alpha}}$	$C^{(4)}$
chiral	$h_-^{2,1}$	$z^{\tilde{a}}$	Ω
	$h_-^{1,1}$	G^a	$B, C^{(2)}$
	$h_+^{1,1}$	T_α	$J, C^{(4)}$
	1	S	$\phi, C^{(0)}$

D7-brane Calabi-Yau orientifolds



$S_+ = S^{(1)} + S^{(2)}$ $\qquad$ $S_- = S^{(1)} - S^{(2)}$

D7-brane action

- Dirac-Born-Infeld & Chern-Simons action:

$$S^{\text{sf}}_{\text{DBI}} = -\mu_7 \int_{\mathcal{W}} d^8\xi \, e^{-\phi} \sqrt{-\det\left(\varphi^*(g+B) - 2\pi\alpha' F\right)}$$

$$S_{\text{CS}} = \mu_7 \int_{\mathcal{W}} \varphi^* \Big(\sum_q C^{(q)} e^B \Big) \, e^{-2\pi\alpha' F}$$

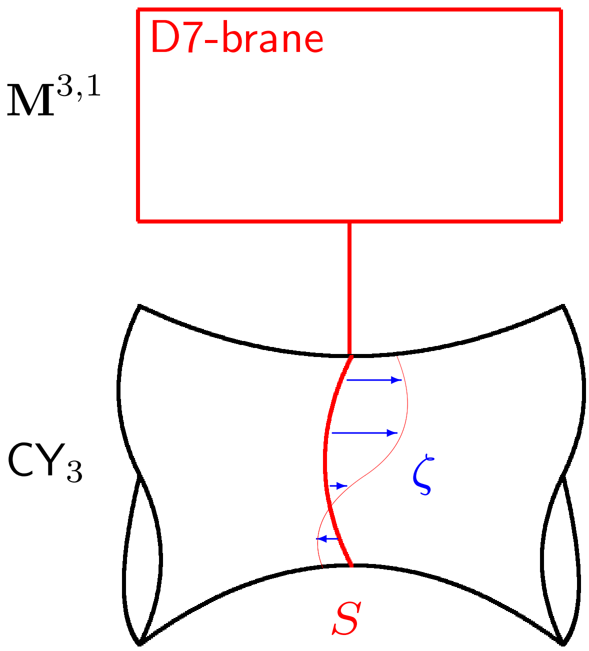
$\mu_7, \ \alpha'$ Coupling constants

$\varphi : \mathcal{W} \hookrightarrow M^{9,1}$ Dynamics of the D7-brane

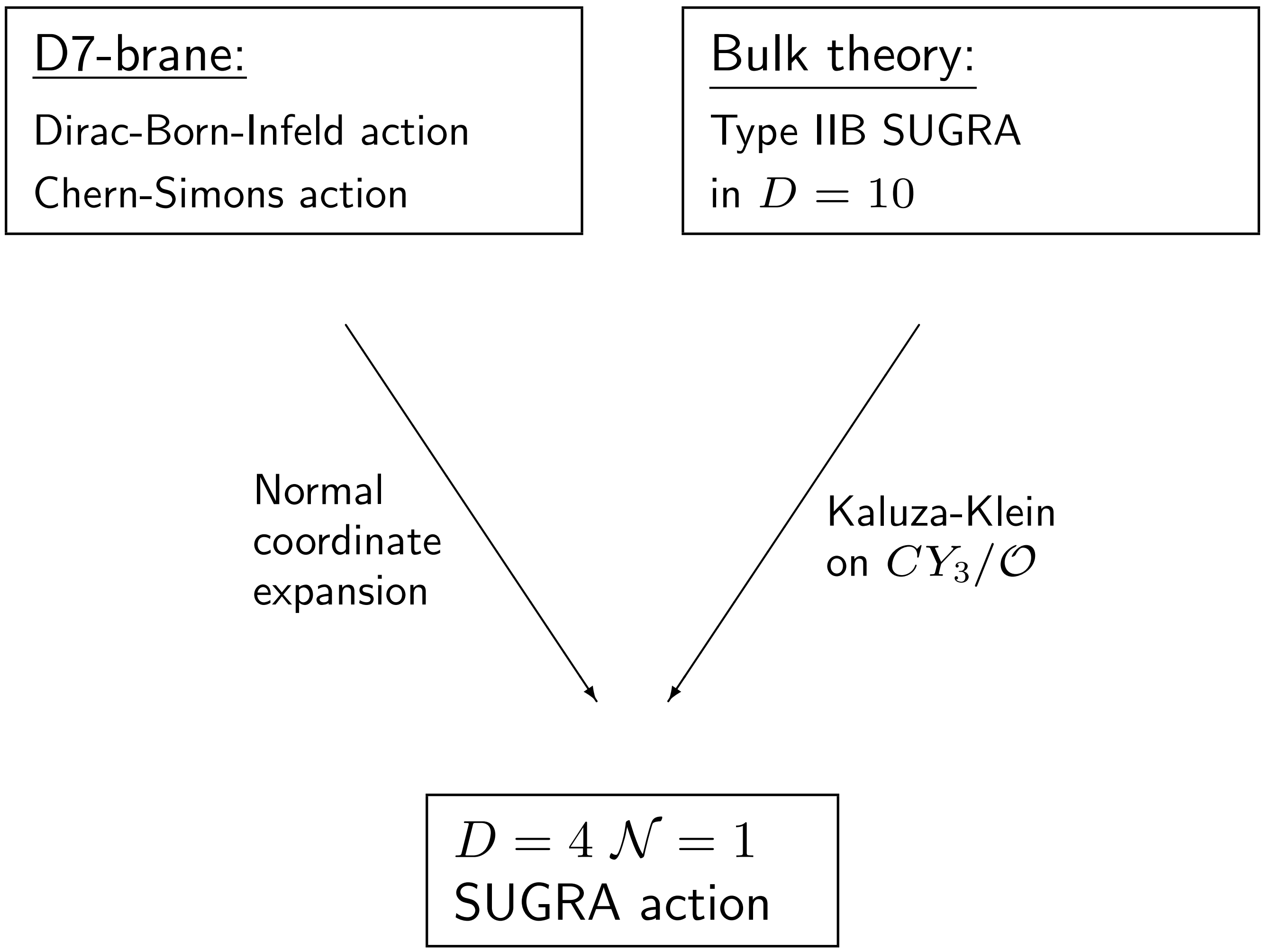
- Dynamics of fermionic fields:

$g, \ B, \ C^{(q)}$, $\varphi : \mathcal{W} \hookrightarrow M^{9,1}$ $\xrightarrow[\text{superembedding}]{\text{superfields}}$ $\hat{g}, \ \hat{B}, \ \hat{C}^{(q)}$, $\hat{\varphi} : \mathcal{W} \hookrightarrow M^{9,1|2}$

- (Super-)Normal coordinate expansion:



$D = 4$ Effective action



$\mathcal{N}=1$, $D=4$ SUGRA Lagrangian

- General $\mathcal{N}=1$, $D=4$ SUGRA Lagrangian:

K	Kähler potential
f	gauge kinetic couplings
V_{F}, V_{D}	F-term and D-term scalar potential

- Generic Kähler potential for D-branes in IIB orientifolds:

$$K = -\ln\left(-i\int_Y \Omega\wedge\bar{\Omega}\right) - \ln\left(-i\left(\tau-\bar{\tau}\right)\right) - 2\ln\mathcal{K}$$

Ω	holom. three-from of CY_3
τ	type IIB dilaton
$\mathcal{K}$	volume of Y

- Definition of the chiral variables
(complex structure of the target space manifold)

$$\tau(S,\zeta) = S + \zeta\cdot\bar{\zeta}$$

$$\Omega = \Omega(z)$$

$$\mathcal{K} = \mathcal{K}(S,G,T,\zeta,a)$$

D7-brane gauge theory

- Gauge kinetic function of D7-brane $U(1)$ gauge theory:

$$f^{\text{D7}} \sim \mu_7 \, T_\Lambda \qquad\qquad \text{Re}\, T_\Lambda \sim \text{Volume of } S$$

- Bulk SUGRA action has a set of global shift symmetries:

$$G^a \longrightarrow G^a + \theta^a$$

- Charged chiral field from a Green-Schwarz term:

Green-Schwarz term in D7-brane action $\tilde{c}_P^{(2)} \wedge F$	eliminate $\longrightarrow$ 2-form fields	charged chiral field trans. non-linearly G^P

- One charged chiral field transforming non-linearly:

$$\nabla G^P = \text{d}G^P - 4\mu_7 A$$

- D-term for the charged field G^P:

$$\text{D} \sim \frac{1}{\mathcal{K}} \int_{S_-} J \wedge B \qquad\qquad V_{\text{D}} \sim \frac{1}{\text{Re}\, T_\Lambda} \text{D}^2$$

- Note $\text{D} = 0$ is a solution with $B = 0$.

D7-brane background fluxes I

Lüst, Mayr, Reffert, Stieberger; Berglund, Mayr; Louis, HJ

Background fluxes for the field strength $F_{\mu\nu}$ of the $U(1)$ gauge theory on the worldvolume of the D7-brane.

D7-brane
background fluxes

Fluxes f:

harmonic forms inherited from the ambient space

$$Q^{\mathrm{D}} \sim \int_{S_-} J \wedge f$$

Fluxes $\tilde{f}$:

harmonic forms not inherited from the ambient space

$$\tilde{Q}^{\mathrm{D}} \sim \int_{S_-} J \wedge \tilde{f}$$

$$\tilde{Q}^{\mathrm{F}}_A \sim \int_{S_+} s_A \wedge \tilde{f}$$

$$A = 1, \dots, h^{2,0}$$

D-terms and F-terms determined from:

$$\mathcal{L}^{\mathcal{N}=1}_{\text{Couplings}} = e^{K/2}\left(\mathcal{D}W \chi \sigma^\mu \bar{\psi}_\mu + \mathcal{D}\bar{W} \bar{\chi} \bar{\sigma}^\mu \psi_\mu\right) + \mathrm{D}\, \psi_\mu \sigma^\mu \bar{\lambda} - \mathrm{D}\, \bar{\psi}_\mu \bar{\sigma}^\mu \lambda + \dots$$

D7-brane background fluxes II

- Computation of fermionic terms:

$$\mathsf{D} \to \mathsf{D} - Q^{\mathsf{D}} - \tilde{Q}^{\mathsf{D}} \quad \Rightarrow \quad \mathsf{D} \sim \int_{S_-} J \wedge \left(B - f - \tilde{f}\right)$$

$$W_{S_+} \sim \tilde{Q}^{\mathsf{F}}_A \zeta^A \sim \int_{S_+} s_A \zeta^A \wedge \tilde{f}$$

- Supergravity analysis: Confirms D-term

$$G^a \xrightarrow[\text{of chiral fields}]{\text{adjustment of}} G^a = G^a(f)$$

$$\tilde{Q}^{\mathsf{D}} \xrightarrow[\text{chiral fields}]{\text{new charged}} T_\alpha \text{ modifiy D-term by } \tilde{Q}^{\mathsf{D}}$$

- D=0 is a solution $\leftrightarrow$ B is not projected out by $\mathcal{O}$

- Holomorphic Chern-Simons-Theory: Confirms F-term

$$W_Y = \int_Y \Omega \wedge \mathrm{Tr}\left(A \wedge \bar{\partial} A + \frac{2}{3} A \wedge A \wedge A\right)$$

$$\Big\downarrow \text{dimensional reduction}$$

$$W_{S_+} = \int_{S_+} s_A \zeta^A \wedge \tilde{f}$$

Kachru, Katz, Lawrence, McGreevy; Lerche, Mayr, Warner; Louis, HJ

Example: One Kähler modulus

- Calabi-Yau orientifold with $h_+^{1,1} = 1$ and $h_-^{1,1} = 0$
  Bulk moduli: S, T Brane moduli: ζ

- Kähler potential:
  $$K(S,T,\zeta) = -\ln\left[-i(S-\bar{S}) + 2i\,\zeta\cdot\bar{\zeta}\right] - 3\ln\left[T+\bar{T}\right]$$

- D-term from D7-flux charge $\tilde{Q}^{\mathsf{D}}$:
  $$V_{\mathsf{D}} \sim \frac{1}{T+\bar{T}}\left(\frac{\tilde{Q}^{\mathsf{D}}}{T+\bar{T}} - \sum_i q_i |X_i|^2\right)^2$$

  X_i multiplets of charge q_i from D-brane intersections

  Burgess, Kallosh, Quevedo

- F-term from D7-flux charges $\tilde{Q}^{\mathsf{F}}$:
  $$V_{\mathsf{F}} \sim \left(\tilde{Q}^{\mathsf{F}}\cdot\tilde{Q}^{\mathsf{F}}\right)\frac{1+e^{\phi}\,\zeta\cdot\bar{\zeta}}{(T+\bar{T})^3}$$

- If T stabilized by non-perturbative effects:
  mechanism to uplift AdS vacua

  Kachru, Kallosh, Linde, Trivedi

- Gauge transformation: $\delta T \neq 0$
  $\Rightarrow$ $W_{\text{gaugino}} \sim e^{-aT}$ is modified

  Binétruy, Dudas

Conclusions

- Computed $\mathcal{N} = 1$ supergravity spectrum and determined effective action for a D7-brane in a Calabi-Yau orientifold model.

- Discussed two types of internal D7-brane fluxes.

- Derived flux-induced D- and F-terms by a fermionic computation.

- Analyzed a simple model and confirmed the proposed D-term structure of Burgess, Kallosh and Quevedo.

- However: Only for specific D7-brane fluxes and a very special class of Calabi-Yau geometries D7-fluxes provide for a source to uplift AdS vacua.