Title: Separating brane-flux degrees of freedom

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Abstract: In string backgrounds with flux and branes, there are subtleties in identifying the independent, globally-defined degrees of freedom due to required gauge patching, which we illustrate with background flux. Work by Cariglia and Lechner (extending Dirac and Teitelboim) allows separation of D-brane and flux degrees of freedom without doubling the gauge sector in a democratic formalism. We review the Cariglia-Lechner formalism and adapt it for compactifications, point out some previously unremarked features, and give alternate derivations of some new terms in the 10D (and 11D) supergravity actions in the presence of branes. Along the way, we will discuss how to integrate gauge potentials that are only locally defined. Finally, we show how to find the independent degrees of freedom and derive their equations of motion.

Disentangling Brane + flux d.o.f.

I. Type of diagonalization in terms of finding "hidden explicit" dependences

A. Still basic questions re: how to derive 4D EFT for warped flux compactifications

- Constraints from EOM mix 10D d.o.f. in a single 4D mode

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I. Type of diagonalization in terms of finding "hidden explicit" dependences

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- Possibly gauge transformations that eliminate naive 10D modes similar to cosmological pert.

IS. Definitional mixing of 10D modes by nontrivial Bianchis

- Potentials must be patched together by gauge transformations but fluctuating sources change the potential
- From calculus of variations p.o.v., this is an explicit dep. of potential on magnetic source
- Example: Harmonic background $F_3 + H_3$
  - C_2, B_2 are gauge patched, but $\delta C_2, \delta B_2$ globally defined.
  - But $\tilde{F}_5 = dC_4 - C_2 \wedge H_3$, so δC_4 is still gauge patched

warped flux compactifications

- Constraints from EOM mix 10D d.o.f. in a single 4D mode
- Possibly gauge transformations that eliminate naive 10D modes similar to cosmological pert.

- Resolution: re-write Bianchi

$$d\,\delta\widetilde{F}_5 = -d\left[\delta C_2 \wedge H_3 - \delta B_2 \wedge F_3 + \cdots\right]$$

so $\delta\widetilde{F}_5 = (d\,\delta C_4') - \delta C_2 \wedge H_3 - \delta B_2 \wedge F_3 + \cdots$

C. Similar issue of patching "base" RR potentials around higher dim D-branes

- Can avoid using democratic formulation (sort of) but costs doubling the RR d.o.f.

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- Want theory of lower-rank potentials w/ D-branes
  Follow Dirac's string formalism generalized by Teitelboim

- Cariglia + Lechner (2004) worked out IIB SUGRA w/ intersecting branes
  - Mostly interested in anomalies
  - Identified new terms in SUGRA action

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but costs doubling the RR d.o.f.

II D-brane currents + Dirac branes

A.
$$S_{WZ} = \mu_p \int_{\mathcal{M}} C \wedge e^{\mathcal{F}} \quad \text{where } \mathcal{F} = 2\pi\alpha' F_2 + \eta B_2$$

- leads to currents
$$j_{p+1}^{\mu_1 \cdots \mu_{p+1}} = \mu_p \int_{\mathcal{M}} dX^{\mu_1} \wedge \cdots dX^{\mu_{p+1}} \delta^{10}(x, X) \; ; \quad j_{p-1}^{\mu_1 \cdots \mu_{p-1}} = \mu_p \int dX^{\mu_1} \wedge \cdots dX^{\mu_{p-1}} \mathcal{F} \delta^{10}(x, X)$$

- Can be electric in EOM $d \star F_{p+2} = (-1)^{4-p} \star j_{p+1} + \cdots$

or magnetic $\quad d\tilde{F}_{p+2} = \beta_p * j_{7-p} + \cdots \qquad \beta_p = \pm 1$

- $d * j$ has contribution on ∂M and from dF

  ∂M terms generally cancel dF_2 terms. Not so for $H_3 \neq 0$.

- Sum over branes $\quad d * j_{p+1} = \eta\, H_3 \wedge * j_{p+3}$

- Can avoid using democratic formulation (sort of) but costs doubling the RR d.o.f.

B. Answer in EOM + Bianchis

$$d \star \tilde{F}_{p+2} = -(-1)^p \star j_{p+1} + \alpha_p \star \tilde{F}_{p+4} \wedge H_3 + \tilde{\alpha}_p \tilde{F}_{6-p} \wedge H_3$$

$$d\tilde{F}_{p+2} = \beta_p \star j_{7-p} + \tilde{\beta}_p \tilde{F}_p \wedge H_3$$

- Consistent if

$$\eta = -\tilde{\alpha}_p \beta_{4-p} + (-1)^p \alpha_p = (-1)^p \beta_p \beta_{p-2} \tilde{\beta}_p$$

- Define

$$\tilde{F}_{p+2} = dC_{p+1} + \tilde{\beta} C_{p-1} \wedge H_3 + \ldots \Rightarrow \alpha_p = -\tilde{\beta}$$

- In either 10D supergravity, $\beta_p \beta_{p+2} = -1$

C. Dirac brane formalism

- If you find some form K_{D-p-2} s.t. $d{\star}K = \star j$

then $\tilde{F}_{p+2} = dC_{p+1} + \cdots + (-1)^p \beta_p \star K_{D-p-2}$

Now C_{p+1} globally defined

- Define a Dirac brane w/ world volume N s.t. $\partial N = M$. The J has $d{\star}J = \star j$

- In compactification, take $\partial N = M - M^{*}$

  - Dirac brane runs from dynamical D-brane to a fixed reference brane.

Then $F_{p+2} = dC_{p+1} + \cdots + H_3 \wedge \star K_{D-p-2}$

Now C_{p+1} globally defined

- Define a Dirac brane w/ world volume $\mathcal{N}$ s.t. $\partial\mathcal{N} = \mathcal{M}$. The J has $d\star J = \star j$

– In compactification, take $\partial\mathcal{N} = \mathcal{M} - \mathcal{M}^{\star}$

- Dirac brane runs from dynamical D-brane to a fixed reference brane w/ fixed reference w.v. gauge field

- C_{p+1} is patched but about reference brane

$d\star J_{p+1} - H_3 \wedge \star J_{p+3}$

Consistent ...

$$\eta = -\tilde{\alpha}_p \beta_{4-p} + (-1)^p \alpha_p = (-1)^p \beta_p \beta_{p-2} \tilde{\beta}_p$$

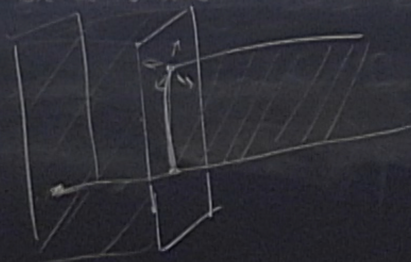
- Define $\hat{F}_{p+2} = dC_{p+1} + \tilde{\beta} C_{p-1} \wedge H_3 + \dots \Rightarrow \alpha_p = -\tilde{\beta}$

- In either IIB supergravity, $\beta_p \beta_{p+2} = -1$

$$d * J_{8-p} = * \left(j_{7-p} - \hat{j}_{7-p} \right) + \eta H_3 \wedge * J_{10-p}$$

- Now $\hat{F}_{p+2} = dC_{p+1} + \tilde{\beta} C_{p-1} \wedge H_3 + \beta_p * J_{8-p}$ automatically solves Bianchi.

- Brane ending on a brane



- In compactification, take $\partial N = \mathcal{M} - \mathcal{M}^*$
  - Dirac brane runs from dynamical D-brane to a fixed reference brane w/ fixed reference W.V. gauge field
  - C_{p+1} is patched but about reference brane

III SUGRA action w/ branes

Cariglia + Lechner found new terms in C.S. action

A. Independence of EOM from Dirac brane currents

- CS action

$$S_{CS}^{(1)} = \sum_p \gamma_p \int C_{p+1} \tilde{F}_{6-p} H_3 \quad \text{has} \quad \frac{\delta S}{\delta C_{p+1}} = \gamma_p \hat{F}_{6-p} H_3 + (-1)^p \gamma_{4-p} \left(\hat{F}_{6-p} - \beta_{4-p} \star J_{p+4} \right)_\wedge H_3$$

- Remove by adding

$$S_{CS}^{(2)} - \sum_p (-1)^p \gamma_{4-p} \beta_{4-p} C_{p+1} \star \underline{J_{p+4}} H_3$$

- brane ending on a brane

B. Dualize from democratic formalism

- Democratic IIA SUGRA

  - field strengths $\tilde{\hat{F}}_{p+2} = dC_{p+1} + \hat{\beta} C_{p-1} H_3 + \beta_p * J_{8-p}$, p even

  - $$S = -\frac{1}{2\kappa_0^2} \int \left\{ \frac{1}{4}|\hat{F}_0|^2 + \frac{1}{4}|\hat{F}_2|^2 + \frac{1}{4}|\hat{F}_4|^2 + \cdots + \frac{1}{4}|\hat{F}_{10}|^2 + \frac{1}{2} C_1 \wedge * j_1 + \cdots + \frac{1}{2} C_9 \wedge * j_9 \right\}$$