Brane and Antibrane Dynamics

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based on **1412.5702**

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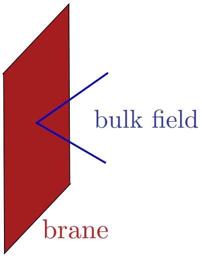
Motivation: *Brane actions*

Branes actions important for many aspects of string physics, *e.g.* singularity resolution in Polchinski-Strassler or enhançon.



Interpretation of brane actions ambiguous:

A brane is a source for bulk fields which are singular at the brane and when inserted into the brane action give divergent result.

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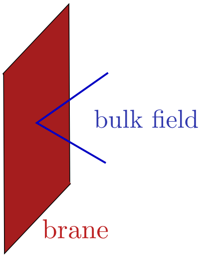

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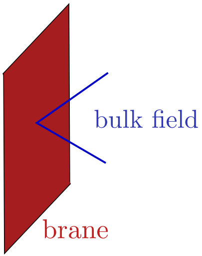

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Brane probe actions: self-fields of brane are not included in the brane's action $\sim$ formal limit $\#$ branes $\rightarrow 0$

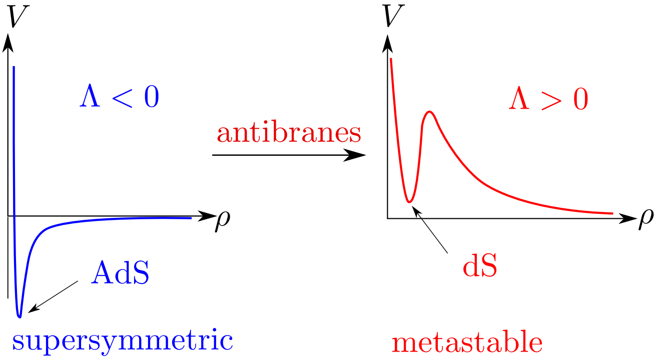
Brane effective actions: Effective field theory is correct framework for treating classical and loop divergences and dynamics.
[Goldberger,Wise'01] + others, *[Michel,Mintun,Polchinski,AP,Saad'14]*

Motivation: *Antibranes in Cosmology*

De Sitter vacua from KKLT mechanism in string theory:

[Kachru,Kallosh,Linde,Trivedi'03;

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



Motivation: *Antibranes in Gauge/Gravity duality*

Metastable states in field theory from antibranes in bulk:

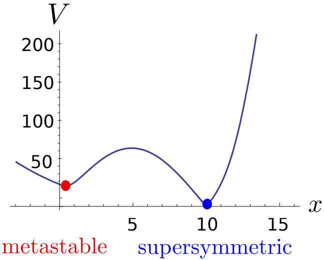
↑

involves strong coupling → hard w/out field theory dualities

[Intriligator,Seiberg,Shih'06]

e.g. Bubbling AdS space dual to mass-deformed M2 brane theory

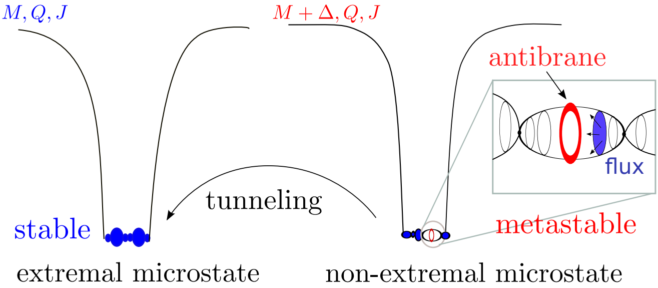
[Lin,Lunin,Maldacena'04]



[Pasini,Massai,AP'14]

Motivation: *Antibranes in Black Holes*

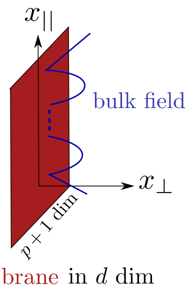
Non-extremal microstates from antibranes in extremal microstates:



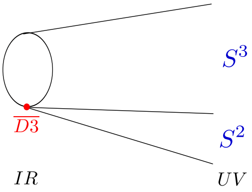
[Bena,AP,Vercnocke'11+'12]

Plan

1. Brane effective action
   - Probe actions and beyond
   - Divergences
   - Brane dynamics



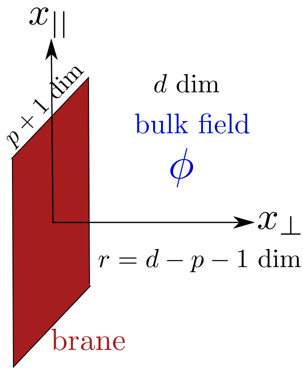
2. Antibranes in flux backgrounds
   - De Sitter vacua from antibranes
   - $\overline{D3}$ in Klebanov-Strassler



Brane effective actions

A Toy Model

Free massless scalar field ϕ in d spacetime dimensions with brane in $p+1$ dimensional subspace and interaction $\mathcal{L}_{brane}(\phi, \partial\phi)$:



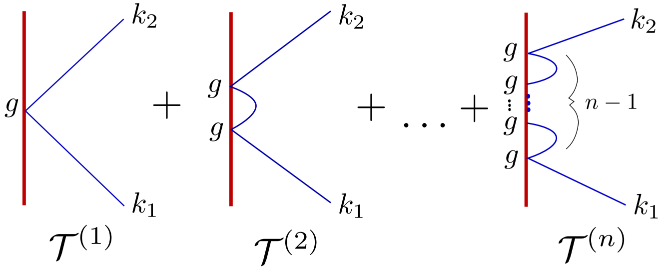
$$S = -\frac{1}{2}\int d^d x \partial_M \phi \partial^M \phi + \int d^{p+1} x_{\|} \mathcal{L}_{brane}(\phi, \partial\phi)$$

M, N spacetime; m, n $\perp$ brane; μ, ν $\|$ brane

Compute scattering amplitudes $\mathcal{T}^{(i)}$ and study divergences in EFT.

Brane - bulk field interaction

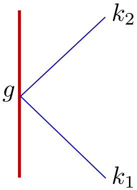
First, second, ..., nth order terms in amplitude for scattering of ϕ from the brane with interaction $\mathcal{L}_{brane}(\phi, \partial\phi) = \frac{1}{2}g\phi^2$:



Momentum $\parallel$ to brane is conserved: $k_{1\parallel} = k_{2\parallel} = k_\parallel$.
Momentum $\perp$ to brane diverges $\rightarrow$ cutoff at $k_\perp = \Lambda$.

Probe approximation and beyond

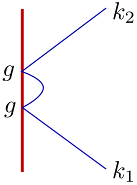
$\mathcal{T}^{(1)}$ is scattering $k_1 \to k_2$ in presence of brane at order g:



$$\mathcal{T}^{(1)} = g(2\pi)^{p+1}\delta^{p+1}(k_{1\|} - k_{2\|}) \equiv g\delta_\|$$

This corresponds to the probe approximation.

$\mathcal{T}^{(2)}$ is scattering $k_1 \to k_2$ in presence of brane at order g^2:



$$\mathcal{T}^{(2)} = g^2\delta_\| \int^\Lambda \frac{d^r k_\perp}{(2\pi)^r}\frac{1}{k_\|^2 + k_\perp^2}$$

This diverges for $r \geqslant 2 \to$ cutoff at $k_\perp = \Lambda$.

The brane interacts with its own induced field
$\Rightarrow$ *beyond the probe approximation.*

...

Divergences in brane actions

$\mathcal{T}$ is scattering $k_1 \to k_2$ in presence of brane at all orders g:

$$r = 1: \; \mathcal{T}^{(1)} = g\delta_{\|}\,,\; \mathcal{T}^{(2)} = g^2\delta_{\|}\frac{1}{2k_{\|}}\,,\; \ldots \;\to\; \mathcal{T}_{r=1} = \frac{2gk_{\|}}{2k_{\|}-g}\delta_{\|}$$

$$r = 2: \; \mathcal{T}^{(1)} = g\delta_{\|}\,,\; \mathcal{T}^{(2)} = g^2\delta_{\|}\frac{1}{4\pi}\ln\frac{\Lambda^2}{k_{\|}^2}\,,\; \ldots \;\to\; \mathcal{T}_{r=2} = \frac{1}{\frac{1}{g}+\frac{1}{4\pi}\ln\frac{k_{\|}^2}{\Lambda^2}}$$

...

$\mathcal{T}_{r=1,2,3,4,\ldots}$: conv, log div, lin div, quadr + log div,...

For $r \geqslant 2$: renormalize (add counter terms, adjust coupling g,...)

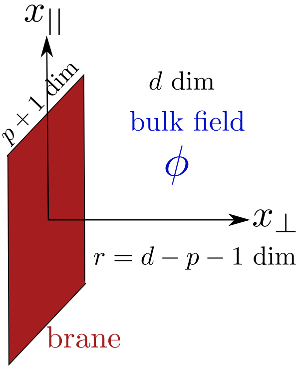
Solving the classical field equation

$$\partial_{\|}^2\phi + \partial_{\perp}^2\phi = -g\delta^r(x_{\perp})\phi$$

brings in full machinery of effective field theory.

A Toy Model (upgrade)

Free massless scalar field ϕ in d spacetime dimensions with brane in $p+1$ dimensional subspace and interaction $\mathcal{L}_{brane}(\phi, \partial\phi)$ and moving in the transverse directions $X^m(x_\parallel)$:



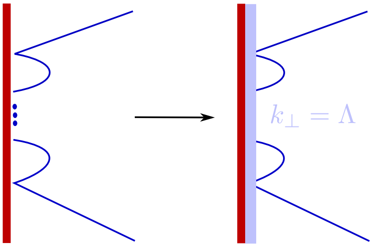
$$
\begin{aligned}
S &= -\frac{1}{2}\int d^d x \partial_M \phi \partial^M \phi \\
&\quad + \frac{g}{2}\int d^{p+1} x_\parallel \phi^2 \\
&\quad - \frac{\tau}{2}\int d^{p+1} x_\parallel \partial_\mu X^m \partial^\mu X^m
\end{aligned}
$$

M, N spacetime; m, n $\perp$ brane; μ, ν $\parallel$ brane

Describes brane motion and scattering of scalars from the brane accompanied by excitations of oscillations of the brane.

Wilsonian effective action

Brane effective action contains all terms allowed by symmetry with transverse momentum cut off at Λ that is matched to UV theory.



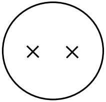
$$S_{brane} = \frac{1}{2}\int d^{p+1}x_{\parallel} \sum_{l,j=0}^{\infty} \sum_{m} \frac{\kappa_{lj}}{\Lambda^{2l+2j+r-2}} \times T^{jm}(\partial_\perp)\partial_{\mu_1}\ldots\partial_{\mu_l}\phi \, T^{jm}(\partial_\perp)\partial^{\mu_1}\ldots\partial^{\mu_l}\phi$$

To study amplitudes to accuracy Λ^{-s} retain all terms with scaling dimension of the interaction $\Delta \leqslant s$.

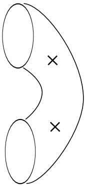
Matching of EFT to UV theory

For D-branes the UV theory is string theory w/ cutoff $\Lambda = 1/\sqrt{\alpha'}$.

$\mathcal{T}^{(1)}$ is effective description for *disc*
w/ 2 closed string vertex operators
EFT - UV match: brane couplings κ to LO in g_s



$\mathcal{T}^{(2)}$ is effective description for *annulus*
w/ 2 closed string vertex operators
EFT - UV match: brane couplings κ to LO in g_s^2



etc

Application of brane effective actions:

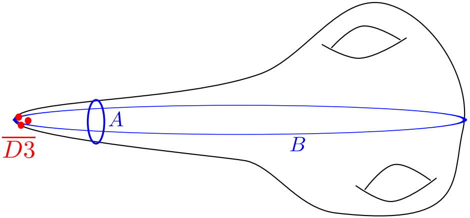
Antibranes in flux backgrounds

de Sitter Vacua from Antibranes

IIB string theory compactified on a Calabi-Yau in presence of flux:

$$\int_A F_3 = M$$

$$\int_B H_3 = -K$$



KKLT mechanism:

excites stabilized supersymmetric Anti de Sitter vacua by adding one or more antibranes *(branes with opposite supersymmetry to bgd)*.

(Talk by R. Kallosh.)

[Giddings,Kachru,Polchinski'01; Kachru,Pearson,Verlinde'01;

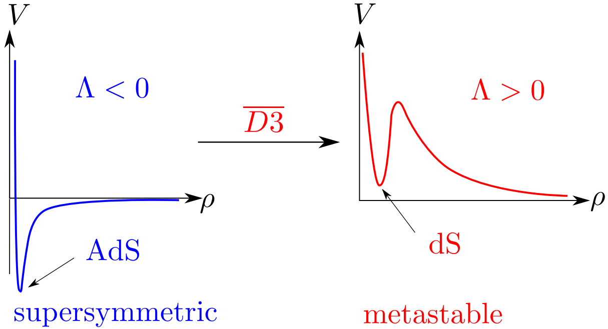
Kachru,Kallosh,Linde,Trivedi'03;

Kachru,Kallosh,Linde,Maldacena,McAllister,Trivedi'03; Kallosh,Wrase'14;

Bergshoeff,Dasgupta,Kallosh,Van Proeyen,Wrase'15]

de Sitter Vacua from Antibranes

Antibranes break supersymmetry by small amount and lift AdS to dS with cosmological constant Λ tuned by number of $\overline{D3}$ and flux quanta without destabilizing the vacuum if Calabi-Yau sufficiently warped.



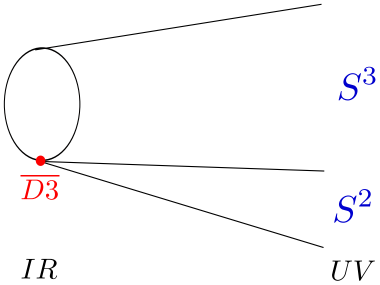
tadpole: $$0 = \int_{CY} H_3 \wedge F_3 \qquad\qquad 0 = \overline{N} + \int_{CY} H_3 \wedge F_3$$

Antibranes in Klebanov-Strassler

Local model of warped throat: Klebanov-Strassler (KS) warped deformed conifold threaded by imaginary self-dual (ISD) flux

$$G_3 = F_3 + \frac{i}{g_s} H_3$$

$$\star_6 G_3 = i G_3$$



Correct framework?

DBI-WZ probe action: small number of $\overline{D3}$ in KS are metastable and decay via brane-flux annihilation *[Kachru,Pearson,Verlinde'01]*

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Supergravity backreaction: large number of $\overline{D3}$ in KS give rise to singularities in the fluxes H_3, F_3 $\Rightarrow$ Good or bad singularities?

[McGuirk,Shiu,Sumitomo'09;Bena,Grana,Halmagyi'09] + many many others

Good if *resolved* (polarization) and *cloaked* by horizon (finite T).

[Gubser'00] (Talks by S. Massai and T. Van Riet.)

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Brane effective action: single $\overline{D3}$ in KS

[Michel,Mintun,Polchinski,AP,Saad'14]

Correct criterion for a good singularity in fields external to brane?

$\Rightarrow$ Matching onto string perturbation theory.

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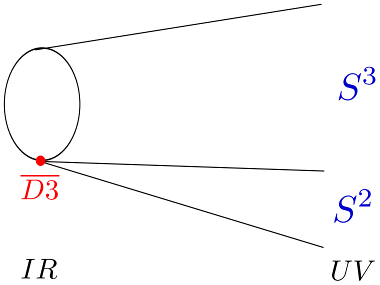


Scale of geometry $L \gg \sqrt{\alpha'}$ + flux dilute → EFT valid.
Relevant low-energy dof of EFT: $\overline{D3}$ position.
ISD flux →$\overline{D3}$ *minimizes energy at tip of the KS throat*.

EFT for Antibranes in Klebanov-Strassler

IIB supergravity action:

$$S_{IIB} \sim \alpha'^{-4} \int d^{10}x\sqrt{-g}\left[e^{-2\phi}(R + \frac{1}{4}(\partial\phi)^2 + |H_3|^2) + |F_3|^2 + \frac{1}{2}|F_5|^2\right]$$
$$+ \alpha'^{-4} \int C_4 \wedge H_3 \wedge F_3$$

Scaling dimension:

- $\Delta[dx] = -1$, $\Delta[\partial] = 1$, $\Delta[C, B, g] = \frac{d-2}{2} = 4$

Engineering dimension:

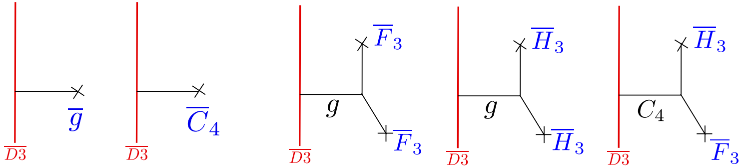
- $\delta[dx] = 1$, $\delta[\partial] = -1$, $\delta[C, B, g] = 0$

Coupling:

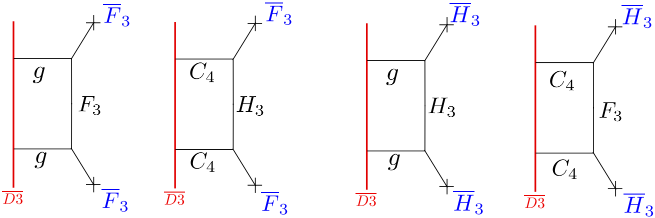
- bulk vertex: $1/g_s^2$ (gravitational), g_s^0 (Chern-Simons)
- brane vertex: $1/g_s$ (NS), g_s^0 (R)
- propagators: g_s^2 (NS), g_s^0 (R)

EFT for Antibranes in Klebanov-Strassler

Contribution from $\mathcal{T}^{(1)}$:

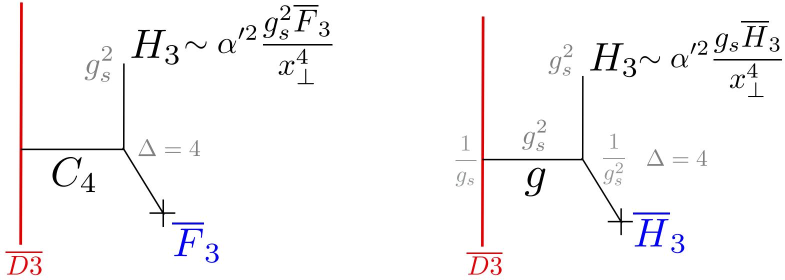


Contribution from $\mathcal{T}^{(2)}$:



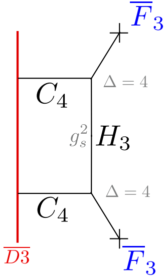
Perturbation of background flux

Potentially problematic issue: backreaction on H_3

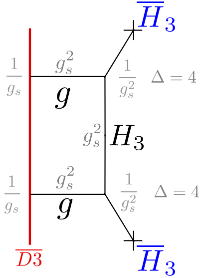


The induced H flux is a *small perturbation* of the background H flux at weak coupling even at the limit of EFT $x_\perp \sim \sqrt{\alpha'}$.

Mass correction from fluxes



$$\alpha'^{-1} g_s^2 \int d^4x \sqrt{-g_4} F_3^2$$



$$\alpha'^{-1} g_s^0 \int d^4x \sqrt{-g_4} H_3^2$$

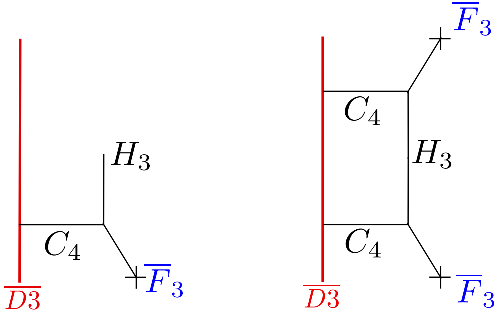
$$\Delta M \sim \alpha^{-1} \left(g_s^2 \left(\partial \overline{F}_3 \right)^2 + \left(\partial \overline{H}_3 \right)^2 \right) X^2$$

Mass term from leading order potential $\alpha'^{-2} g_s^{-1} \int d^4x \sqrt{-g_4}$:

$$M \sim \alpha'^{-2} \left(g_s \overline{F}_3^2 + g_s^{-1} \overline{H}_3^2 \right) X^2$$

The mass correction is *suppressed in α'/L^2 and g_s*.

Summary: single antibrane



Self-consistent use of effective field theory:

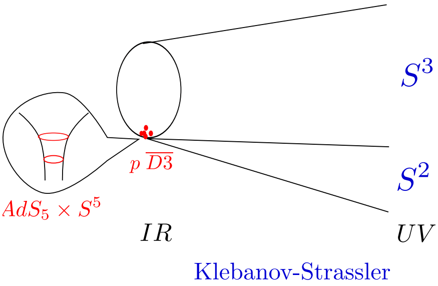
No large corrections that would signal breakdown.

Low-energy dof is antibrane position which is energetically limited to bounded space (close to tip of KS throat) $\rightarrow \exists$ minimum.

Multiple antibranes

For p *coincident* D-branes → EFT on the brane non-Abelian.

When $g_s p \gg 1$ brane theory strongly coupled but supergravity good. (Talk by S. Massai.)



When background varies slowly on scale of brane radius $(g_s p)^{1/4}\alpha'^{1/2}$, *i.e.* $p \ll M = \int_{S^3} F_3$ → effective brane description.

Antibranes attract at long distances (screening) but might repel at short distances (talk by S. Massai) → separate inside bounded space to new minimum. Then EFT for a single antibrane applies.

Conclusions

Effective field theory description of (anti) branes:

- Allows use of brane actions *beyond probe approximation*, treatment of *classical and quantum divergences*.
- In flux backgrounds supersymmetry-breaking antibranes metastable if number p of antibranes not too large.

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For a single $\overline{D3}$ in flux threaded Klebanov-Strassler throat:

- backreaction on flux $H_3 \propto \frac{g_s^2 \alpha'^2 F_3}{x_\perp^4}$ small
- mass correction suppressed by powers of g_s & α'/L^2

and within this approximation *no instability*.

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THANK YOU!