Title: Micromanaging de Sitter holography

Date: Jun 17, 2010 04:15 PM

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Abstract: TBA

Micromanaging de Sitter Holography

based on

- X. Dong, B. Horn, ES, G. Torroba '10
- J. Polchinski + E.S. '09
- Karch '04
  (+ Alishahiha, ES, Tong '04

- For reviews of previous work on moduli stabilization : Douglas, Kachru, Graña, Frey, ES, ..

- other attempts at cosmo. dualities
  - dS/CFT
    Strominger...
  - FRW/CFT
    Freivogel et al
  - Skenderis talk

We'd like to know the basic degrees of freedom required to describe real (= cosmological, ~~SUSY~~) spacetime, and a framework for computing observables.

This talk:

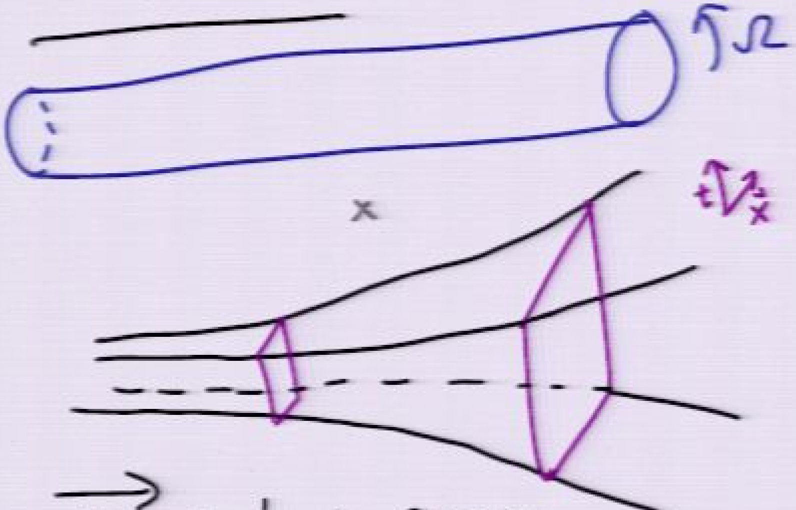
Build up from AdS/CFT dual pairs, obtaining a concrete but semi-holographic description of dS & its decays.

- framework - techniques - candidate model

→ Microscopic parametric count of Gibbons - Hawking dS entropy

AdS/CFT

Maldacena



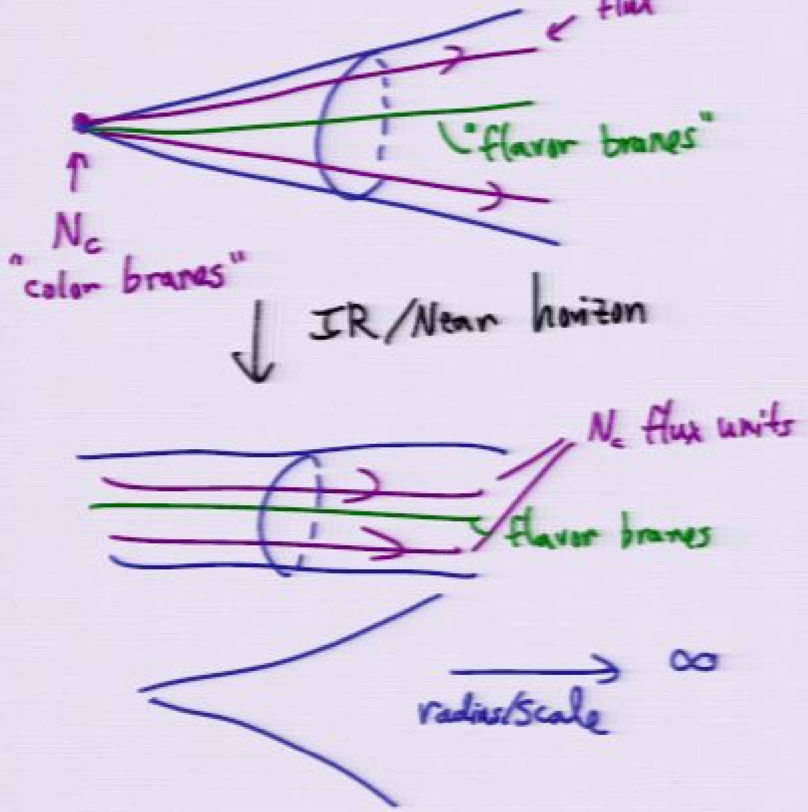
r : scale in QFT

(gravitational redshift factor)

$$ds^2 = \frac{r^2}{R_{AdS}^2}\underbrace{\left(-dt^2+d\vec{x}^2\right)}_{\text{spacetime on which QFT lives.}} + \frac{R_{AdS}^2}{r^2}dr^2 + ds_\Omega^2$$

$r \to \infty$: UV-complete QFT

AdS/CFT microscopic degrees of freedom are the low-energy degrees of freedom on branes  (the source of the redshift).



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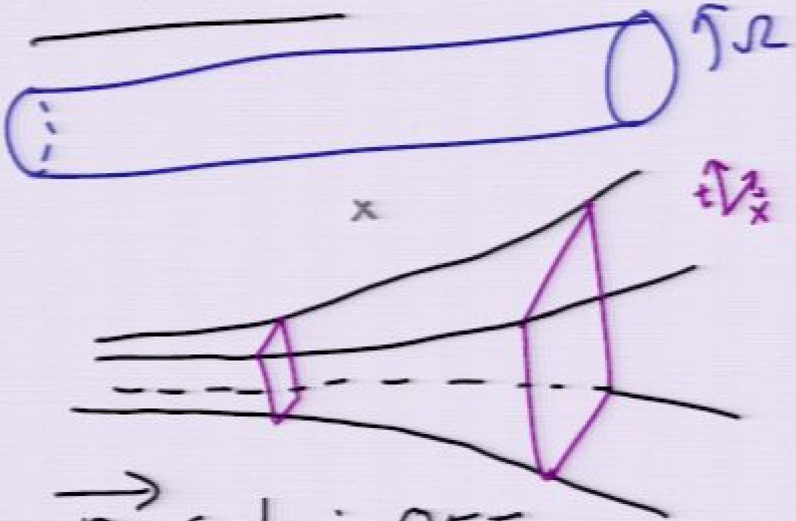

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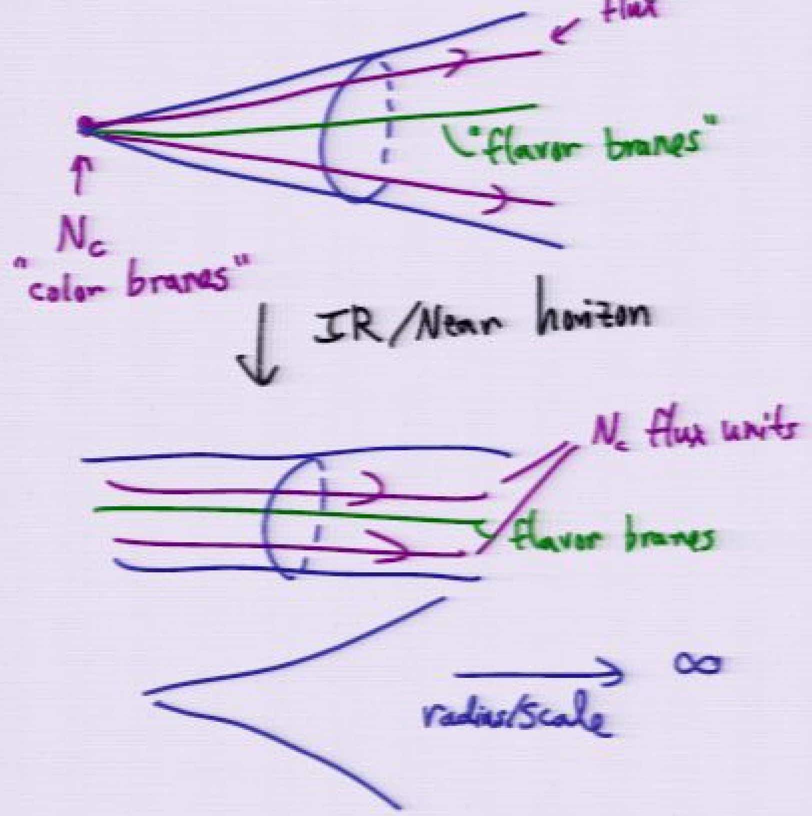
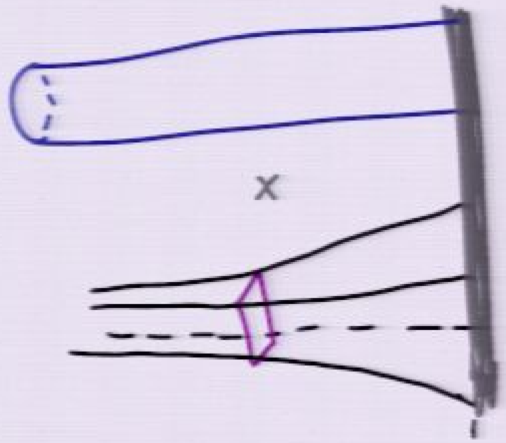


Warped Compactification / Randall-Sundrum



$\int \Omega$

$\int_t \sqrt{\;}_x$

$0 \leq r \leq r_{uv}$: cutoff

$\Rightarrow$
- Gravity in 4d is dynamical
- QFT provides holographic description of IR regime

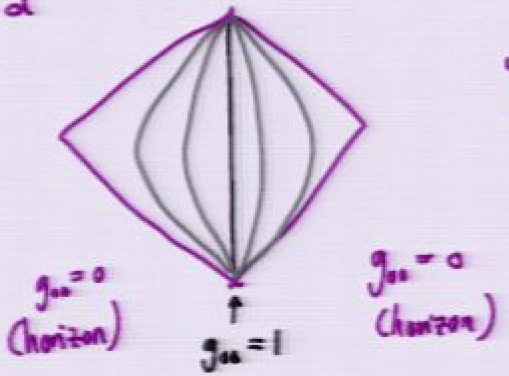
  $r < r_{uv}$

  but this QFT is cut off and coupled to gravity.

Macroscopic dS semi-holography

dS is a 2-throated warped compactification

$$ds^2_{dS_d} = \sin^2\frac{r}{L}\, ds^2_{dS_{d-1}} + dr^2$$



"dS/dS"

☆ The 2 warped throats have a right to a holographic dual description, carrying the bulk of the horizon entropy.

- Gravity still propagates in $d-1$ dim's.

i.e. semi-holographic cf Randall-Sundrum

Gubser Witten
Hawking Maldacena Strominger
Verlinde
Klebanov Strassler
Giddings Kachru Polchinski

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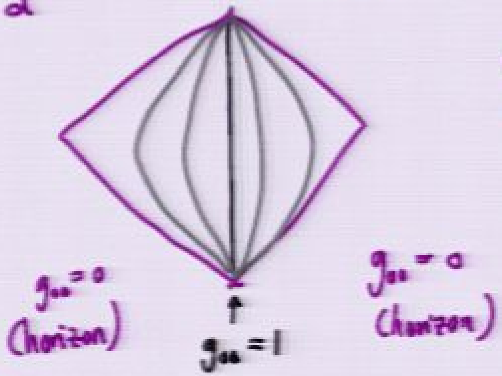

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Semi-holographic dS and Entropy

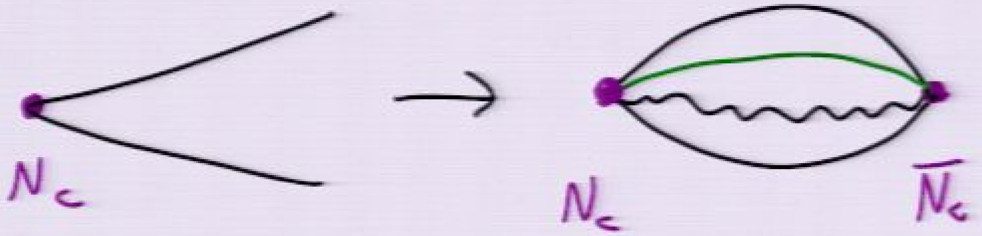
As in Randall-Sundrum theory

$$\frac{1}{G_{N,d-1}} = M_{d-1}^{d-3} \sim \underset{\substack{\uparrow \\ \text{gravity} \\ \text{side} \\ \text{(classical)}}}{R_{dS} M_d^{d-2}} \sim (R_{dS} M_d)^{d-2} \left(\frac{1}{R}\right)^{d-3} \sim \underset{\substack{\uparrow \\ \text{QFT} + \text{GR}_{d-1} \\ \text{side} \\ \text{(quantum)}}}{S \left(\frac{1}{R}\right)^{d-2}}$$

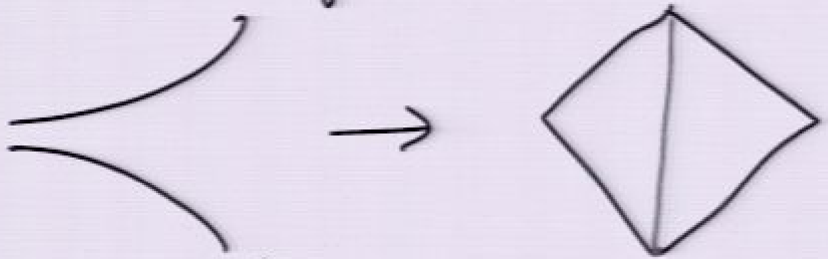
We'd like to understand microscopically the $\mathcal{O}(S)$ degrees of freedom that build up the 2 throats.

Outline/Summary:

- Upgrading AdS brane construction to dS $\Rightarrow$ becomes compact



qualitatively matching the macroscopic dS/dS duality



while revealing the microscopic degrees of freedom building up the throats/horizon

AdS/CFT near horizon geometry

e.g. $$AdS_3 \times S^3/\mathbb{Z}_k \times \underbrace{T^4}_{\text{size} L}$$

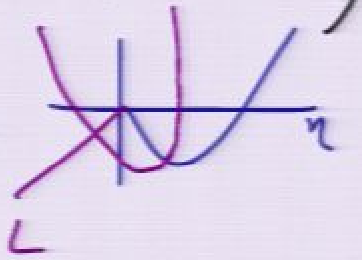
$$\begin{tikzcd}
\text{size } R_f \arrow[r] & S^1_f \arrow[r] & S^3 \arrow[d] & \\
 & & S^2 & \text{size } R \arrow[l]
\end{tikzcd}$$

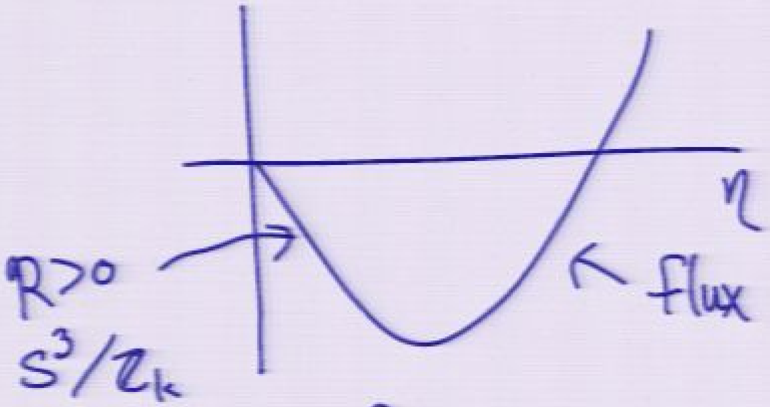
Effective potential

$$\mathcal{U} = \frac{M_3}{\alpha'}\left\{\frac{R_f^2}{R^4} - \frac{1}{R^2} + \frac{g_s^2 k^2}{R^4 R_f^2}\left[\frac{N_{D1}^2}{L^8} + N_{D5}^2\right]\right\}$$

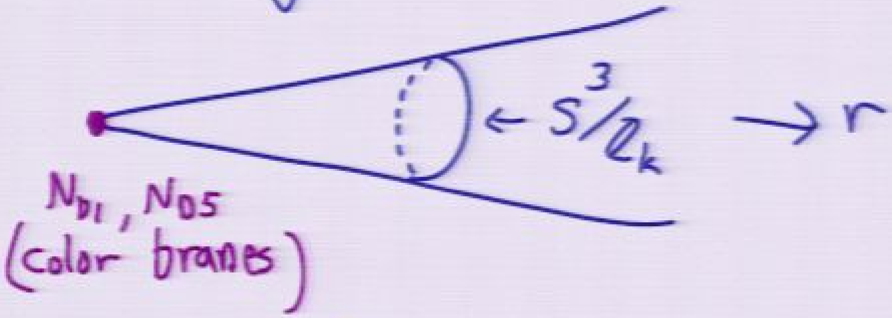
$$= M_3^3 k^3 \left\{-\frac{\eta^4}{k} + k\eta^6\left[\frac{N_{D1}^2}{L^4} + N_{D5}^2 L^4\right]\right\}$$

where $\eta = \dfrac{g_s}{R^2 L^2}$





$\updownarrow$

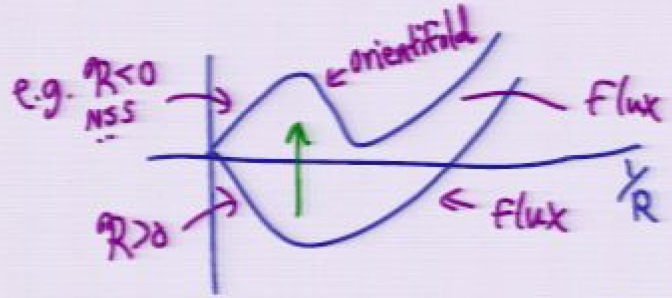


cone :
$$\frac{\left(\frac{dR}{dr}\right)^2}{R^2} = \underset{\uparrow \text{positive curvature}}{+}\frac{1}{R^2}$$

$\hookrightarrow$ $R = r : \; dr^2 + r^2 d\Omega^2$

Basic Idea:

Now suppose we obtain [example to come] an "uplifted" potential

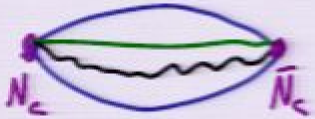


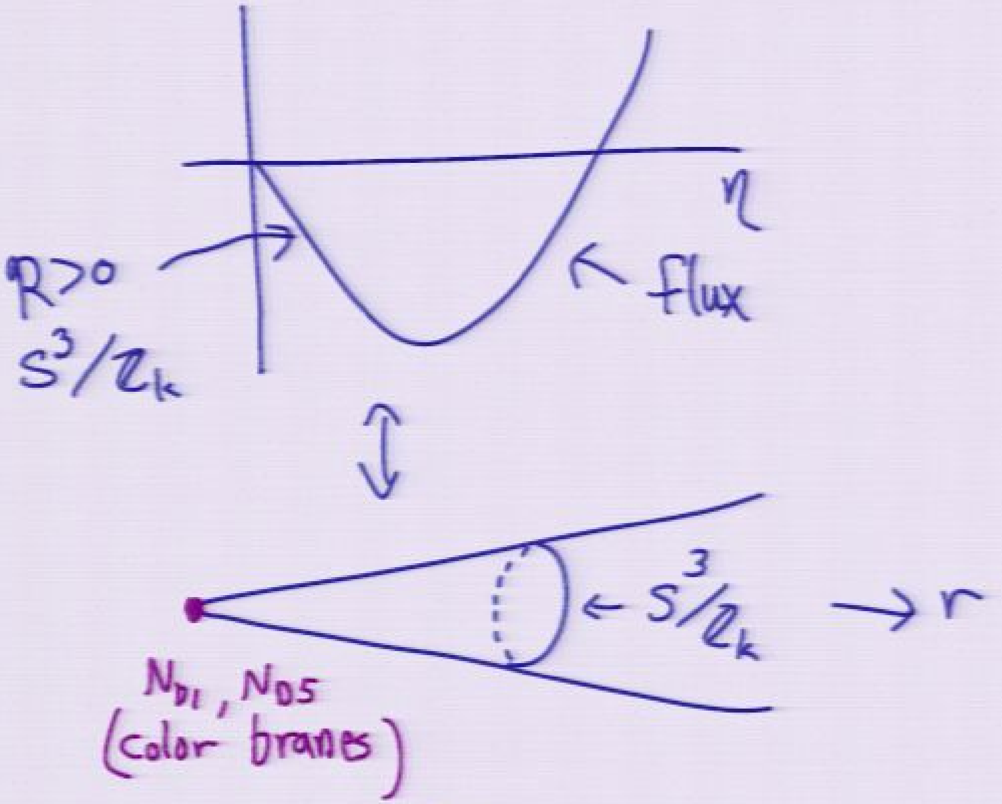
by adding appropriate ingredients to this model $\Longrightarrow$ effect on brane construction:

$$\left(\frac{dR}{dr}\right)^2 = -\frac{1}{R^2} + \frac{\text{const}}{R^n} + \cdots$$

O-plane codimension

$\Rightarrow$ Now compact; no longer a cone.





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$$\frac{\left(\frac{dR}{dr}\right)^2}{R^2} = +\frac{1}{R^2}$$

positive curvature

$\hookrightarrow$ $R = r$: $dr^2 + r^2 d\Omega^2$

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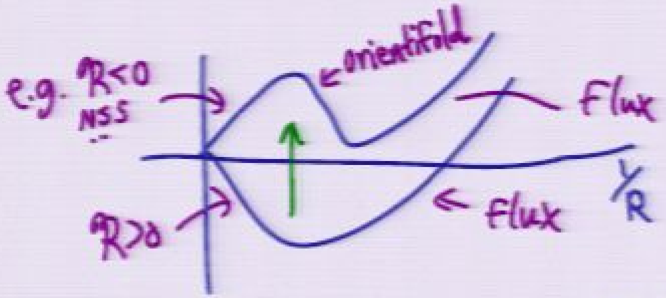

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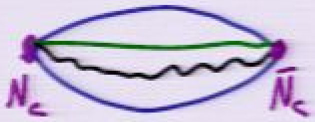

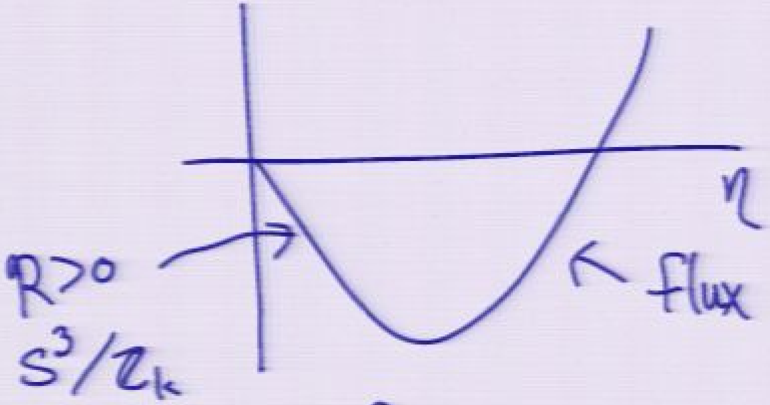

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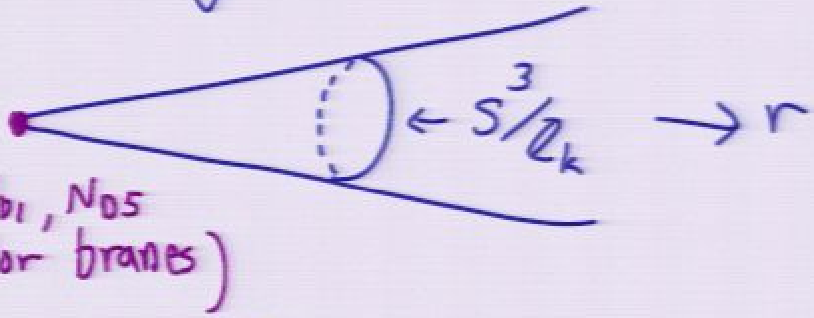

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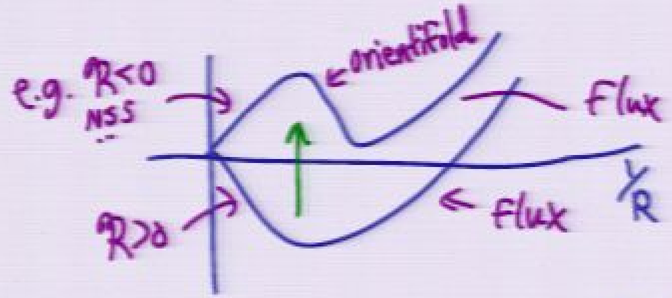

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More generally, at given other scalars $\{\sigma_I\} = \{g_s, L, \dots\}$ with $\dot{\sigma}_I(t_0) = 0$

$$\left(\frac{dR}{dr}\right)^2 = -\frac{1}{R^{n_1}} + \frac{\text{const}}{R^{n_2}}$$

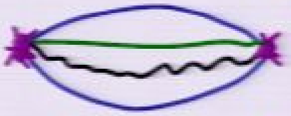
e.g.

$n_1 = 0$

D7 on $S^3/\mathbb{Z}_k$

$n_2 = 2$

O5 at real codim. 2 on $S^3/\mathbb{Z}_k$

Here the tips  have only conical singularities.

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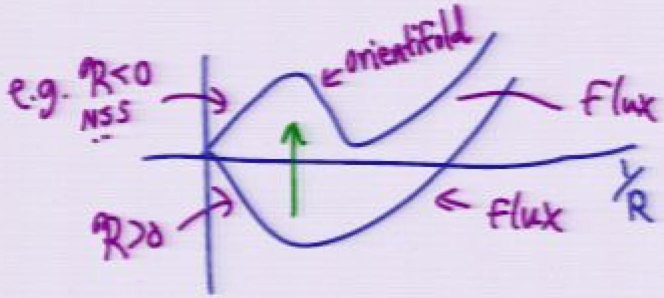

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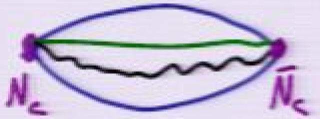

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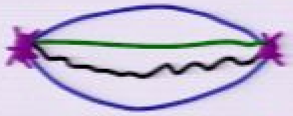
Here the tips  have only <u>conical</u> singularities.

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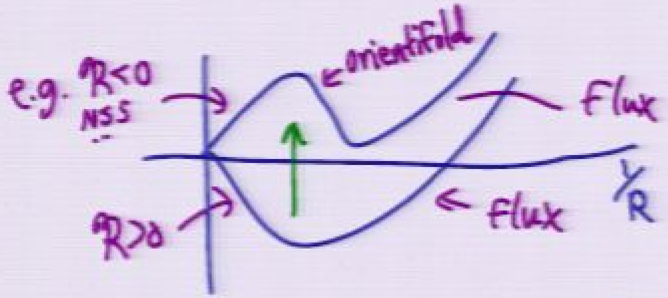

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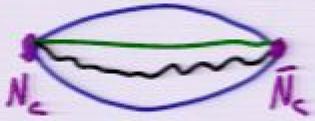

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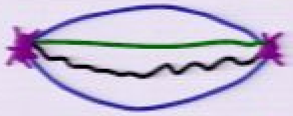
Here the tips  have only <u>conical</u> singularities.

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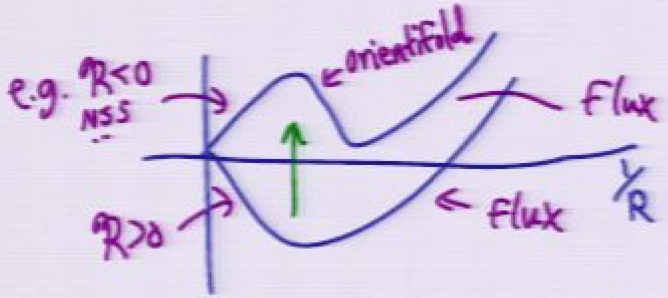

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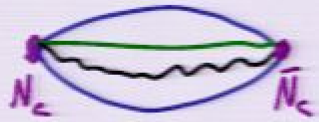

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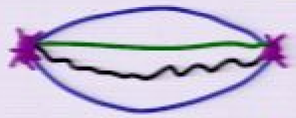
Here the tips  have only <u>conical</u> singularities.

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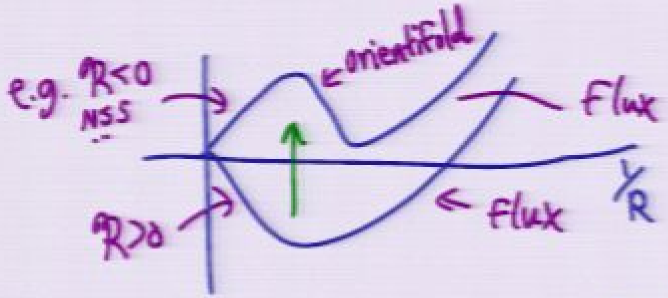

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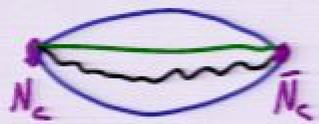

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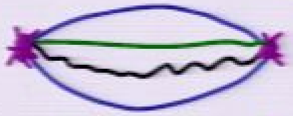
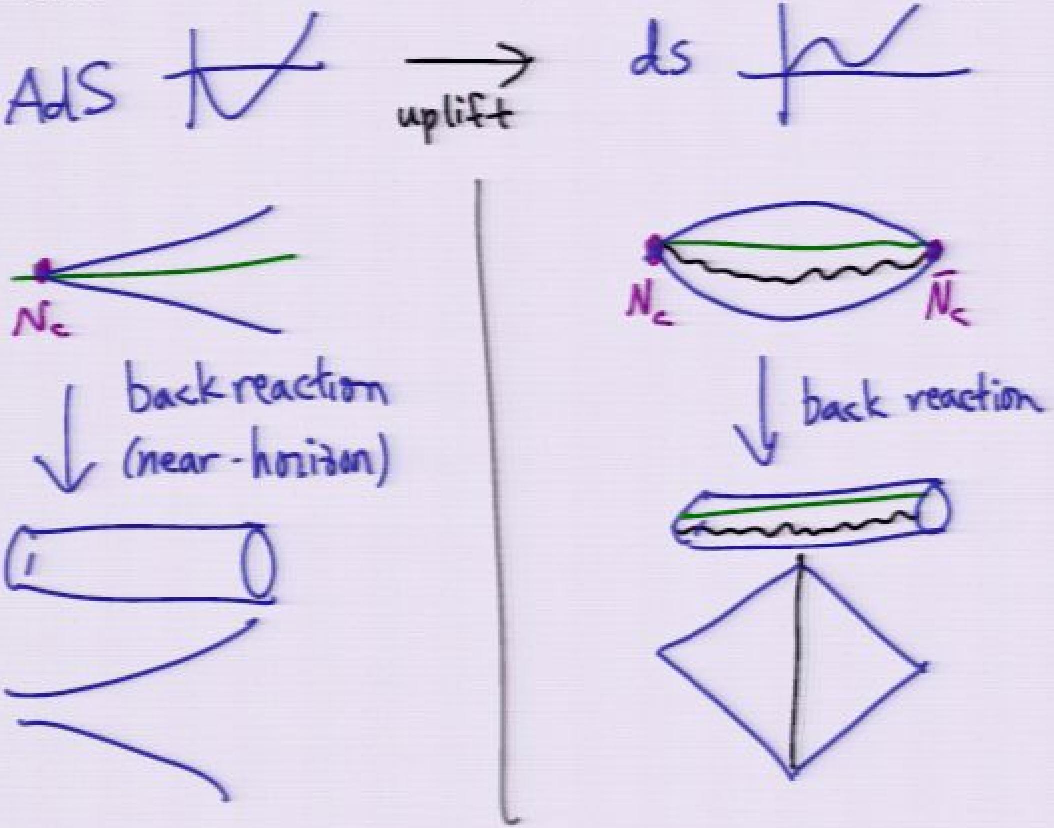
Here the tips  have only conical singularities.

This fits with the macroscopic result above (dS = warped compactification)



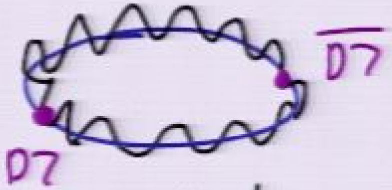
with the <u>microscopic</u> degrees of freedom of the two throats given by the brane construction. N_c colors ; + flavors & orientifold projection from uplifting.

Notes

- pairwise SUSY among most ingredients

- D7-$\overline{D7}$ in nontrivial $S^3/\mathbb{Z}_k$ Wilson line vacua

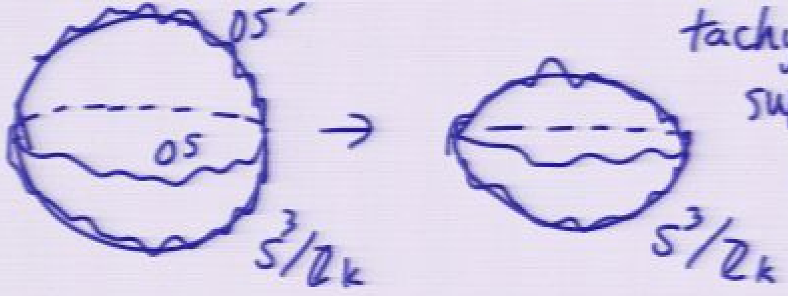
T-dual $\tilde{S}^1_f$:



- anisotropy modes non-tachyonic at sufficiently small $a \sim \theta(\epsilon)$:

$$\frac{4ac}{b^2} \sim \frac{\theta(\epsilon)\cdot c}{b^2} \leftarrow$$

O-planes' tachyons/tadpoles suppressed by ϵ



Can compute much more

Alishahiha Karch ES '04

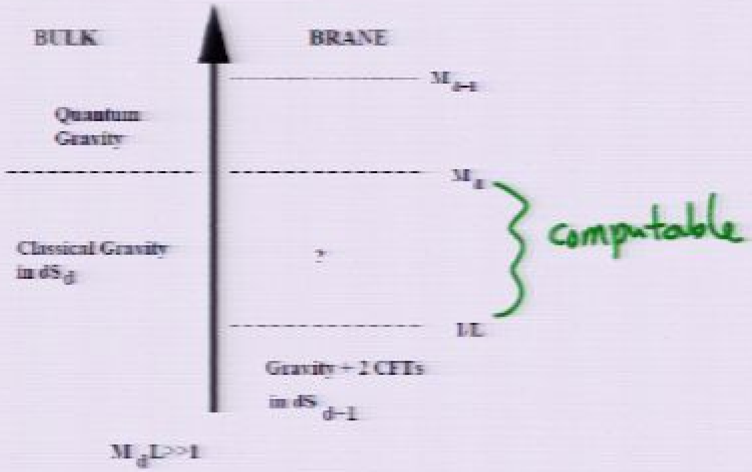
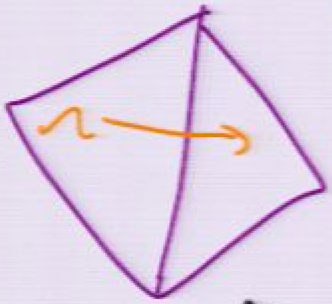


Figure 1: The hierarchy of scales. $M_{d-1}^{d-3} = L\, M_d^{d-2}$ appears as an induced scale beyond M_d, the ultimate cutoff of the theory.

- $c_{Tot} = 0$ as befits theory with gravity
- 

  Tunneling between throats

  cf Dimopoulos et al

  $\Rightarrow$ direct couplings

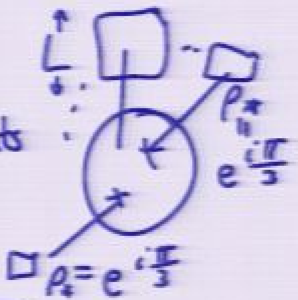
  $$\int d^{d-1}x\sqrt{g}\,\mathcal{O}^{(1)}\,\mathcal{O}^{(2)}$$
- operator dimensions dressed by GR_{d-1}

Potential for $\beta \equiv \frac{kR_f}{R}$, R, L, g_s:

$\tilde{\eta} = \frac{g_s}{R^2 L^2}$

$\rho = b_T + iL^2$

$\frac{(\nabla\rho)^2}{\mathrm{Im}\rho^2}$ gradients



$$U \approx 16 M_5^3 k^3 \left\{ \left(4\pi^2 - \frac{2\pi^2}{3\beta^2} \left[24 - n_\rho - \hat{n}_\rho \underbrace{\left(\left(\log \frac{L^2}{L_*^2} \right)^2 + \frac{(b_T - b_*)^2}{L^4} \right)} \right] + \frac{\pi k n_{NS5}}{L^2 \beta^3} \right) \frac{\tilde{\eta}^4}{k} - \left(2\pi R^2 - \frac{n_{D7} R^4 \beta}{2k} \right) \frac{\tilde{\eta}^5}{\beta^3} + 4\pi^2 \left(N_{D5}^2 L^4 + \frac{(N_{D1} + b_T^2 N_{D5})^2}{L^4} + 2 b_T^2 N_{D5}^2 \right) \frac{k\tilde{\eta}^6}{\beta^4} \right\}$$

- $n_\rho = 4 = \#$ of ρ5-branes

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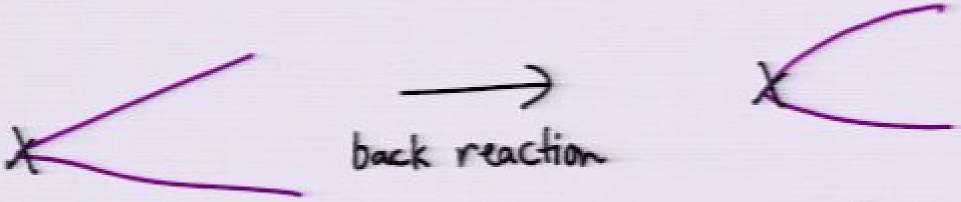

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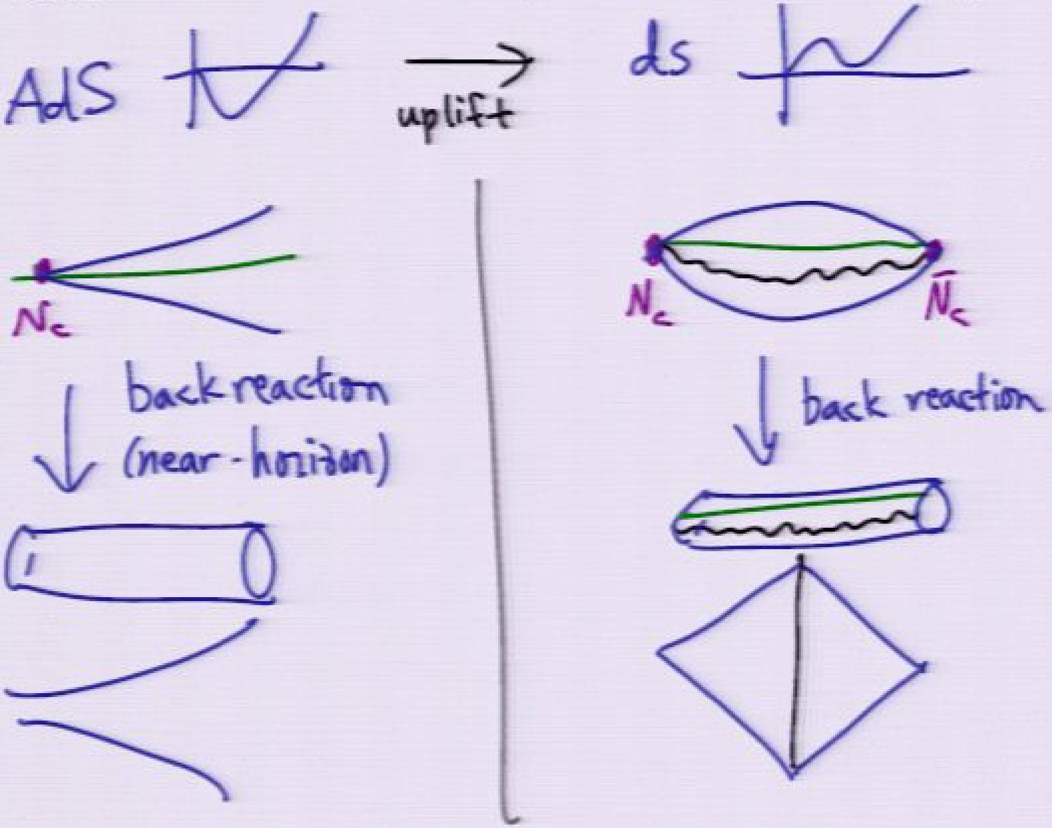
the curvature of the base.

It's been tempting to realize neutral black holes/branes

cf Danielsson et al

and dS via brane-antibrane systems. We land on $\eqsim$ this, but full stabilization involves many important details.

This fits with the macroscopic result above (dS = warped compactification)



with the <u>microscopic</u> degrees of freedom of the two throats given by the brane construction. N_c colors ; + flavors & orientifold projection from uplifting.

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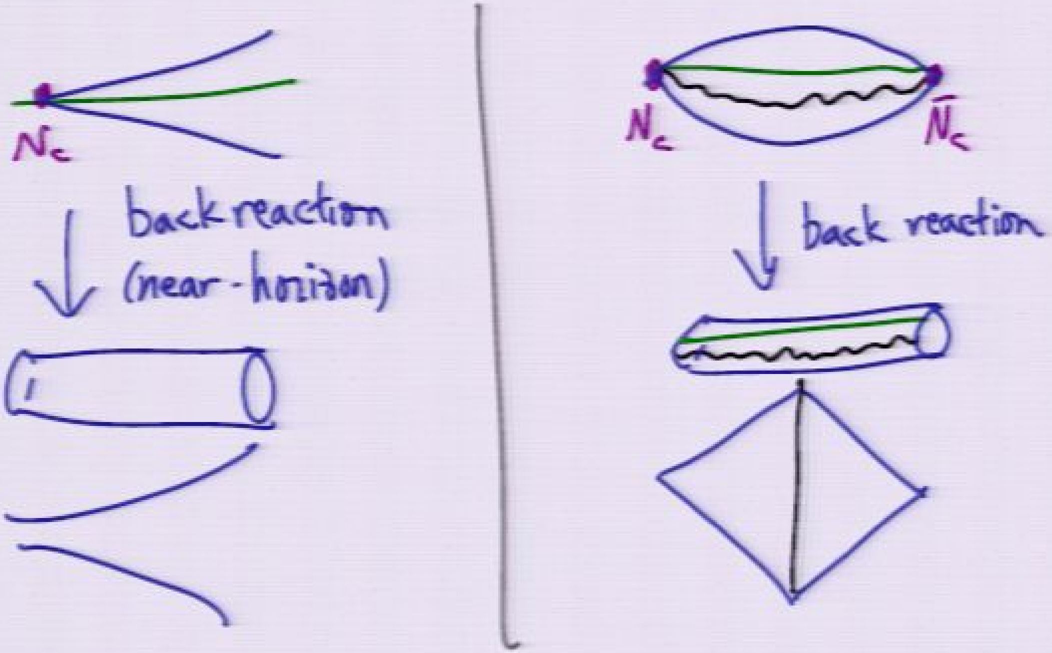

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More generally, at given other scalars $\{\sigma_I\} = \{g_s, L, \ldots\}$ with $\dot{\sigma}_I(t_0) = 0$

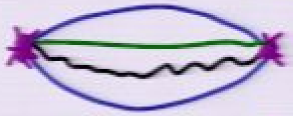
$$\left(\frac{dR}{dr}\right)^2 = -\frac{1}{R^{n_1}} + \frac{\text{const}}{R^{n_2}}$$

e.g. $n_1 = 0$

D7 on $S^3/\mathbb{Z}_k$

$n_2 = 2$

O5 at real codim. 2 on $S^3/\mathbb{Z}_k$

Here the tips  have only conical singularities.

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J. Polchinski,
ES '09

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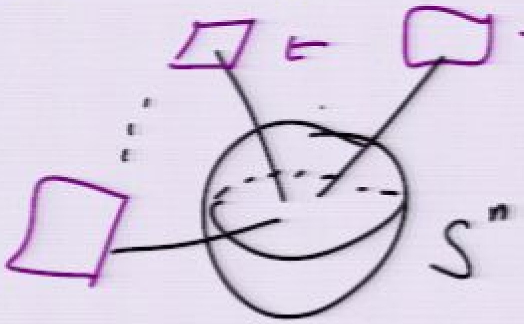

vary size and/or shape
(ρ or τ)

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Hellerman/McGreevy/Williams...
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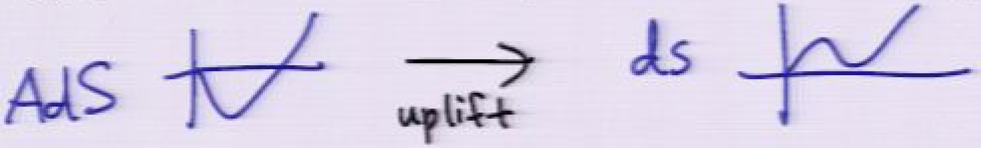

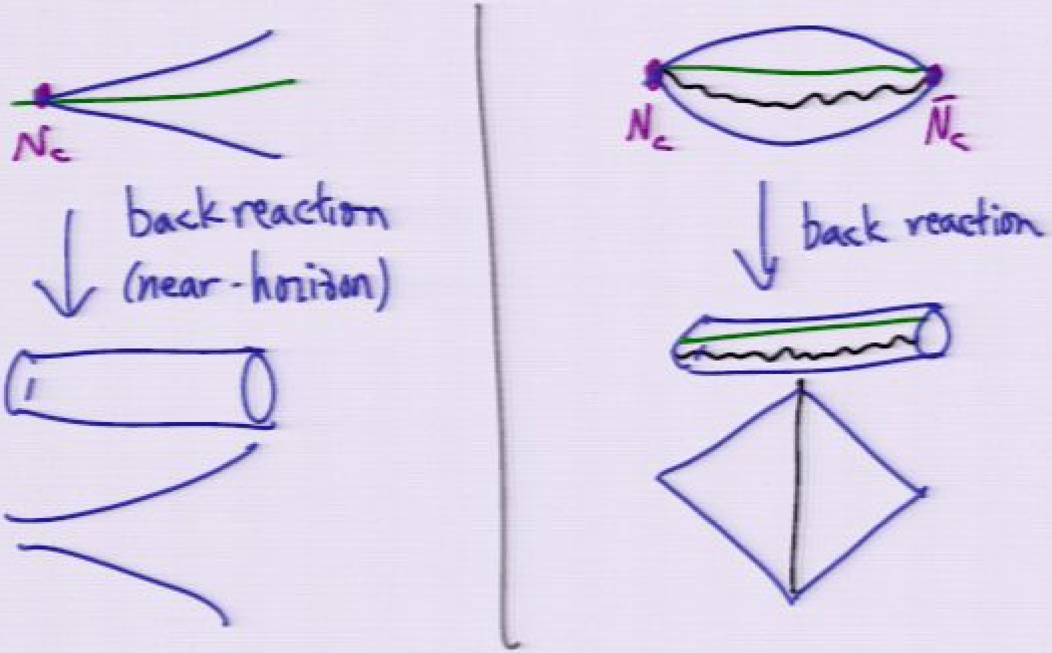

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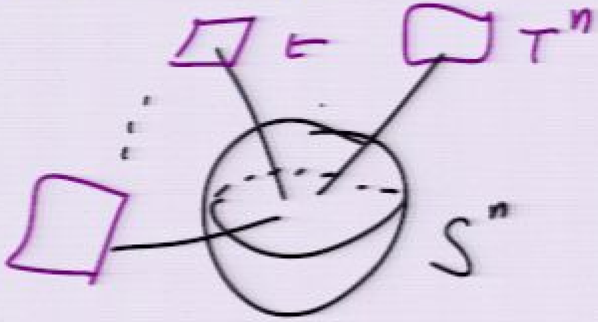

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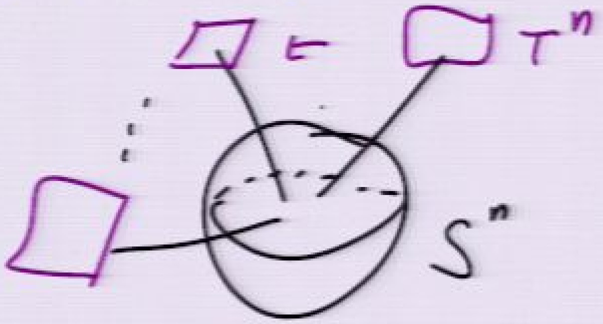

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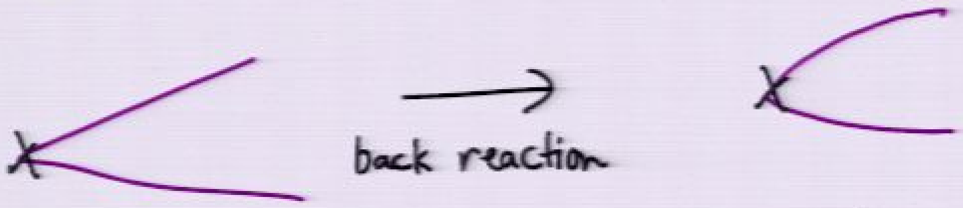

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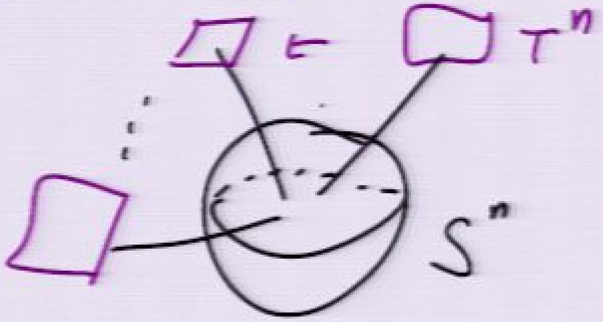

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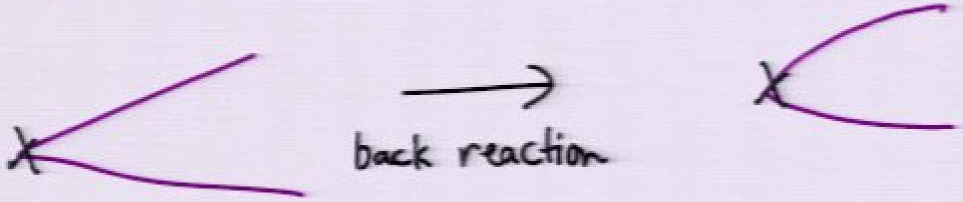

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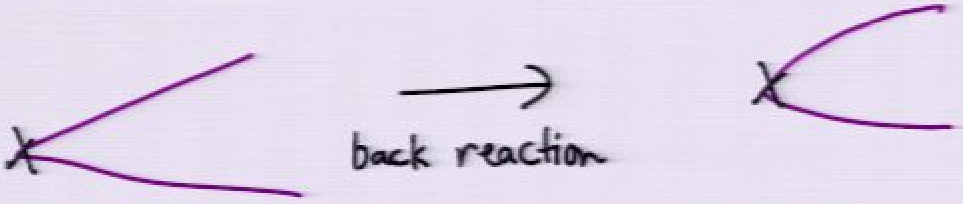

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A concrete example

$dS_3 = dS_2$
+ large-c
matter

				$S^3/\mathbb{Z}_k, r$				T^4			
		0	1	2	3	4	5	6	7	8	9
colors	D1	x	x								
	D5	x	x					x	x	x	x
fibration	ρ5	x	x	x	x					x	x
	ρ5'	x	x			x	x	x	x		
negative term	O5	x	x		x	x				x	x
	O5'	x	x	x			x	x	x		
	NS	x	x		x	x		x		x	
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or D5s	D7-$\bar{T}$	x	x	x	x	x	x		x	x	
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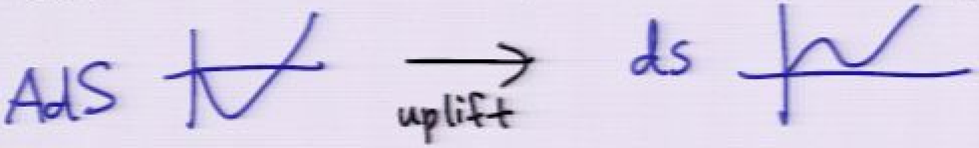

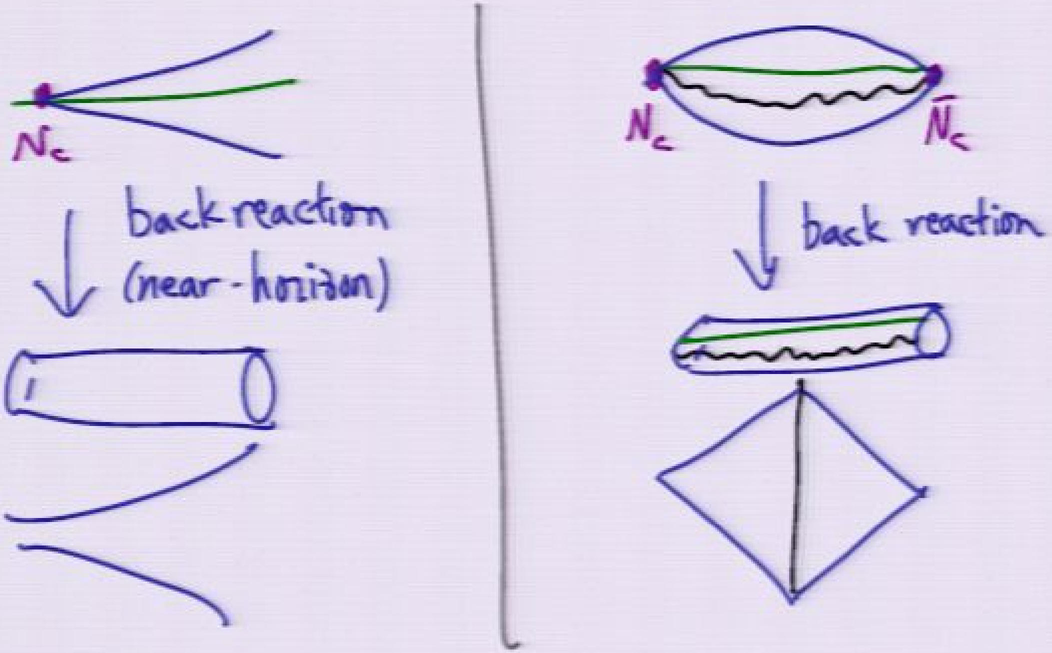

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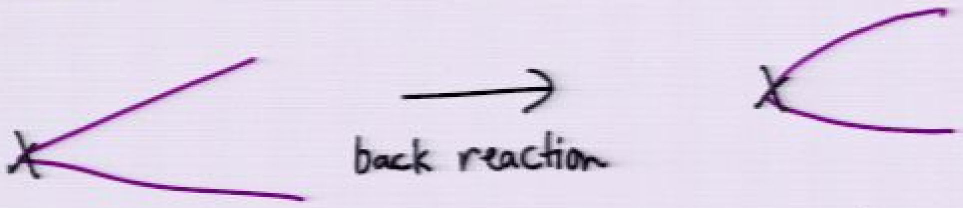

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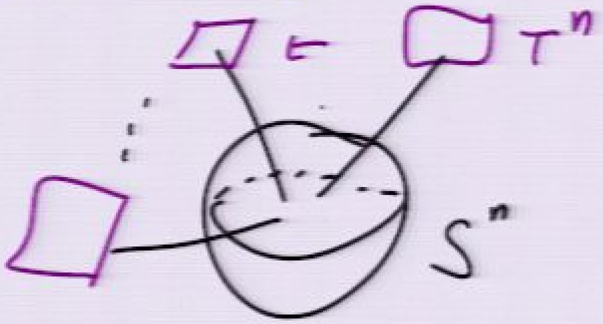

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Potential for $\beta \equiv \frac{kR_f}{R}$, R, L, g_s:

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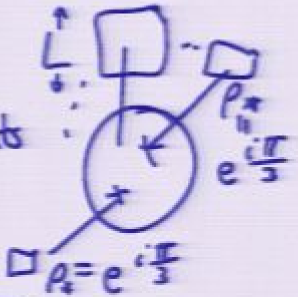
$$\rho = b_T + iL^2$$

$$\frac{(\nabla\rho)^2}{\mathrm{Im}\rho^2}$$ gradients



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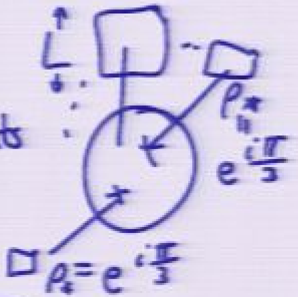

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(2) $\partial_L\left(\frac{\tilde{a}^2}{\tilde{b}^3}\right) \equiv 0 \Rightarrow$

$$24 - n_p - \hat{n}_p\left(\log\frac{L^2}{L_*^2}\right)^2 = 3\hat{n}_p \log\left(\frac{L^2}{L_*^2}\right)$$

- L bounded : $L < \exp(\cdots)$

$\Rightarrow$ $$k\, n_{NS5} = \frac{4\pi}{3}\beta\,\hat{n}_p\left(\log\frac{L^2}{L_*^2}\right)^2 + \mathcal{O}(\epsilon)$$

$\frac{\tilde{a}^2}{\tilde{b}^3} \equiv \frac{4}{27}$

bounded

Altogether, ∃ dS solution with

$R_f \sim \frac{R}{k}$ $\quad R^2 \sim L^2 \sim k \sim \sqrt{\frac{N_{D1}}{N_{D5}}}$

$N_{D5} \sim \sqrt{\frac{1}{\epsilon}}$ $\quad g_s \sim \epsilon$ $\quad R_{dS}^2 \sim \frac{R^2}{\epsilon}$

Numerical results:

$k = 44$

$N_{D1} = 156 \quad N_{D5} = 5$

$R \sim \mathcal{O}(10)$ or $\mathcal{O}(100)$

$\epsilon \sim 0.002$

$L \sim 3 \ , \quad R_f \sim 1$

positive mass matrix

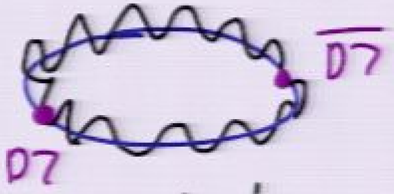
Ongoing work on dS_4, with parametrically large quantum #'s

Notes

- pairwise SUSY among most ingredients

- D7-$\overline{D7}$ in nontrivial $S^3/\mathbb{Z}_k$ Wilson line vacua

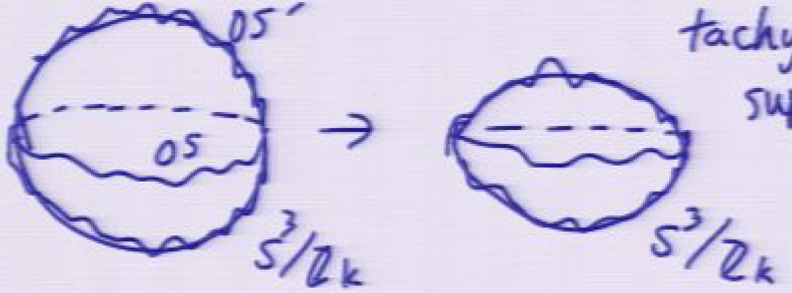
T-dual $\tilde{S}^1_f$:



- anisotropy modes non-tachyonic at sufficiently small $a \sim \mathcal{O}(\epsilon)$:

$$\frac{4ac}{b^2} \sim \frac{\mathcal{O}(\epsilon)\cdot c}{b^2} \leftarrow$$

O-planes' tachyons/tadpoles suppressed by ϵ



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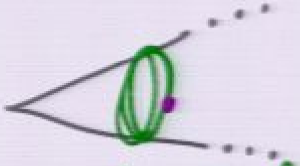
⇒ Gibbons-Hawking entropy

$$S \sim M_3 R_{dS} \sim \frac{R_f R^2 L^4}{g_s^2} \cdot R_{dS}$$

$$\sim \frac{k N_{D1} N_{D5}}{\epsilon^{3/2}}$$

(parametric count of horizon degrees of freedom )

$\epsilon^{-3/2}$ factor: cf Polchinski-ES '09 from hierarchy $R_{dS}^2 \sim \frac{R^2}{\epsilon}$



↳ # light winding strings $\sim (R_{dS}/R)^3 \sim \frac{1}{\epsilon^{3/2}}$

Can compute much more

Alishahiha Karch ES '04

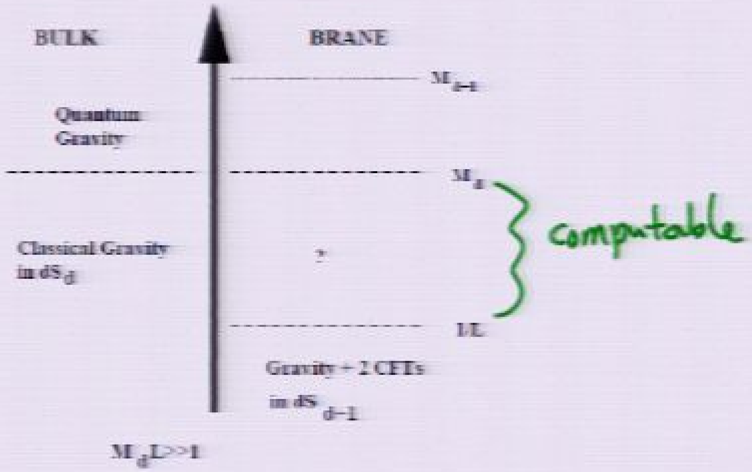


Figure 1: The hierarchy of scales. $M_{d-1}^{d-3} = L\, M_d^{d-2}$ appears as an induced scale beyond M_d, the ultimate cutoff of the theory.

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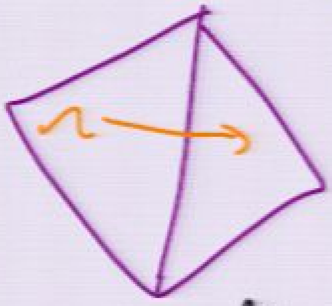
- 

  Tunneling between throats

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dS decays:

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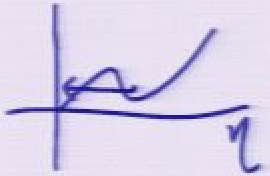

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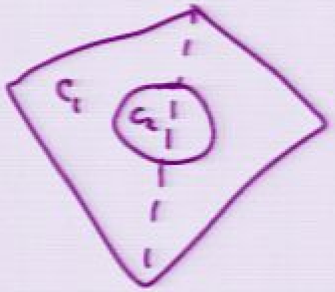
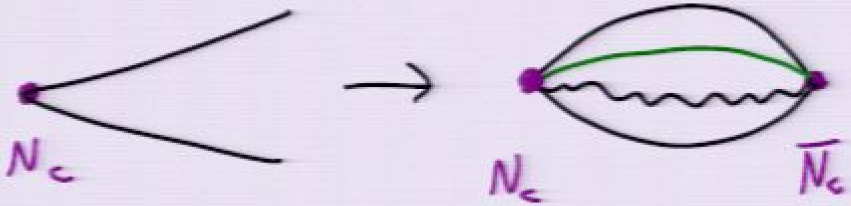


time-dependent RG flow

cf Strominger

Summary

- Upgrading AdS brane construction to dS ⇒ becomes compact



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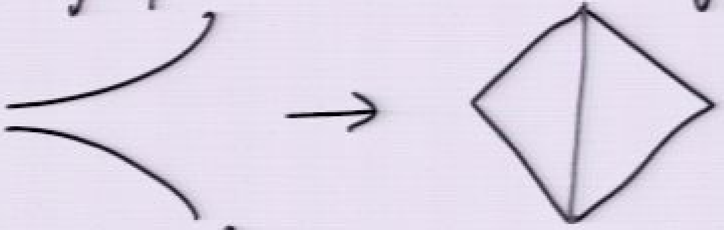

while revealing the microscopic degrees of freedom building up the throats/horizon

- cf [15] U. H. Danielsson, A. Guijosa and M. Kruczenski, "Brane-antibrane systems at finite temperature and the entropy of black branes," JHEP 0109, 011 (2001) [arXiv:hep-th/0106201].

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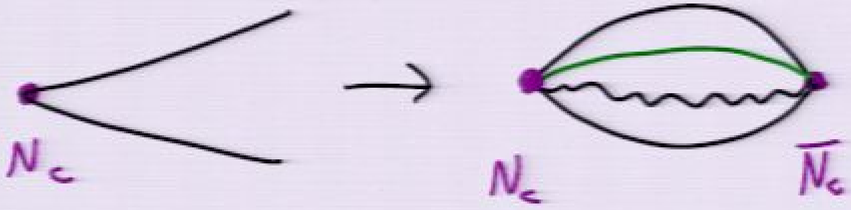

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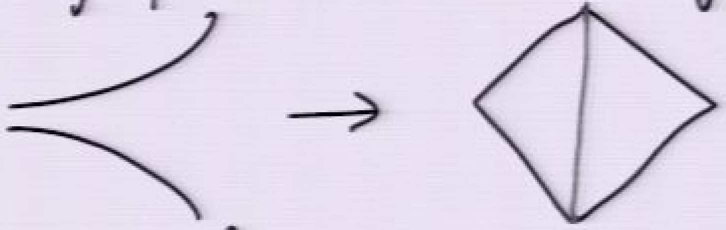

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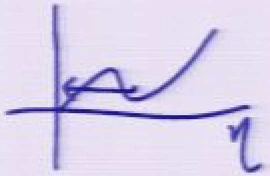

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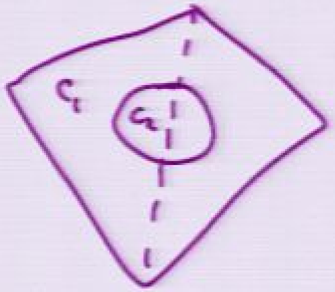

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cf Strominger

⇒ Gibbons-Hawking entropy

$$S \sim M_3 R_{dS} \sim \frac{R_f R^2 L^4}{g_s^2} \cdot R_{dS}$$

$$\sim \frac{k N_{D1} N_{D5}}{\epsilon^{3/2}}$$

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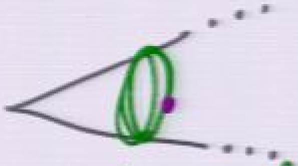

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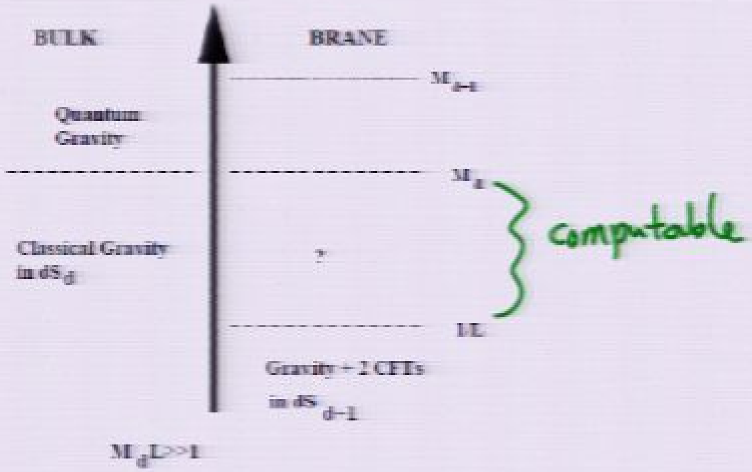

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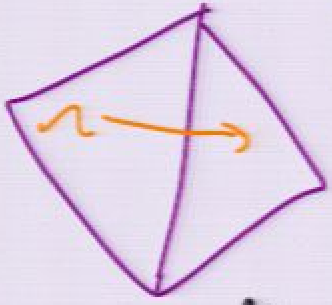
- 

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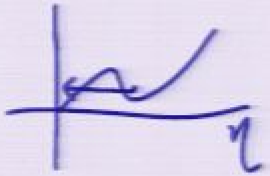

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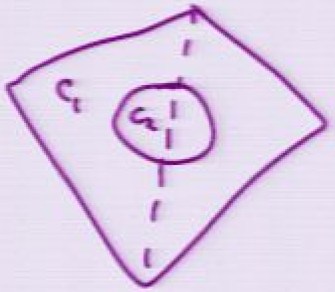

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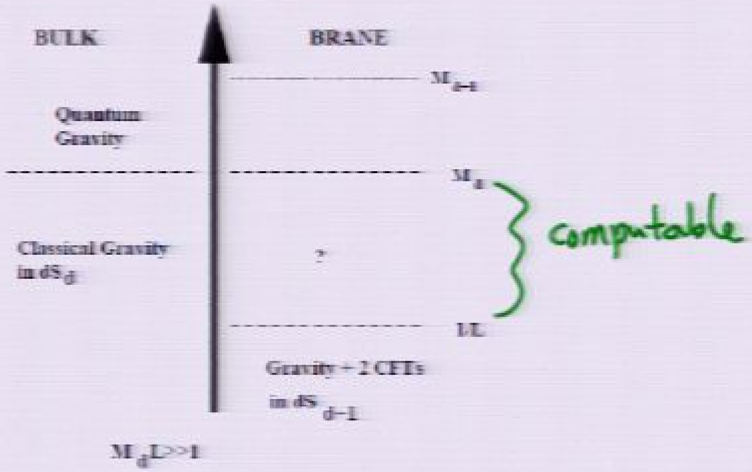

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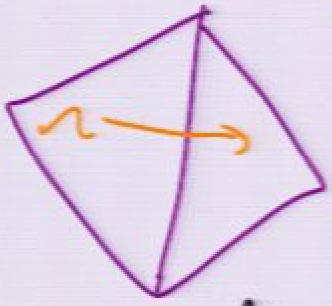

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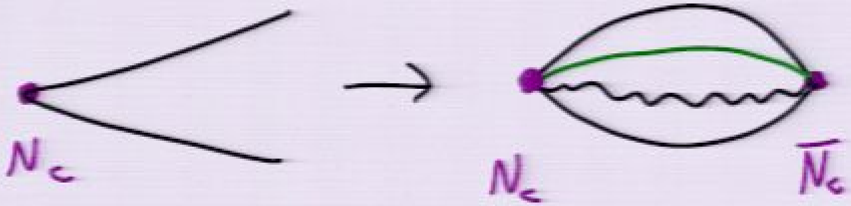

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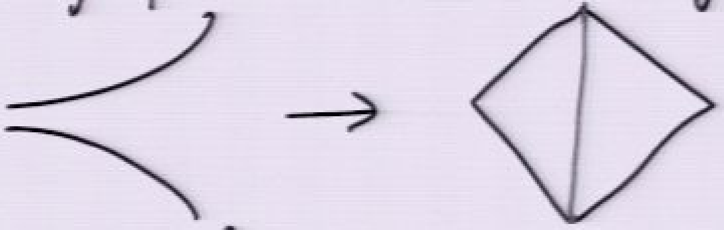

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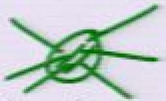
Many Open Questions

- Systematic analysis of simple, explicit dS models? cf Shiu et al
- More useful (than brane construction) presentation of the d-1 matter sector? cf $N=2$ ology: defined by brane construction
- Physics of UV cutoff & couplings?
- Liouville + large-c matter is a familiar system in worldsheet string theory. What are the appropriate observables in the present setting?



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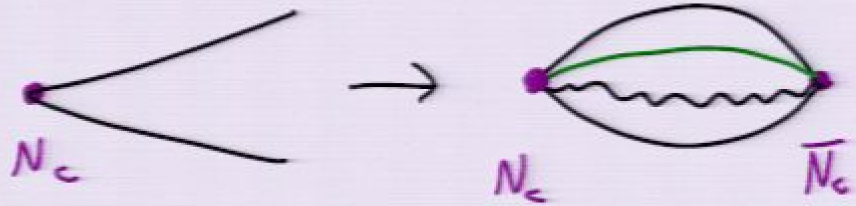

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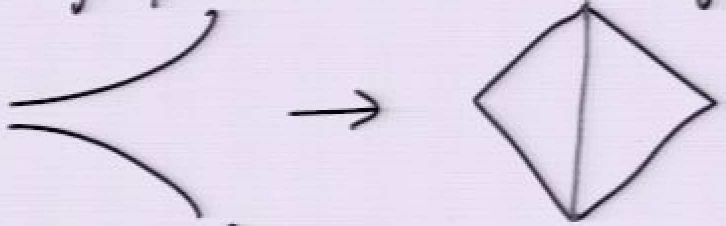

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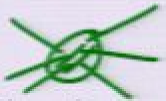

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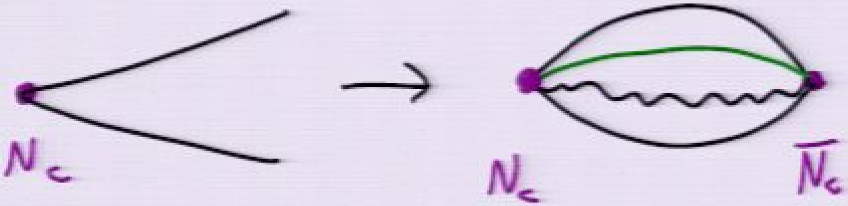

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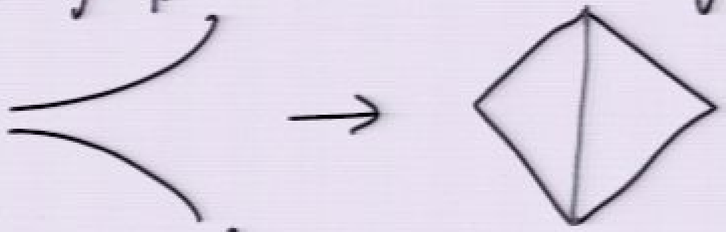

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More on control trade-offs between SUSY & ~~SUSY~~ :

1) Old-fashioned perturbation theory sufficient for control $g \ll 1$, $\frac{\alpha'}{R^2} \ll 1$..
(as in most real-world physics yet studied)

2) SUSY ⇒ protection, i.e. allows control of certain observables at strong coupling, and legislates against certain corrections in any case.

3) SUSY prevents some useful terms in the moduli potential which otherwise help stabilize moduli → can delay stabilization until the level of non-pert. effects, exponentially small barriers.

We'd like to know the basic degrees of freedom required to describe real (= cosmological, ~~SUSY~~) spacetime, and a framework for computing observables.

This talk:

Build up from AdS/CFT dual pairs, obtaining a concrete but semi-holographic description of dS & its decays.

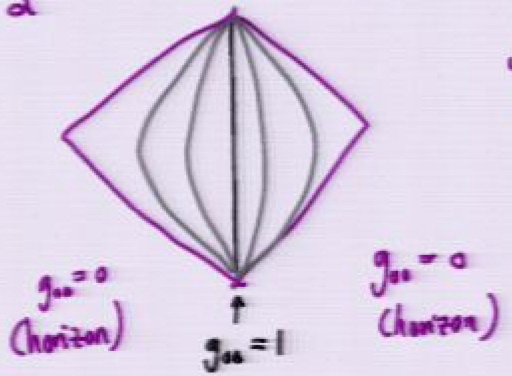
- framework - techniques - candidate model

→ Microscopic parametric count of Gibbons - Hawking dS entropy

Macroscopic dS semi-holography

dS is a 2-throated warped compactification

$$ds^2_{dS_d} = \sin^2\frac{r}{L}\, ds^2_{dS_{d-1}} + dr^2$$



"dS/dS"

☆ The 2 warped throats have a right to a holographic dual description, carrying the bulk of the horizon entropy.

- Gravity still propagates in $d-1$ dim's.

i.e. semi-holographic cf Randall-Sundrum

Gubser
Witten

Hawking
Maldacena
Strominger

Verlinde

Klebanov
Strassler

Giddings
Kachru
Polchinski