Micromanaging de Sitter Holography

based on

- X. Dong, B. Horn, ES, G. Torroba '10
  in progress
- 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. holography
- dS/CFT Strominger
- FRW/CFT Freivogel et al

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

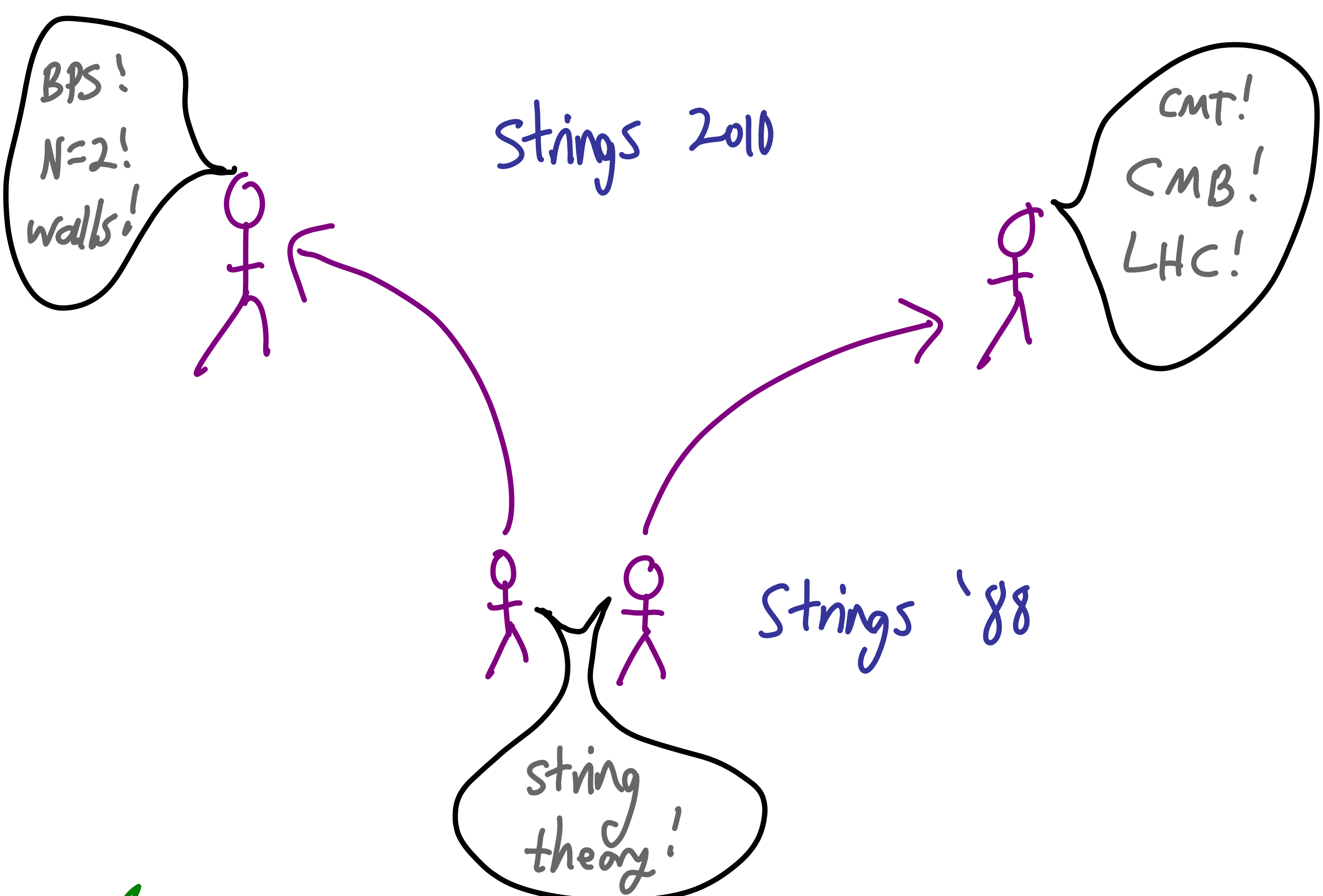
This talk:

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

We need a framework for physics with cosmological horizons: accelerated expansion $\Rightarrow$ observers lose causal contact



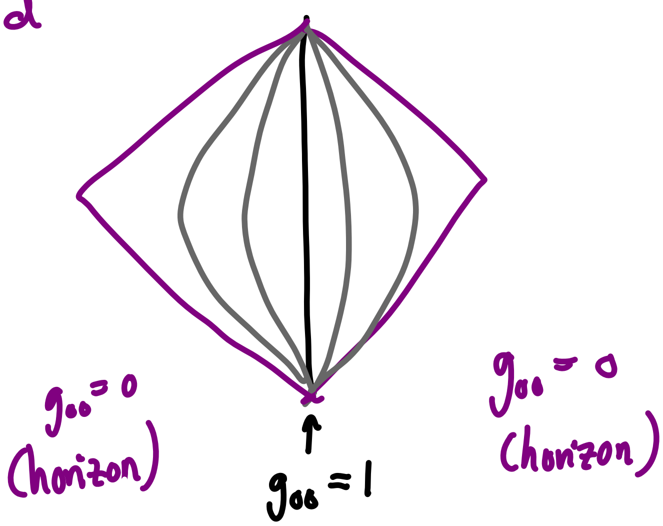
(There are some "metaobservers"...)

Macroscopic dS semi-holography

dS is a 2-throated warped compactification

Karch et al

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



"dS/dS"

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

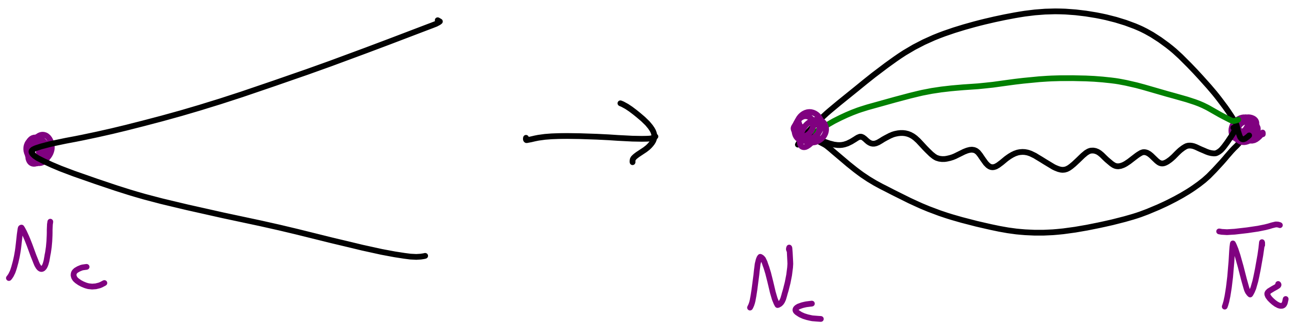
- Gravity still propagates in $d-1$ dim's.

i.e. semi-holographic cf Randall-Sundrum

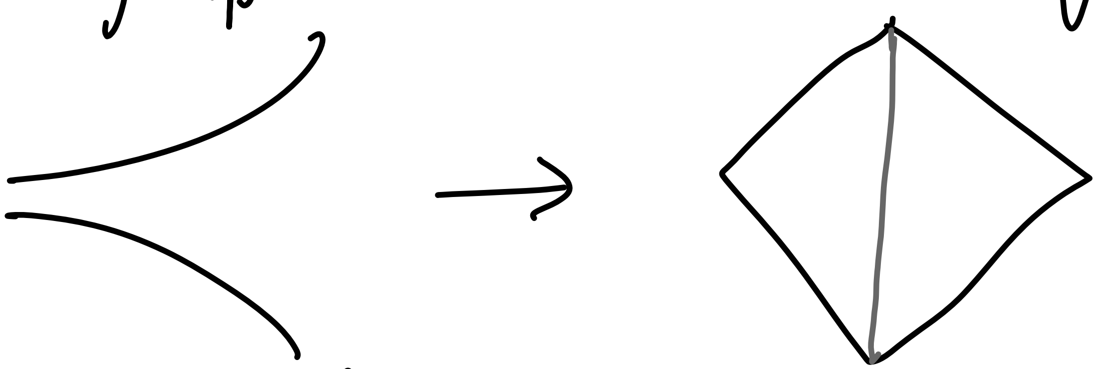
Gubser Witten Hawking Maldacena Strominger Verlinde Klebanov Strassler Giddings Kachru Polchinski

Outline / Summary :

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

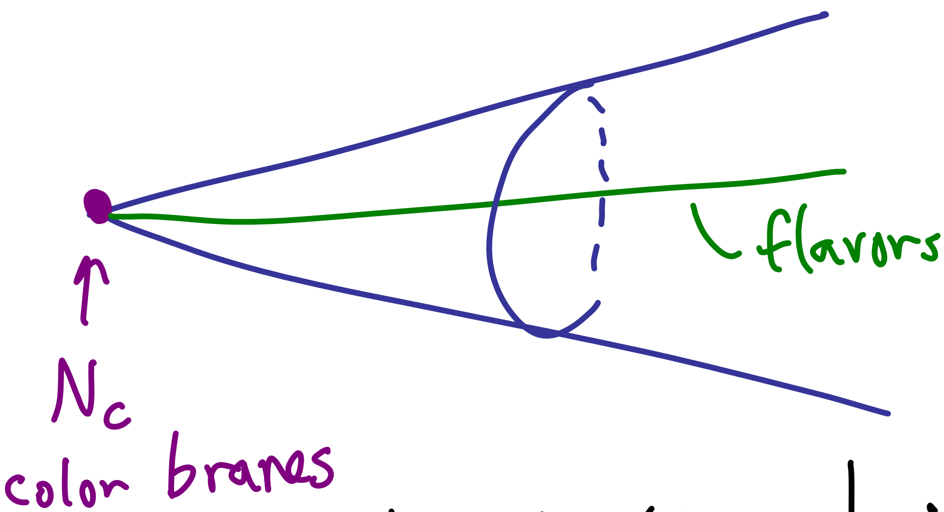


matching the macroscopic semi-holographic dS/dS duality

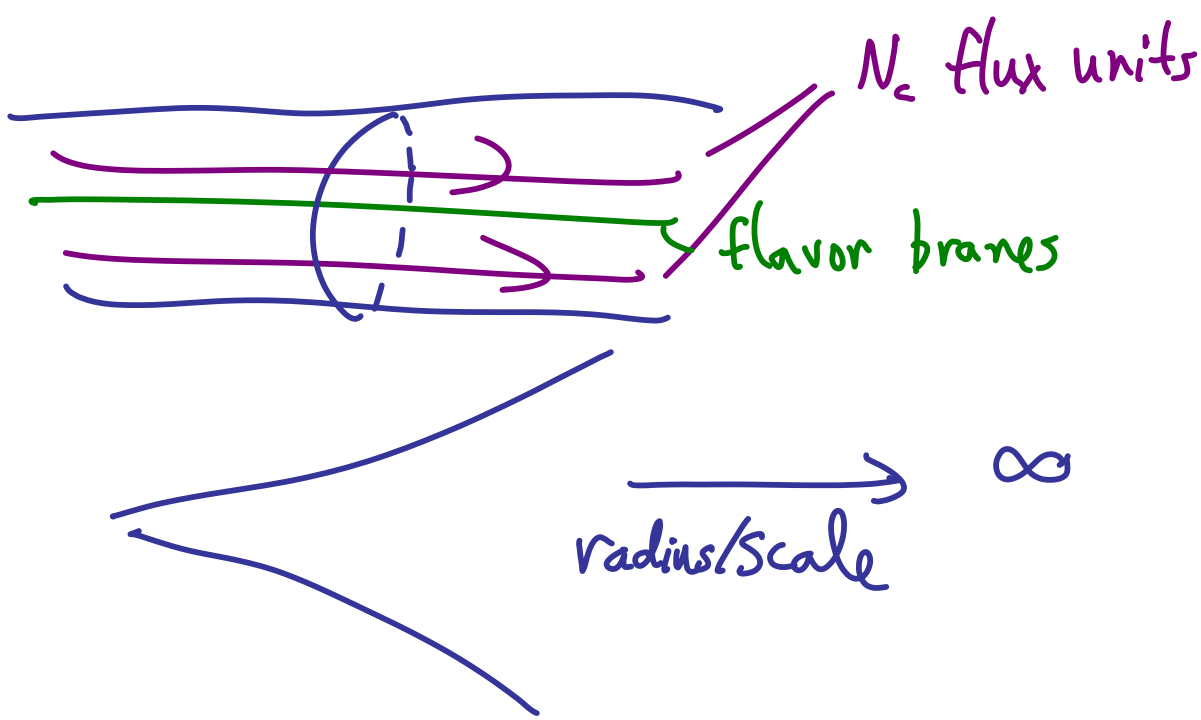


while revealing the microscopic degrees of freedom building up the throats/horizon

First, recall
AdS/CFT brane constructions



$\downarrow$ IR/Near horizon



AdS/CFT near horizon geometry

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

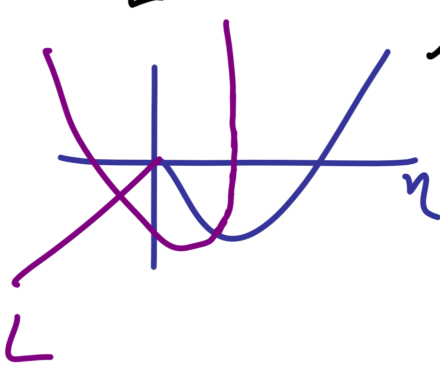
$$\text{size } R_f \rightarrow S^1_f \rightarrow S^3$$
$$\downarrow$$
$$S^2 \leftarrow \text{size } R$$

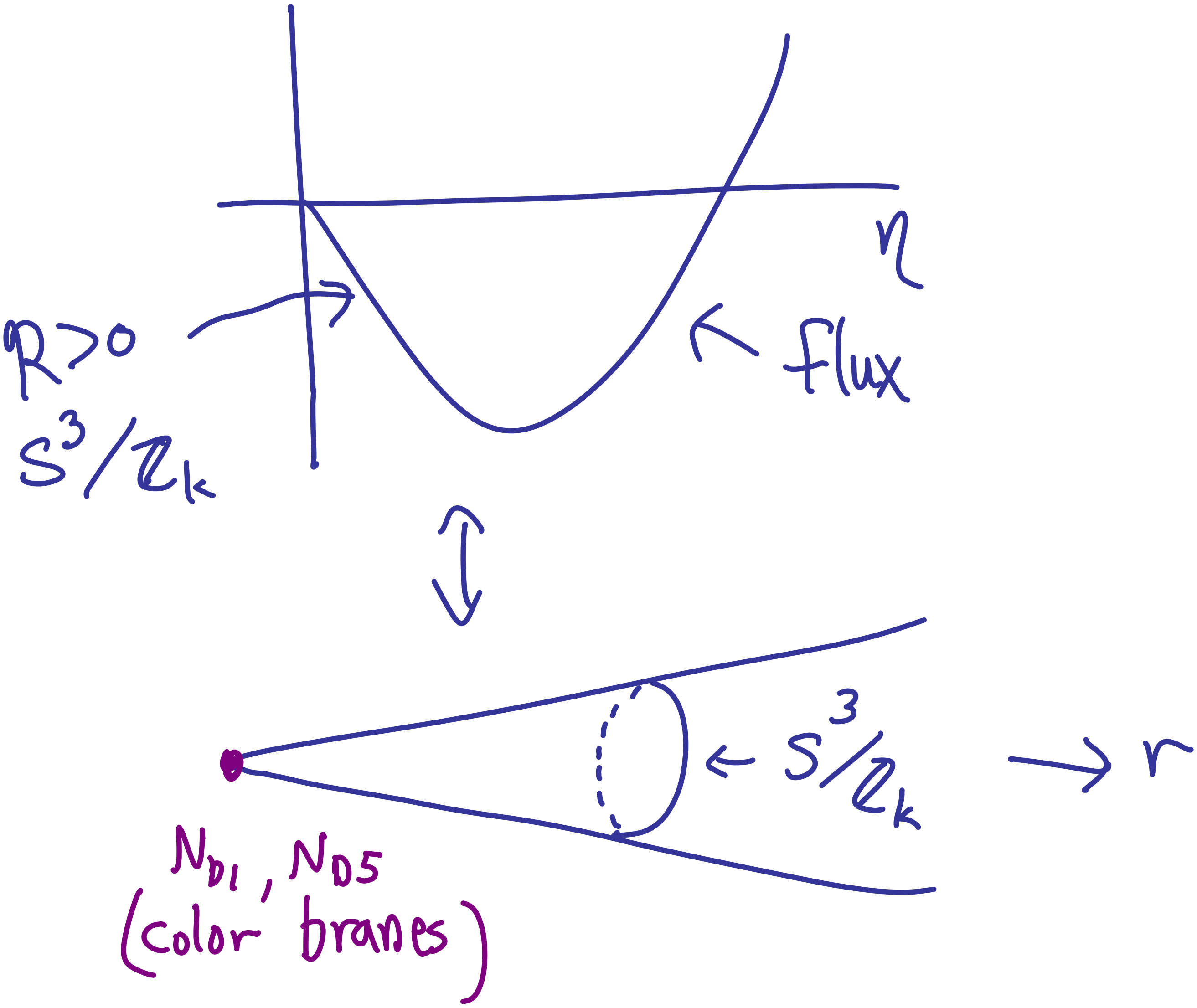
Effective potential

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

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

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





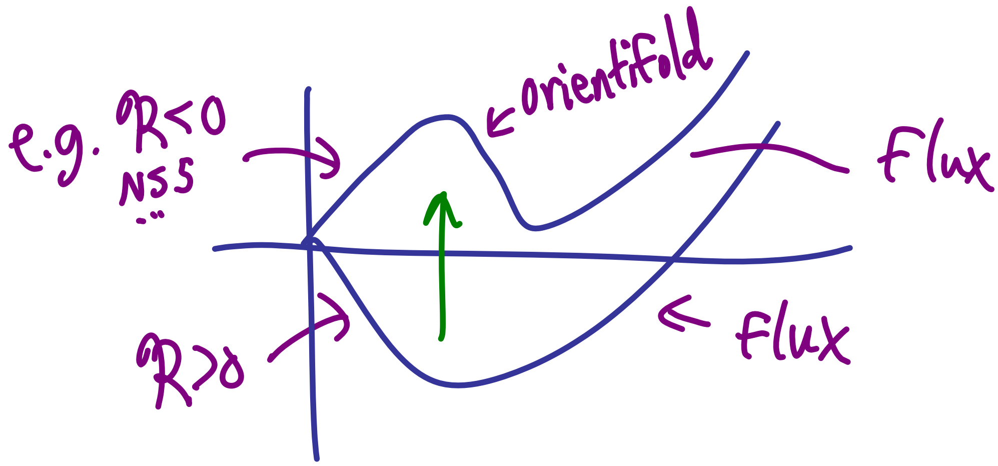
cone :

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

positive curvature

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

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

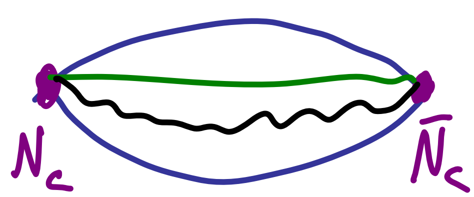


by adding appropriate ingredients to this model $\Longrightarrow$ effect on brane construction:

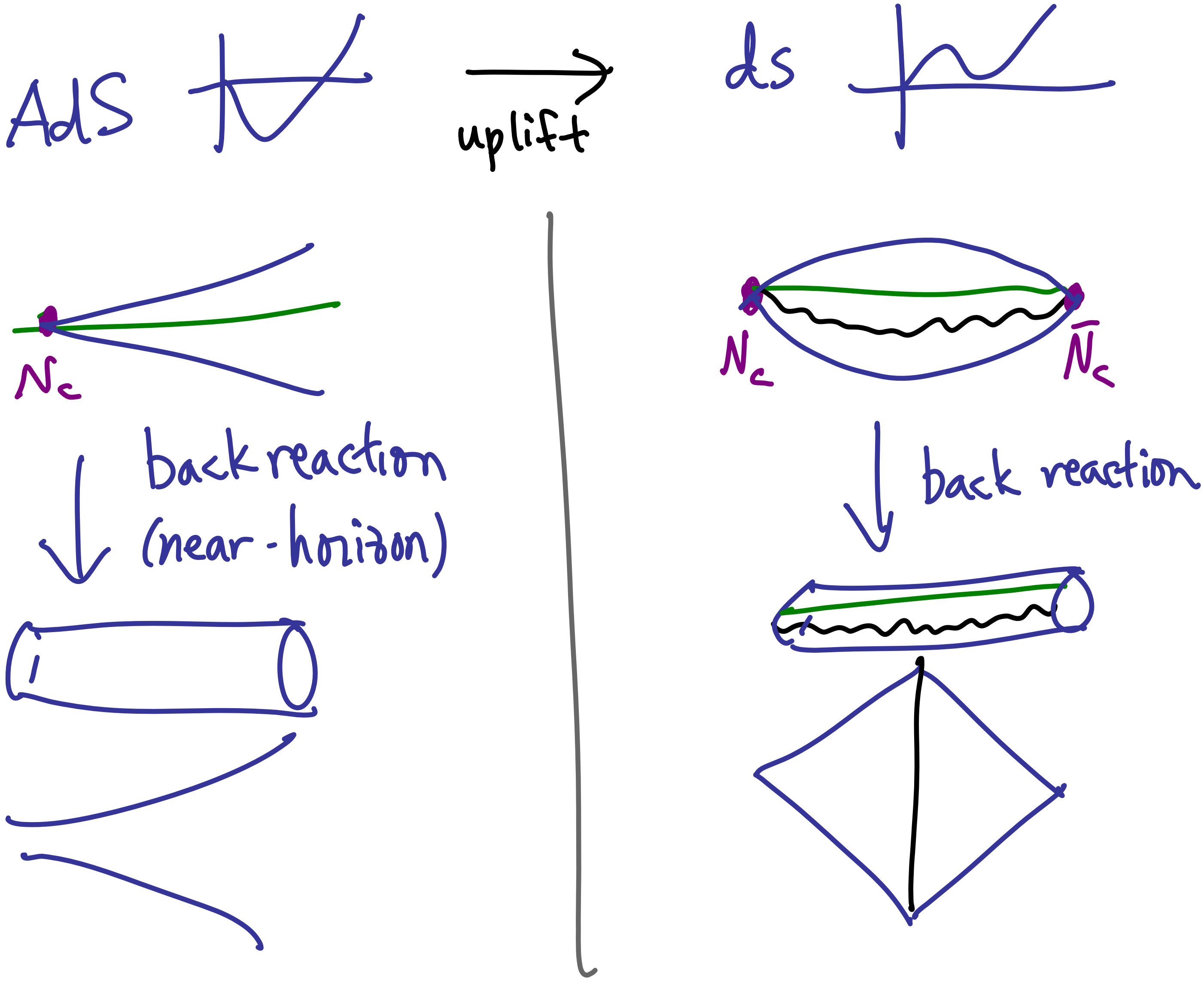
$$\left(\frac{dR}{dr}\right)^2 = -\frac{1}{R^2} + \frac{\text{const}}{R^n} + \cdots$$

n: O-plane codimension

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



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



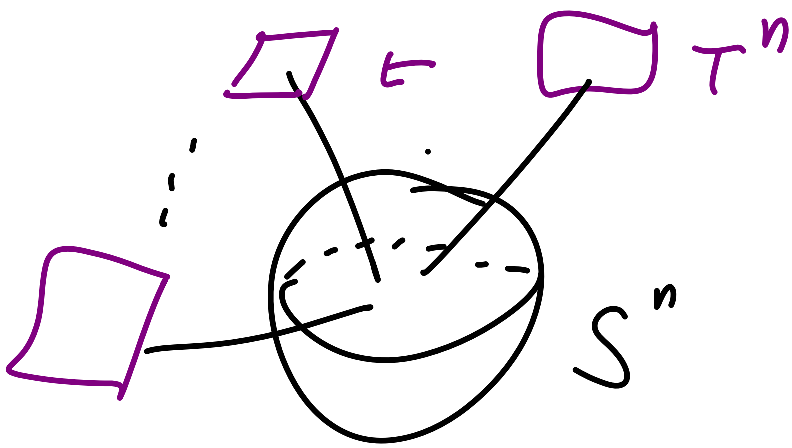
with the <u>microscopic</u> degrees of freedom of the two throats given by the brane construction. N_c colors ; + flavors & orientifold projection from uplifting.

Techniques:

J. Polchinski, ES '09

- $AdS \times S \times T^n$

"uplift" curvature energy via variation of T^n (or axio-dilaton, cf F theory) over the original Freund-Rubin base.



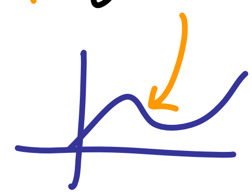
vary size and/or shape (ρ or τ)

Vafa, ...
Hellerman/McGreevy/Williams ...
Shelton Taylor Wecht ..

can use e.g. SUSY sigma model to describe fibration, with motion of "stringy cosmic branes" described appearing in the superpotential

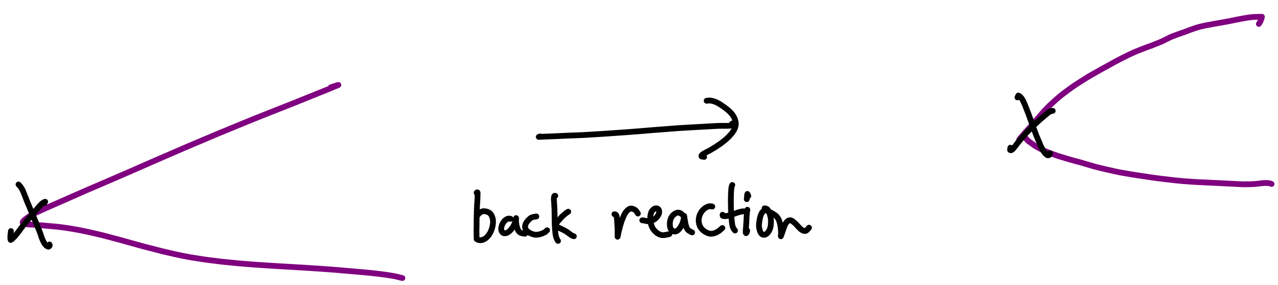
T^n fibration can consistently cancel (CY), under-cancel, or over-cancel the curvature of the base.

- Orientifolds provide crucial negative term in moduli potential



In 10d: $$ds^2_{\text{O-plane}} = dx_\perp^2\left(1-\frac{r_0^n}{r^n}\right) + \frac{dx_\parallel^2}{1-\frac{r_0^n}{r^n}}$$

counteracts deficit angles introduced by elliptic fibration



- Insist on perturbative control
  - radii $\gg \sqrt{\alpha'}$
  - bound/incorporate warp factor gradients cf Giddings, Douglas, D. + Kallosh, Maharana, Torroba, de Wolfe...

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

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

2) SUSY $\Rightarrow$ 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 $\rightarrow$ can delay stabilization until the level of non-pert. effects, exponentially small barriers.

A concrete example

$dS_3 = dS_2$ + large-c matter

(in progress)

		0	1	2	3	4	5	6	7	8	9
				$S^3/\mathbb{Z}_k$; r				T^4			
colors	D1	x	x								
	D5	x	x					x	x	x	x
fibration	$\rho 5$	x	x	x	x					x	x
	$\rho 5'$	x	x			x	x	x	x		
negative term	05	x	x	x	x	x	x	x	x	x	x
	05′	x	x								
	NS	x	x		x	x		x		x	
	NS′	x	x	x			x		x		x
	D7-$\bar{7}$	x	x	x	x	x	x		x	x	
	D7′-$\bar{7}'$	x	x	x	x	x	x	x			x

(Most pairwise SUSY)

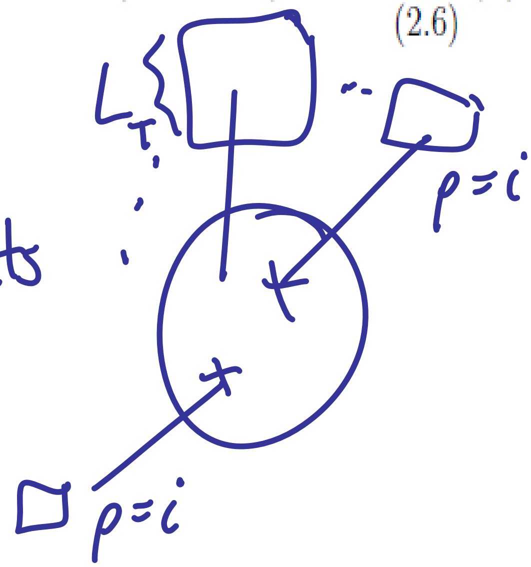
- Potential for $\beta \equiv \frac{R_f}{R}$, R, L, g_s:

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

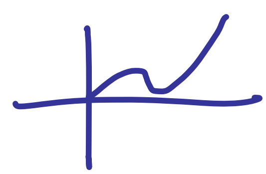
$$\mathcal{U} \sim M_3^3 k^3 \left\{ \left(\frac{1}{k} + \frac{\Delta n + n \log^2 L_T}{k\beta^2} + \frac{n_{NS5}}{L_T^2 \beta^3} \right) \eta^4 - \frac{\eta^5}{\beta^3} \left(R^2 - \frac{n_{D7} R^4 \beta}{k} \right) + k \frac{\eta^6}{\beta^4} \left(\frac{N_{D1}^2}{L_T^4} + N_{D5}^2 L_T^4 \right) \right\} \tag{2.6}$$

cf warp factor

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



$$\mathcal{U} = a\eta^4 - b\eta^5 + c\eta^6$$

Minimizing $\frac{ac}{b^2}$ near $\frac{1}{4}$ 

as a function of other moduli

$\Rightarrow$ dS solution

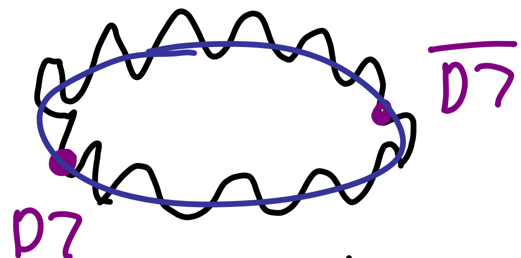
ES '08

Notes

- pairwise SUSY among most ingredients

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

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



- anisotropy modes non-tachyonic at sufficiently small a

- Warp factor e^A :
  - $\mathcal{U}K^2 \to \mathcal{U}K^2 + \mathcal{O}((\nabla A)^2)$
  - Look for $A \ll 1$, $(\nabla A)^2 \ll \nabla^2 A$ solution to $\nabla^2 A = \kappa^2 T_{loc} - \hat{\mathcal{U}}K^2$

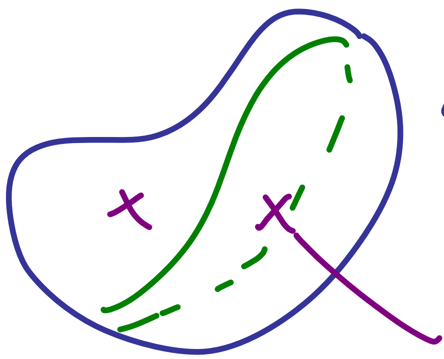
(small gravitational potential b/w sources).

More on Warp factor

cf Giddings
Kachru
Polchinski

Douglas

Douglas/Kallosh



- 4d EFT does not capture internal (10d) Einstein equations including effects of localized sources.
- $\mathcal{U} K^2 \to \mathcal{U} K^2 + \mathcal{O}((\nabla A)^2)$ with varying warp factor $e^{A(y)}$
- warp factor satisfies

Giddings/
Maharana

$$e^{2A}\left[-2\tilde{\nabla}^2 A + 4(\widetilde{\nabla A})^2 - \frac{1}{2}\tilde{R}_6\right] - e^{-2A}\kappa_4^2 U = -\kappa_{10}^2 U_{10} + \mathcal{O}(\beta^2)\,.$$

$\Rightarrow$ if $A \ll 1$, $(\nabla A)^2 \ll \nabla^2 A$ $\Rightarrow$ $\mathcal{U}$ not strongly corrected

(**Note:** This is not in conflict with negative internal curvature, maximally symmetric, compactifications.

- Nilmanifold = metric flux on T^2

  $\updownarrow$ T-dual Kachru Schulz Trivedi Tripathi

  H_3 on T^3

  and $\exists$ known solutions.

- As discussed above, the 10d equations are consistent with $e^A \approx 1$, though it is also very interesting to analyze other regimes.)

$\rightarrow$ • dS solution with

$$R_f \sim \frac{R}{k} \quad R^2 \sim k \quad L_T^2 \sim k \sim \sqrt{\frac{N_1}{N_5}}$$

$$N_{O5} \propto \frac{1}{\sqrt{a_*}} \quad g_s \sim \frac{1}{N_{D5}^2}$$

• Moduli potential $\mathcal{U}$ above a good approximation

e.g. Localized O5s $\rightarrow$

warp factor e^A : $\nabla^2 A = g_s \sum \delta(x_\perp) - \bar{u}$

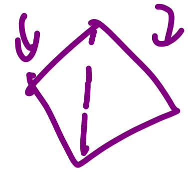
$$\rightarrow \cdots \rightarrow \quad A \sim \frac{g_s}{R_f R} \ll 1$$

$\Rightarrow$ Gibbons-Hawking entropy

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

$$\sim k N_{D1} N_{D5}$$

untuned

(parametric count of horizon degrees of freedom )

Semi-holographic dS and Entropy

As in Randall-Sundrum theory

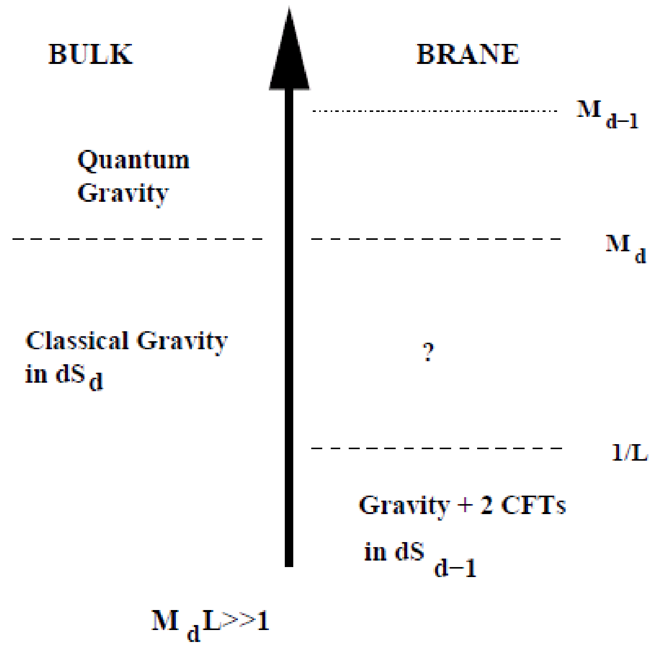
$$M_{d-1}^{d-2} = \int dr \sqrt{g} = S \cdot (\text{cutoff})^{d-2}$$

gravity$_d$ side (classical)

QFT + GR$_{d-1}$ side (quantum)

Can compute much more

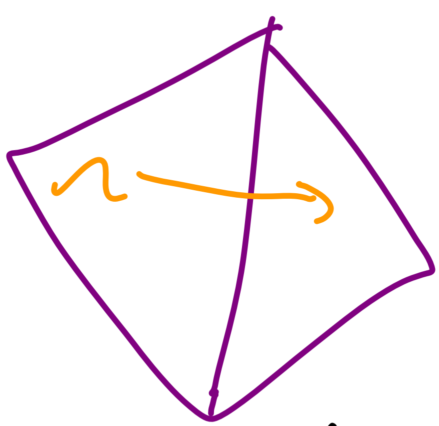
Alishahiha Karch ES '04



computable

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

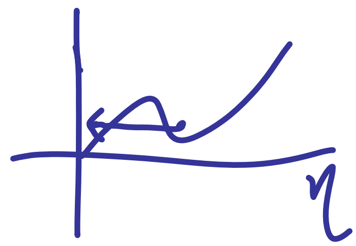
$$\int d^{d-1}x \sqrt{g}\, \mathcal{O}^{(1)} \mathcal{O}^{(2)}$$

- operator dimensions dressed by GR_{d-1}

dS decays:

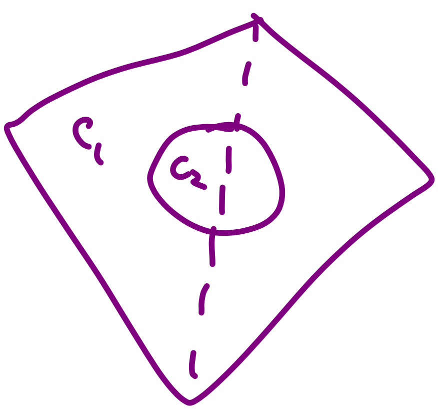
- Flux dual to color sectors decays via Schwinger effect

- $g_s \to 0$, $R \to \infty$



Involves both QFT_{d-1} & GR_{d-1} ...

cf Shenker

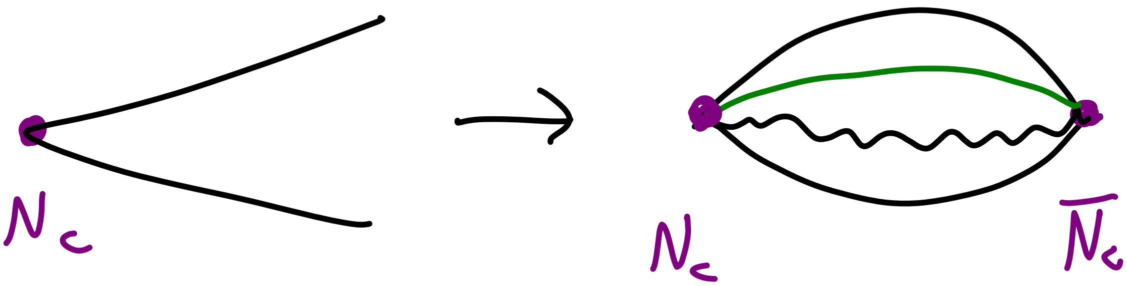


time-dependent RG flow

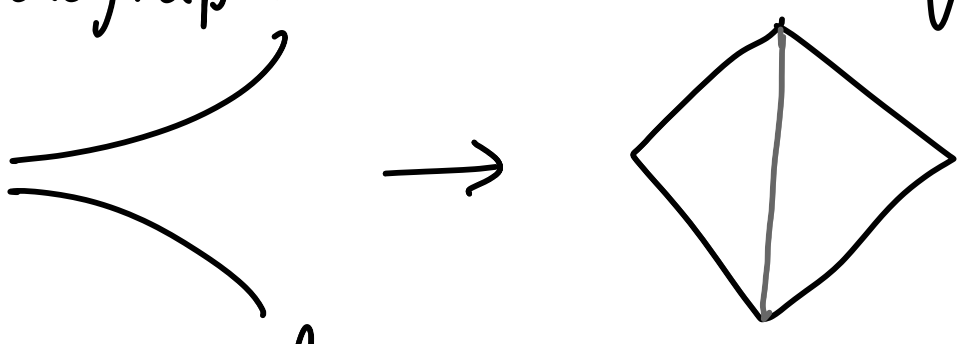
cf Strominger

Summary

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



matching the macroscopic semi-holographic dS/dS duality



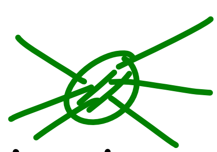
while revealing the microscopic degrees of freedom building up the throats/horizon

- 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].

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?



- Could the theory lead us to a well-defined "measure"?