Time-Dependent Physics in Multi-Brane Constructions

Based on work with

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+ ... ?

Consider a low-energy effective theory involving two (4d) Yang-Mills sectors G_1 & G_2 coupled to each other via

gravity

M theory

Quantum-mechanically, the gauge-invariant excitations in the two YM sectors will mix (modulo selection rules from [discrete] global symmetries, if these exist).

If

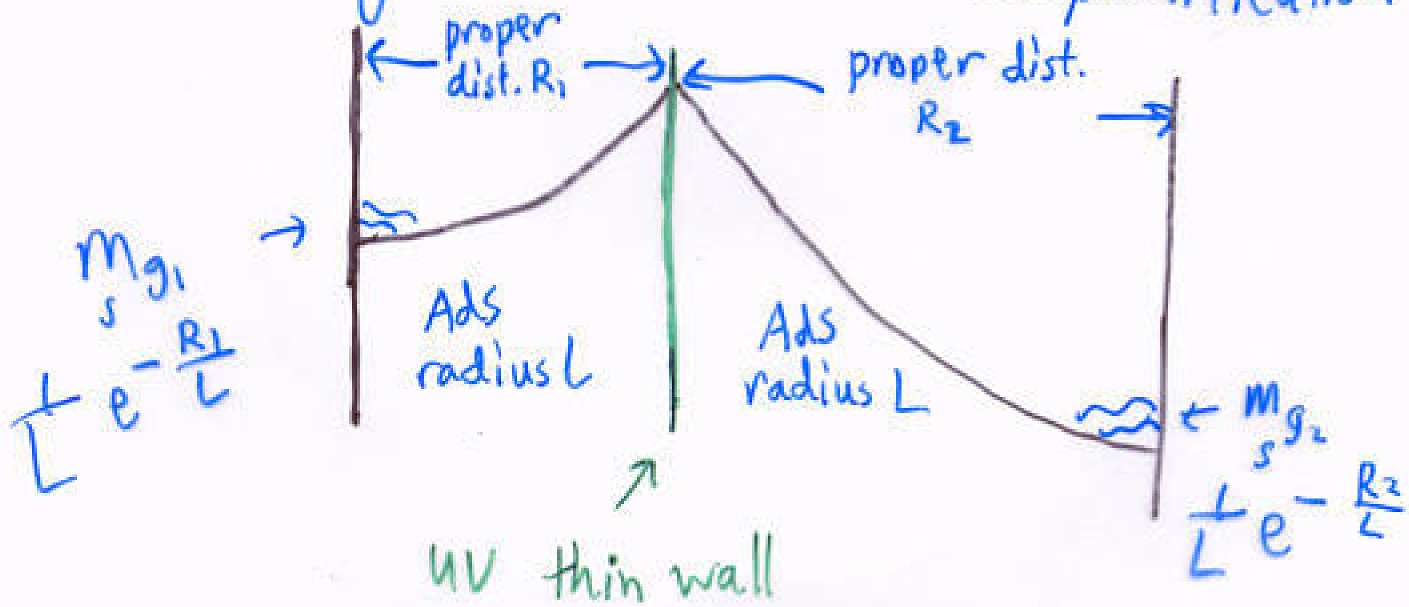
$$M^{(1)}_{\substack{\text{lightest}\\ \text{glueball } g_1}} > M^{(2)}_{\substack{\text{lightest}\\ \text{glueball } g_2}}$$

what is the decay rate $\Gamma_{g_1 \to g_2\text{'s}}$?

If the YM sectors live on branes, the AdS/CFT correspondence transforms this problem, in its regime of utility $g^2_{YM,i} N_i \gg 1 \quad N \gg 1$, to a double-well tunneling problem:

- Both sets of glueballs are made of the same stuff (10-11d gravitons + ...)
- The warp factors in the near-horizon metrics lead to a potential barrier between the lightest modes in each throat.

In order to do explicit calculations, work with RS-esque toy model approximating the branes + compactification



boundary conditions encode (some) information about the compactification

Take $M_{UV} \sim \frac{1}{L} \ll M_4$

$$ds^2 = \frac{L^2}{(|z|+L)^2}\left(\eta_{\mu\nu}dx^\mu dx^\nu + dz^2\right)$$

5d gravitons in this background satisfy the equation of motion $h^{TT}_{\mu\nu} = \frac{L}{|z|+L} \psi_{\mu\nu}$

$$-\partial_z^2 \psi + \underbrace{\frac{15}{4\,(|z|+L)^2}}_{\text{effective Schrodinger potential } V(z)} \psi = \underbrace{m^2}_{\text{4d mass}} \psi$$

in bulk,

with boundary conditions at the UV & IR branes.

Note that (since it came from varying the 5d gravitational action

$$\underbrace{M_5^3}_{\text{5d planck mass}} \int d^5x \sqrt{g} \left(R - \frac{1}{L^2} \right) \quad)$$

this equation of motion is <u>independent of</u> <u>M_5 (& M_4)</u>.

In real life, the IR cutoff arises from confinement dynamics, and the warp factor is not simply $\frac{1}{z^2}$ (cf Strassler - Polchinski)

It will be interesting to calculate the tunneling / decay rate in the exact metric once this is known. This will affect the form of the effective Schrodinger potential $V(z)$, but it will not change the fact that the leading-order tunneling effect is independent of the Planck scale.

cf Klebanov + Co.
mid 90's

In our tunneling problem, consider outgoing wave on the right

$$\psi^{(1)}_{\mu\nu}(z) = \sqrt{m(|z|+L)}\left(A\, H_2^+(m(|z|+L)) + B\, H_2^-(m(|z|+L))\right)$$

$$\psi^{(2)}_{\mu\nu}(z) = C\, H_2^+(m(|z|+L))$$

Normalizable mode in full AdS
$\Updownarrow$
CFT

Non-normalizable mode in full AdS
$\Updownarrow$
couplings in CFT, i.e. asymptotic gravitons/closed strings

where $H_2^{\pm}(x) = J_2(x) \pm i\, N_2(x)$

$$\Big\downarrow\; x \gg 1$$

$$\sqrt{\frac{2}{\pi x}}\; e^{\pm i\left(x - \frac{5}{4}\pi\right)}$$

The transition probability is given by

$$P \sim \left|\frac{C}{A}\right|^2 \sim \left.\left|\frac{H_1^- H_2^+ - H_1^+ H_2^-}{H_1^+ H_2^- + H_1^- H_2^+}\right|^2\right|_{mL}$$

imposing boundary conditions

$$mL \sim e^{-\frac{R_1}{L}} << 1 \Rightarrow$$

$$P \sim \left. \left| \frac{N_2 J_1 - N_1 J_2}{H_1^- H_2^+ + H_1^+ H_2^-} \right|^2 \right|_{mL} + \text{subleading terms}$$

$$\boxed{\begin{aligned} \Rightarrow P &\sim (mL)^4 + \mathcal{O}([mL]^8) \\ &\sim e^{-\frac{4R}{L}} + \mathcal{O}\left(e^{-\frac{8R}{L}}\right) \end{aligned}}$$

$\Rightarrow$ decay rate $\Gamma \sim (\#\,\text{collisions}/\text{time}) \times P$

$$\boxed{\begin{aligned} \Gamma &\sim m^5 L^4 + \mathcal{O}(m^9 L^8) \\ &\sim \frac{1}{L} e^{-\frac{5R}{L}} + \mathcal{O}\left(\frac{1}{L} e^{-\frac{9R}{L}}\right) \end{aligned}}$$

These results exhibit tunneling suppression,

but no $\frac{1}{M_p}$ suppression factors.

What about decay into light modes on the UV brane (compactification)?

A similar 5d analysis reveals that this rate $\check{\Gamma}$ is suppressed by

$$\frac{\check{\Gamma}}{\Gamma} \sim \frac{1}{(M_5 L)^3} \sim \frac{1}{N^2}$$

degeneracy factor for decay into gauge theory excitations

G_1 G_2

"gravity" (compactification)

Going back to the holographic dual gauge theories, we can learn about the 4d effective Hamiltonian coupling the two gauge theories.

gravity	gauge theory
Normalizable mode J of 5d graviton	state with $\langle T_{\mu\nu} \rangle \neq 0$
Non-normalizable mode $iN+J$ of 5d graviton	coupling (asymptotic gravity/closed string mode)

In the cutoff/compactified theory these become dynamical & can mix with gauge theory states

If one had simply 2 CFT's coupled to 4d gravity, would get

$$\tilde{H}_{int} \sim \frac{1}{M_4^4} \underbrace{T^{(1)}_{\mu\nu} T^{(2)}_{\mu\nu}}_{\text{dimension } 8}$$

as the leading coupling between the two CFT's.

This would lead to

$$\tilde{p} \sim \frac{1}{M_4^8} m^8 \Rightarrow \tilde{\Gamma} \sim \frac{m^9}{M_4^8}$$

Our result is different in 2 respects.

1) The UV suppression scale is $M_{UV} \sim \frac{1}{L} \neq M_4$

2) the coupling is effectively via a dimension 6 operator:

$$p \sim m^4 L^4 \Rightarrow \text{prob. amplitude } A \sim m^2 L^2,$$

which would arise from

$$H_{int} \sim L^2 \, \mathcal{O}_{12}^{[6]} \leftarrow \text{dimension-6 operator}$$

our eigenmodes are of the form

$$\psi^{(1)} \sim \left(J + (mL)^2 N\right) \sqrt{m(|z|+L)} \quad \text{on the left}$$

$$\psi^{(2)} \sim \left(J + iN\right) \sqrt{m(|z|+L)} \quad \text{on the right}$$

If we identify

$$J \leftrightarrow T_{\mu\nu}(G_1)$$

$$J + iN \leftrightarrow \mathcal{O}_{\mu\nu}(R^{(5)}, K)$$

← dimension-2 operator made up of newly-normalizable asymptotic gravity

5d curvature

extrinsic curvature at UV brane

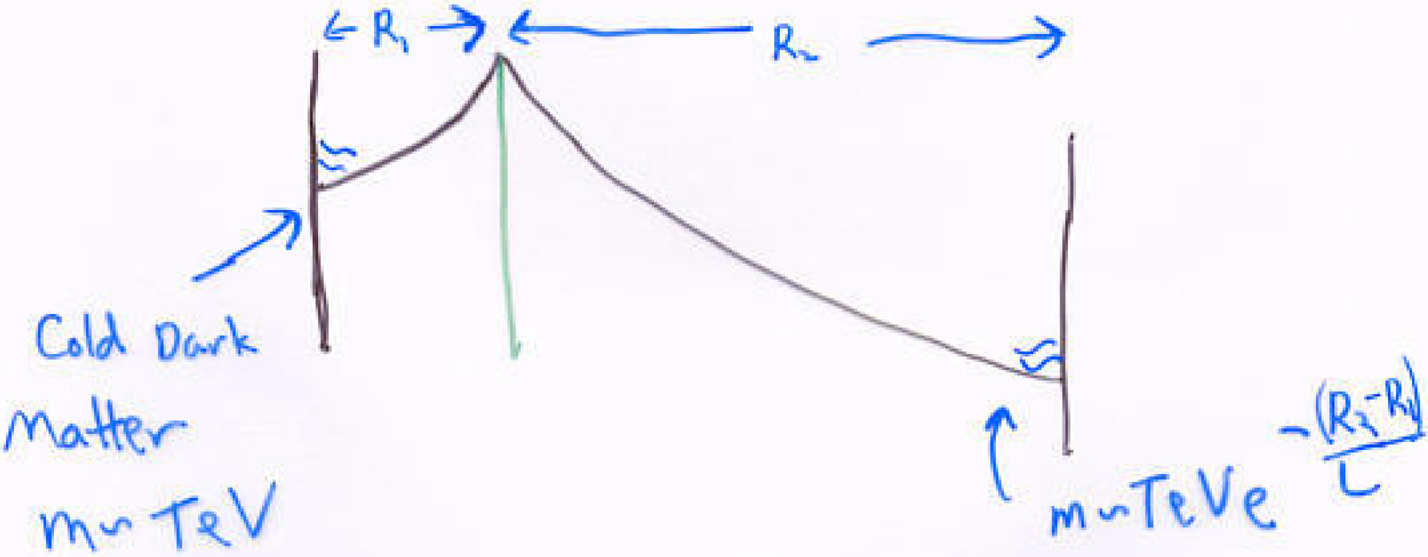
then our result suggests that the stress tensor $T'^{(1)}_{\mu\nu}$ of the low-energy effective QFT_1 in this system is of the form

$$T'^{(1)}_{\mu\nu} \sim T_{\mu\nu}(G_1) + \frac{1}{L^2}\begin{Bmatrix}(mL)^2 \\ \partial_4^2\end{Bmatrix} \mathcal{O}_{\mu\nu}(R^{(5)}, K) + \cdots$$

$$\to \mathcal{H}_{int} \sim L^4 T'^{(1)}_{\mu\nu}\, \mathcal{O}^{(2)}_{\mu\nu} \sim L^2 \underbrace{T_{\mu\nu}(G_1)\, \mathcal{O}^{(2)}_{\mu\nu}}_{\text{dimension 6}} + \cdots$$

One potential application of this tunneling effect is to hidden sector physics.

e.g. source of astrophysical dark matter



In the kind of (fairly generic) compactification we have been discussing, our tunneling/decay effect will change the concentation of hot vs cold dark matter.

ΛCDM works well for structure formation, nucleosynthesis, etc. However a possible discrepancy of collisionless CDM with observations of the shape and/or concentration of dark matter in galactic halos has emerged. The halos are less clumpy and less concentrated than in CDM simulations, according to some analyses.

proposed solutions include

- self-interacting CDM (hadron-scale particles & interactions) Spergel-Steinhardt, ...
- fluid DM Peebles
- no problem after all Primack ...

Our setup suggests the possibility of long-lived, metastable CDM particles which decay $\sim$now (long after nucleosynthesis), reducing the clumping and central concentration of the halos.

We find an interesting coincidence of scales in this scenario:

setting the lifetime $\tau \sim \Gamma^{-1} \sim 10^{10}$ years

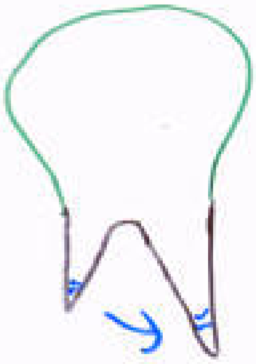
$$\sim 10^{60} / M_4$$

yields

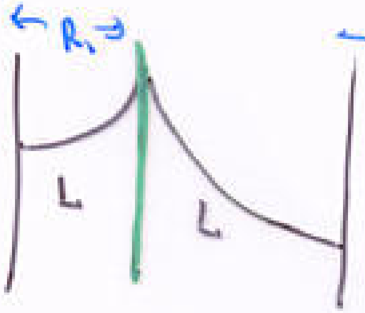
$$L^{-1} \sim 10^{14}\ \text{GeV} \quad \text{GUT scale}$$

$$M_5 \sim 10^{17}\ \text{GeV}$$

Conclusions



Tunneling between brane throats is independent of (and can dominate over) 4d gravity mediated communication



$$\Gamma \sim m^5 L^4 \sim \frac{1}{L} e^{-\frac{5R_1}{L}}$$

$\leftrightarrow$ dimension-6 coupling in 4d

potential applications include decaying astrophysical dark matter

Approach to dS Model-Building using Multiple large-N brane sectors:

To obtain dS space as a solution of string/M theory at low energies, we need a *local* minimum of the scalar potential energy $V(L_i, \alpha)$ in a frame with no moduli-dependence in front of the Einstein term in the d spacetime dimensions.

In this frame, $V \to 0$ as $L_i \to \infty$ and/or $e^{\alpha} \to 0$.

Why is dS construction hard?

$$V\left(\frac{1}{L}\right) \sim \sum_n c_n \left(\frac{1}{L}\right)^n$$

Need $V'\big|_{L_0} = 0 \quad V\big|_{L_0} > 0 \quad V''\big|_{L_0} > 0$

Using the contributions of brane charges + flux quanta, some coefficients c_n can be chosen so that different orders in $\frac{1}{L}$ perturbation theory compete and can balance against each other. (cf Banks-Zaks) The challenge is to get the right signs:

To get (meta-) stable minimum in V above zero, with $L \gg L_p$ for control, want

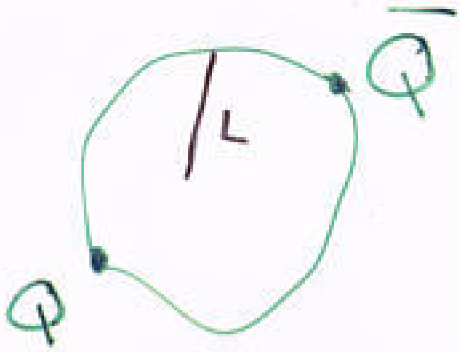
$$V \sim A\left(\frac{1}{L}\right)^a - B\left(\frac{1}{L}\right)^b + C\left(\frac{1}{L}\right)^c$$

$$c > b > a \qquad A, B, C > 0$$

$\frac{B}{A}$, $\frac{C}{A}$ (discretely) tunably large

There are lots of ways to get $\gtrsim \mathcal{O}(1)$ positive contributions (brane tensions, $-$curvature, fluxes ...) and $\mathcal{O}(1)$ negative contributions (orientifold tensions, $+$curvature, ...) but we need a large negative contribution $-B$.

This can come from



(fixed in place by "$(-1)^{F_L}$ xshift" orbifold projection)

$$V \sim \frac{1}{L^a}(Q+\bar{Q}) - \frac{1}{L^b} Q\bar{Q} + \cdots$$

attractive force between branes & antibranes

positive flux contributions

These ingredients, + further projections to reduce angular moduli, may suffice to construct complete models (in progress...)