the dual dynamics of quantum black holes

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w/ Emparan, Luna, Suzuki and Way
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problem

brane black hole evaporation

history

new method

results

history, motivation

Tanaka '02
Emparan, Fabbri, Kaloper '02

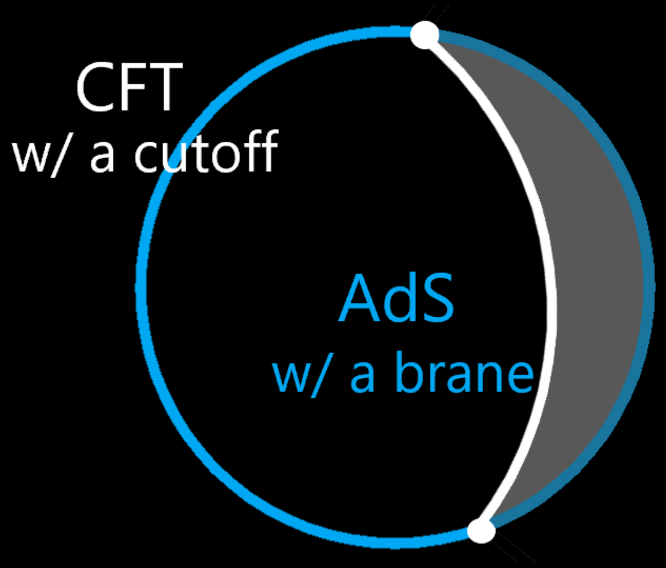
Quantum dynamics in gravity is hard, and we still do not fully understand black hole evaporation

We only have some perturbative idea about what's going on, and our understanding is best in models with low dimensions

An idea emerged ~20 yrs ago when Tanaka and Emparan *et al.* thought about looking at the **dual** of the problem at hand

In essence: put a black hole on a brane and look at its higher-dimensional, classical picture

Such a classicalization of the problem gives a new perspective on the problem, letting us ask questions we could not ask before

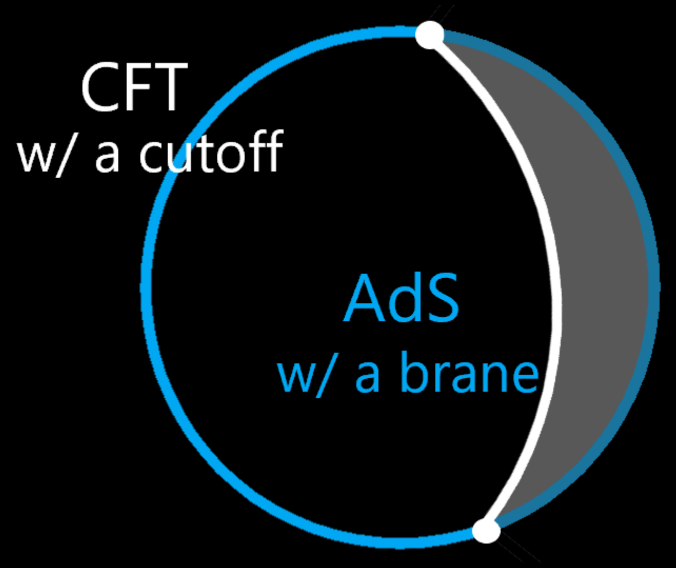


history, motivation

[de Haro, Skenderis, Solodukhin '00]

In a bit more detail,

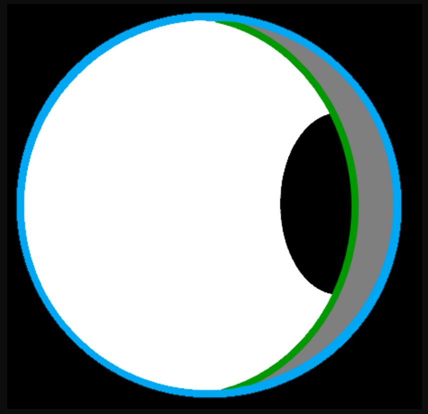
classical dynamics in an AdS_{d+1} bulk with a d-dim brane holographically encodes the quantum dynamics of the dual d-dim CFT coupled to a d-dim gravity on the brane



This means that we can view this setup from two perspectives:

1) either as an object in the bulk w/ some boundary conditions or
2) as a higher-curvature gravity coupled to a cutoff CFT on the brane

history, motivation



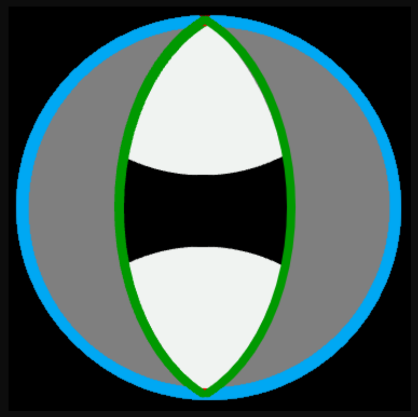
So, how does that look like for brane black holes?

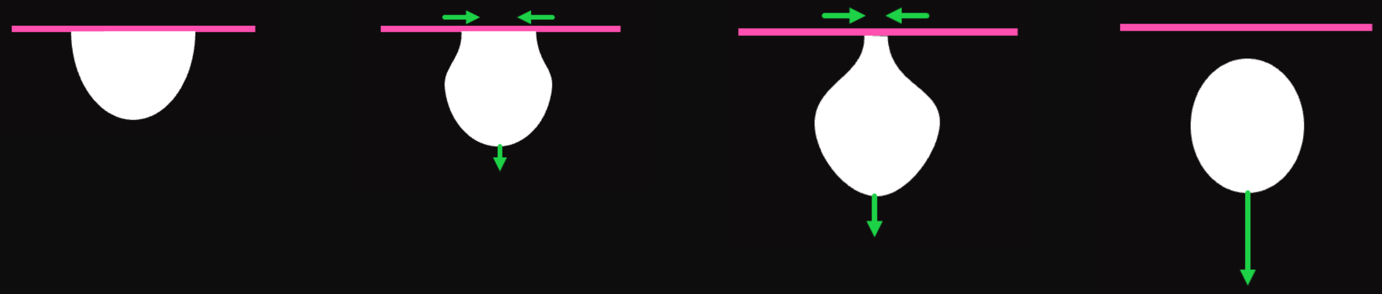
A brane bh evaporating can be represented in several ways

One can construct a *droplet*, or a *funnel*—these are the principal representations

The brane bh is coupled to a strongly-coupled, large N CFT

BH evaporation would then simply mean sliding off the brane





history, motivation

But bear in mind that we don’t have the usual quantum fields à la Birrell and Davies

We have a large N CFT, so the evaporation time should be much shorter than for a few quantum fields

The intuition is that we have many more channels into which the black hole can evaporate, and the rate is enhanced by large N

This would suggest that we *cannot* find stable time-independent solutions of droplets and funnels: they would always evaporate quickly off the brane!

history, motivation

Fitzpatrick, Randall, Wiseman '06
Gregory, Ross, Zegers '08
Figueras, Lucietti, Wiseman '11

The story turned out to be quite different though

People did find stable droplets on Randall-Sundrum branes which were time-independent!

How come an AF black hole surrounded by quantum fields does not evaporate? Where did we make a mistake?

history, motivation

Fitzpatrick, Randall, Wiseman '06
Gregory, Ross, Zegers '08
Figueras, Lucietti, Wiseman '11

The answer lies in the second feature of brane CFTs: they are strongly-coupled

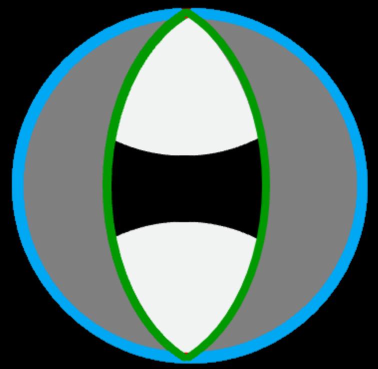
Just as plasma balls emit only color-neutral "glueballs", so does a black hole immersed in a strongly-coupled CFT

But then, its Hawking radiation would have an energy of $O(1)$, and so would be invisible to the classical bulk geometry, which only encodes energies of $O(N^2)$ -- we cannot see the brane bh evaporating!

In other words, if we have access only to *confined dofs* then we don't know how the bh evaporates

history, motivation

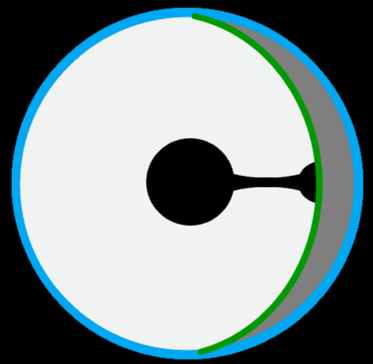
In order to evaporate properly, the bh would need access to the *deconfined* degrees of freedom



What is the bulk dual of this statement?

The deconfined dofs ~ black hole in the bulk

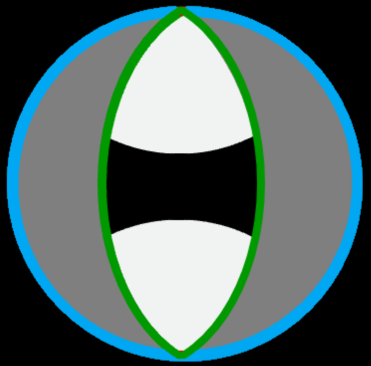
Access ~ the bulk bh must be connected to the brane bh



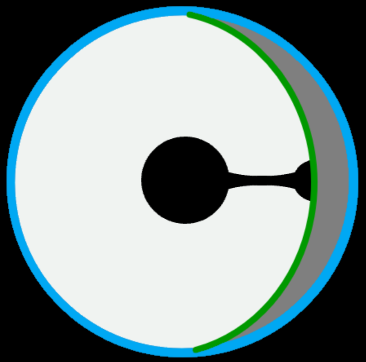
This suggests that funnels and rattles should allow for evaporation!

history, motivation

And what would be the driving mechanism behind this evaporation from the bulk point of view?



We will need the horizons on the brane to pinch-off – this is exactly the physics of the *Gregory-Laflamme (GL) instability*!

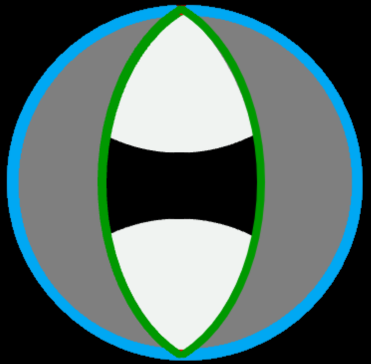


Recall, the GL instability occurs for extended black objects, like black strings, leading to the creation of two or more separate black objects, like black holes

history, motivation

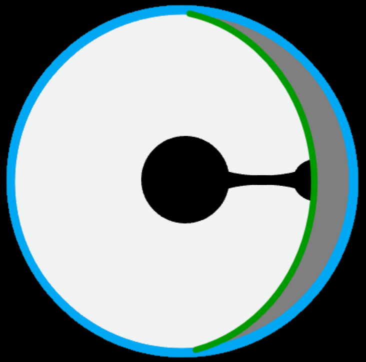
Emparan et al. '13

So let us try to show the pinching/evaporation explicitly



In order to do so, we would need dynamical evolution of the bulk configurations

In general, this requires a difficult numerical procedure



But we will resort to a different method:

the large *d* effective theory

The large *d* method

The large *d* limit effectively separates scales and isolates the dynamics of the horizon

In other words, the spacetime away from the black hole is effectively flat – the large number of dimensions suppresses the effect of the gravitational potential far from the black hole

This suppression simplifies the equations and one can perform complicated dynamical simulations in a matter of seconds/minutes

The large *d* method

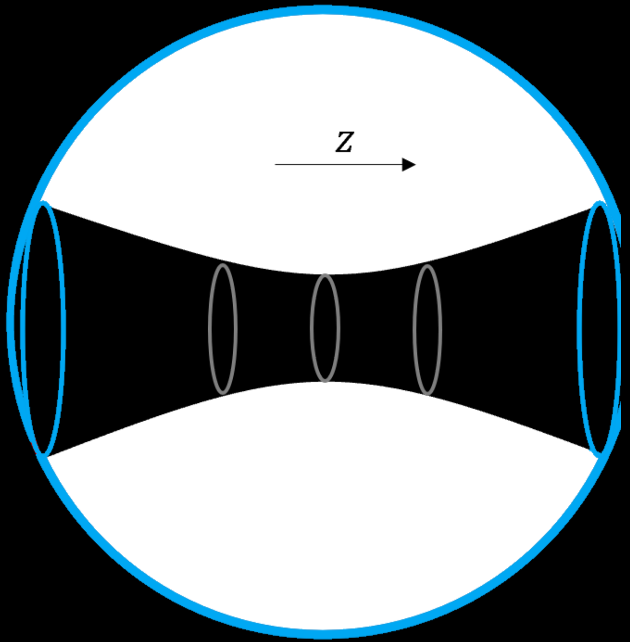
One caveat we should keep in mind:

The large *d* method can only study one type of black holes at a time

This means that we first *have to fix the* brane black hole to be either large or small, and then we can study them

In this talk, our examples will mostly constitute **small AdS brane** black holes, which are the natural ones for the analysis of evaporation

funnels



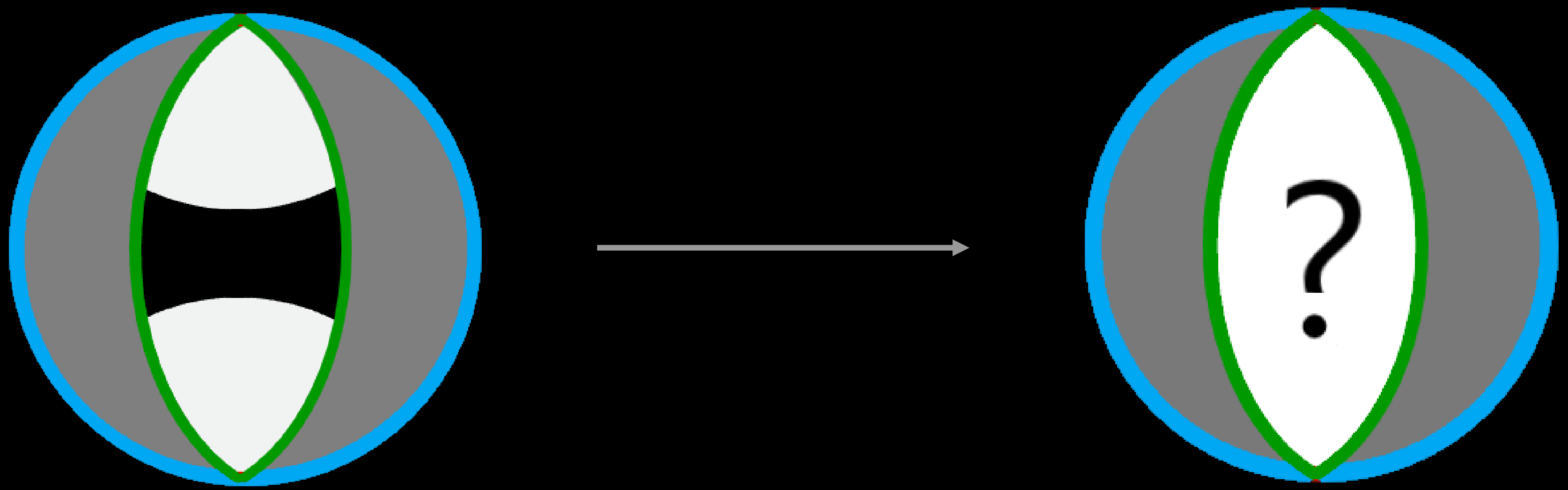
- Let us start with the funnel case first:
- We start with a solution for a black string in global AdS, whose metric can be written as

$$ds^2 = \frac{L^2}{\cos^2 z}\left(dz^2 + ds^2(Sch{-}AdS_{D-1})\right)$$

- We will analyze perturbations of the black string in gAdS, which correspond to different brane-CFT physics, that is, different radiation physics
- And we will look for such perturbations which could lead to the brane black holes sliding off

In pictures and videos

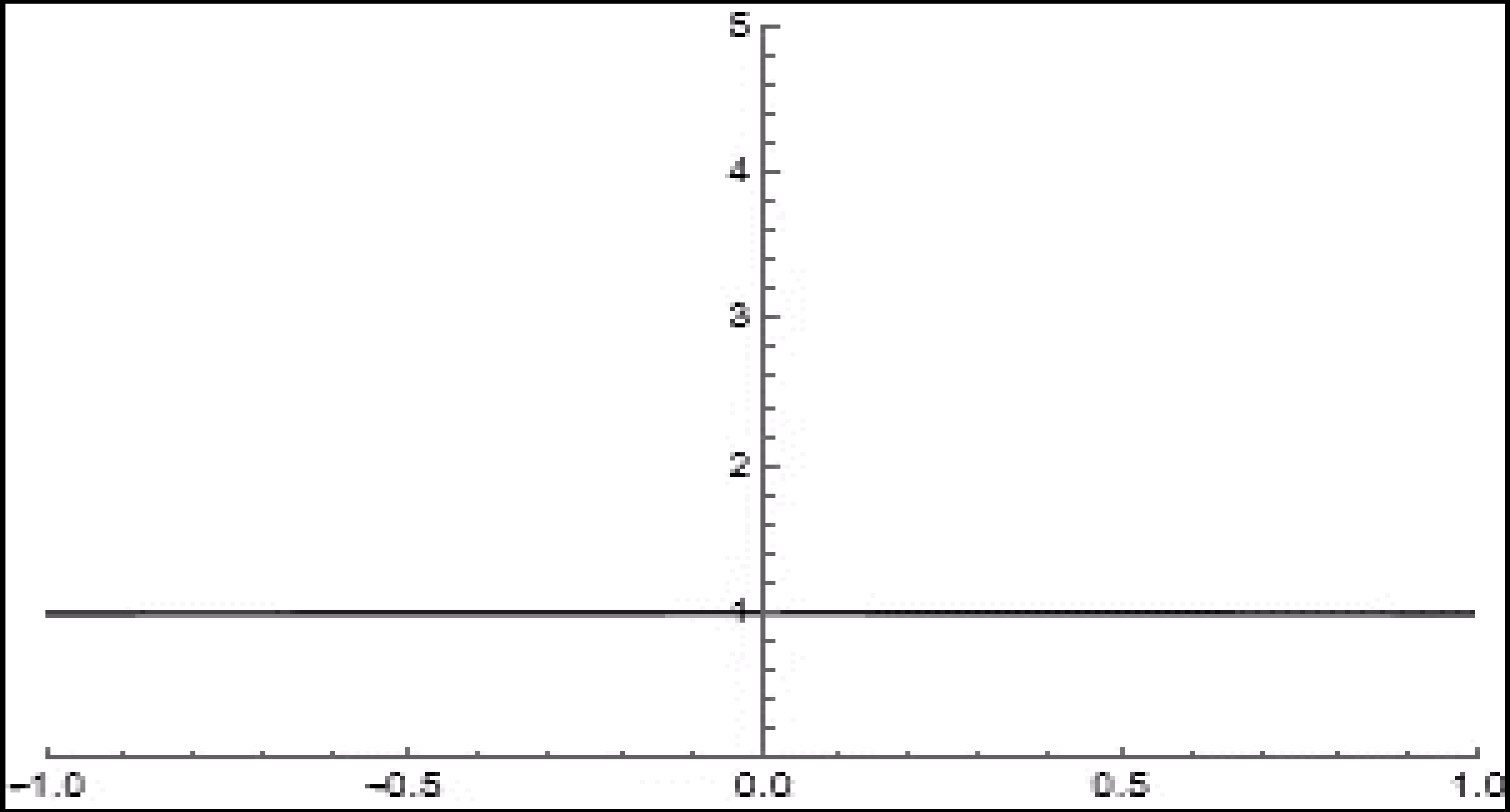
Funnels



Now that we have the funnel, we can perturb it to see when the black holes on branes will evaporate

In pictures and videos

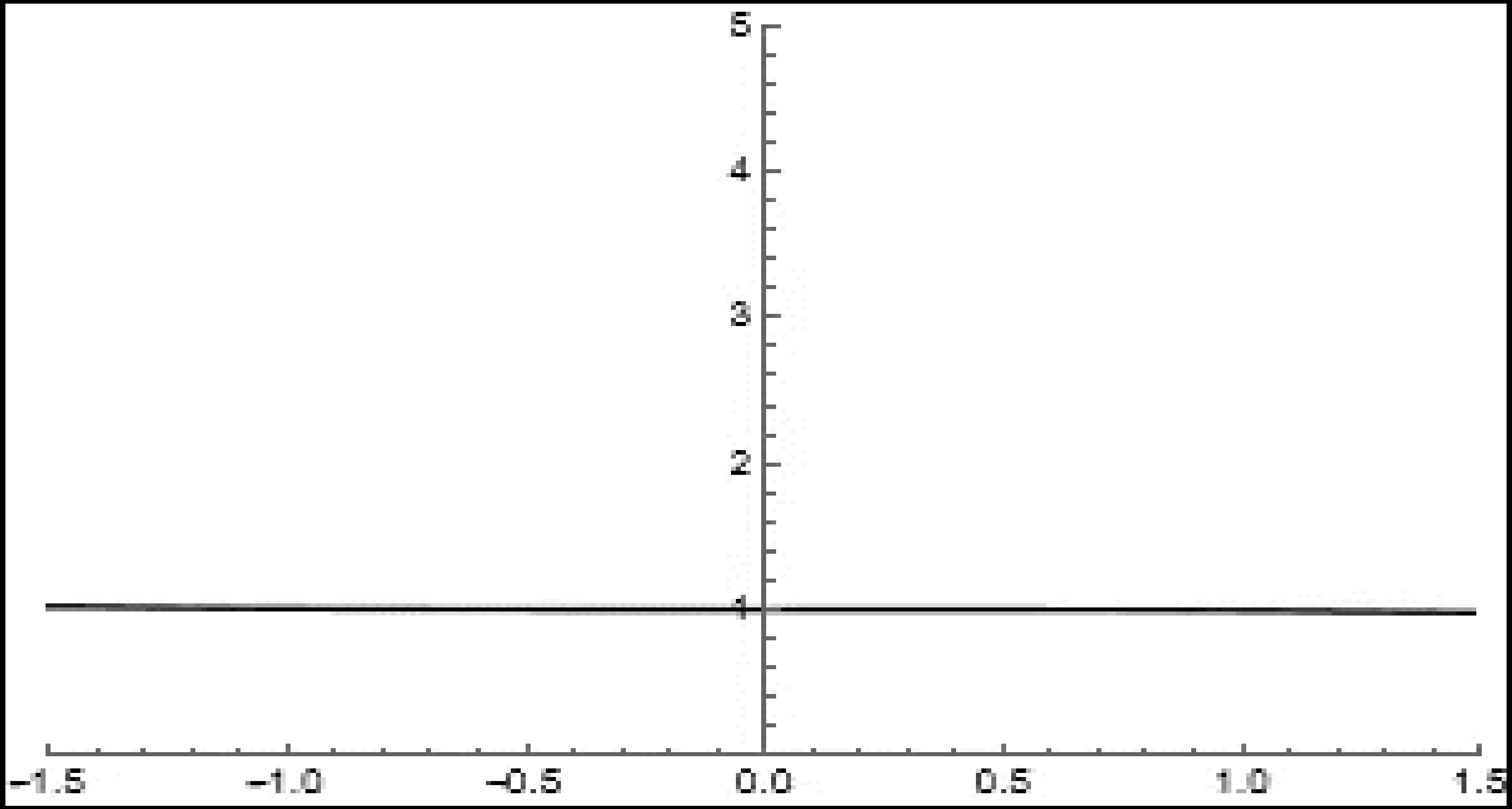
Funnels 1.0



The black holes evaporate on the brane, forming a bigger black hole in the bulk

In pictures and videos

Funnels 2.0



One of the black holes evaporates, making the other one bigger

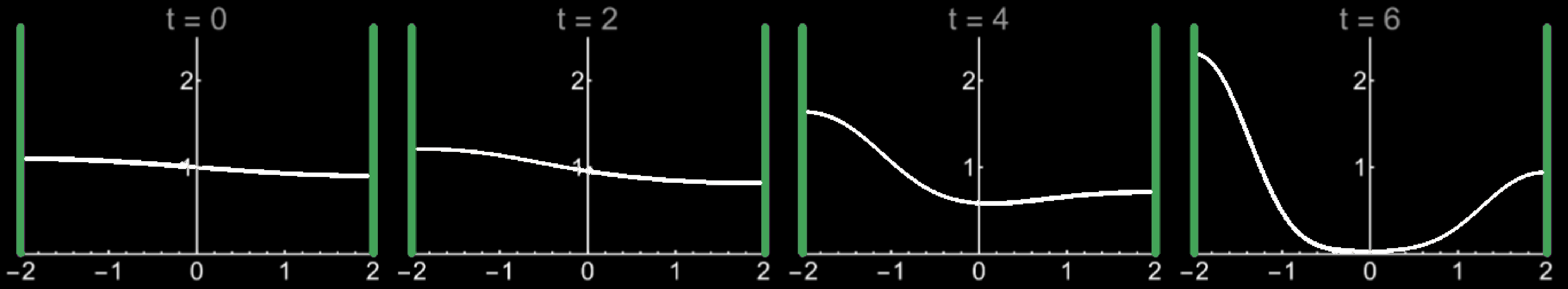
funnels

Emparan, Licht, Suzuki, Tomašević, Way '21

These two examples show full evaporation on either one or both branes

But this holographic setup allows us to have another interesting possibility

Namely, if the funnel is thin enough, the evaporation can start as before, but the Gregory-Laflamme instability can kick in fast enough *in the bulk*, severing the connection between the brane bh and the rest



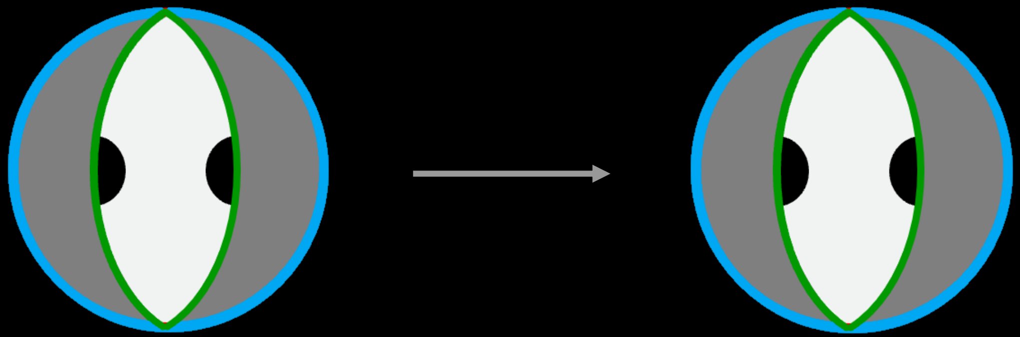
rattles

Now let us try to evaporate rattles

To obtain them, we can start with a funnel solution and perturb it in such a way so as to obtain twin droplets

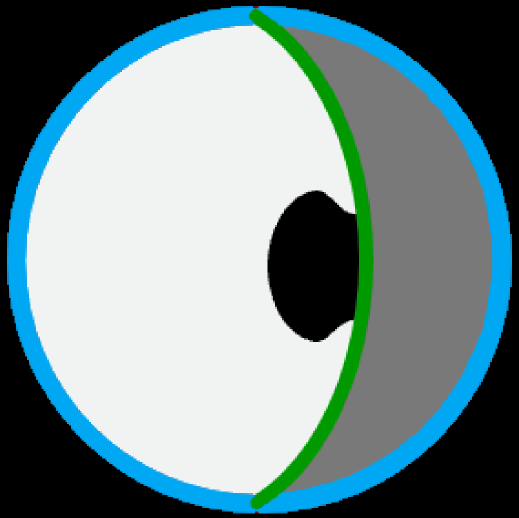
Then we perturb the droplets in various ways and try to find a perturbation that would lead to evaporation of the brane black holes

Note first that we confirm that droplets which are only moderately perturbed do not lead to evaporation

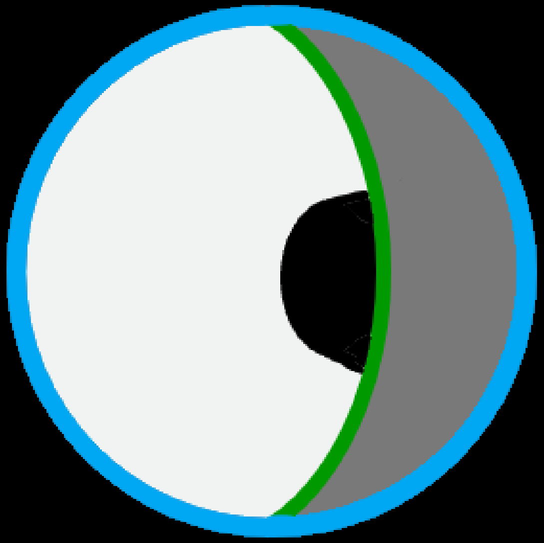


In pictures and videos

Rattles



The situation is the same even if we have only one droplet



Small/moderate perturbations do not lead to an evaporating black hole on the brane!

In pictures and videos

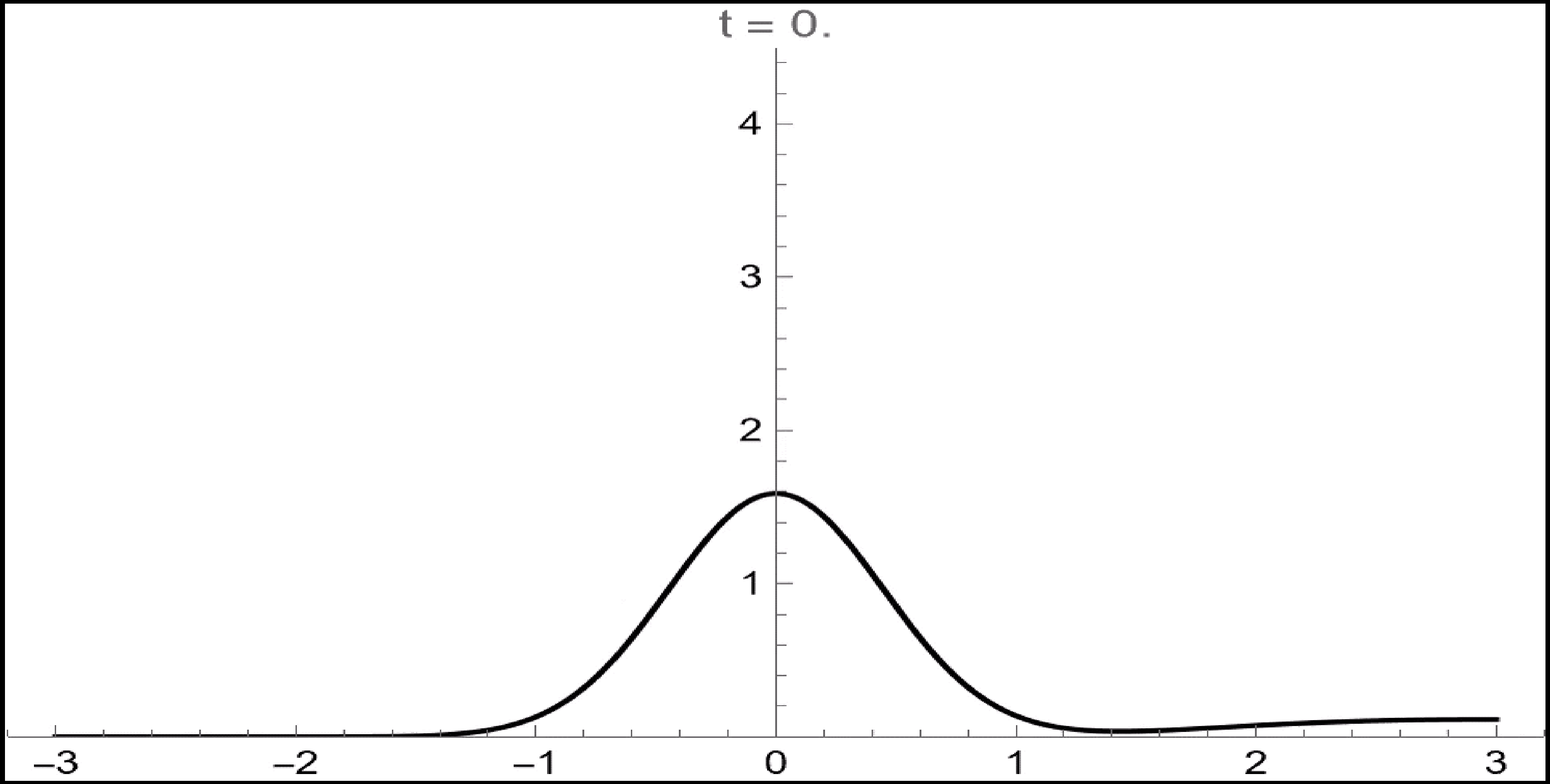
Small rattles

The situation is the same even if we have only one droplet

Small/moderate perturbations do not lead to an evaporating black hole on the brane!

In pictures and videos

Big rattles



But big perturbations do!

questions

How come small rattles don't lead to evaporation, but big ones do?

Both allow the access to the deconfined dofs, so why is there this distinction?

The answer lies in the **second law of thermodynamics**, that is

"heat flows from a hotter system to a colder one"

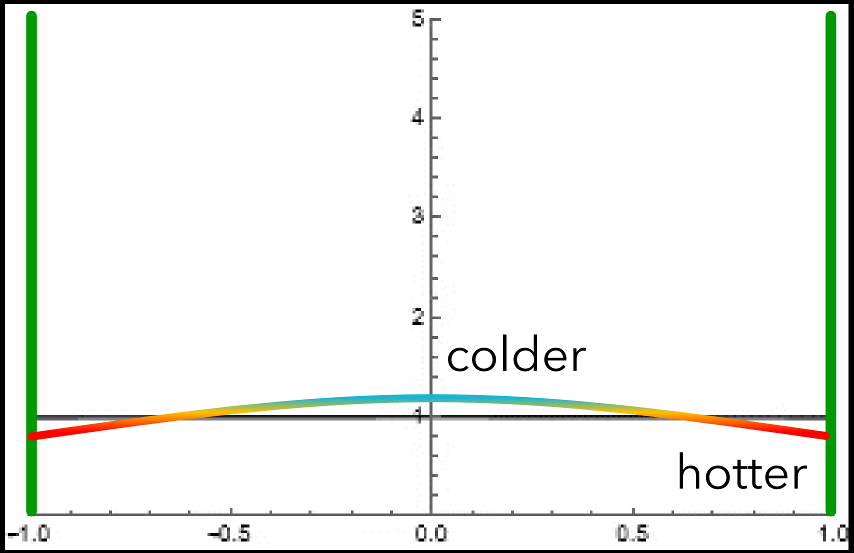
back to thermo-basics

Recall, large black holes in AdS have T = M, while small black holes behave as in AF space and T = 1/M

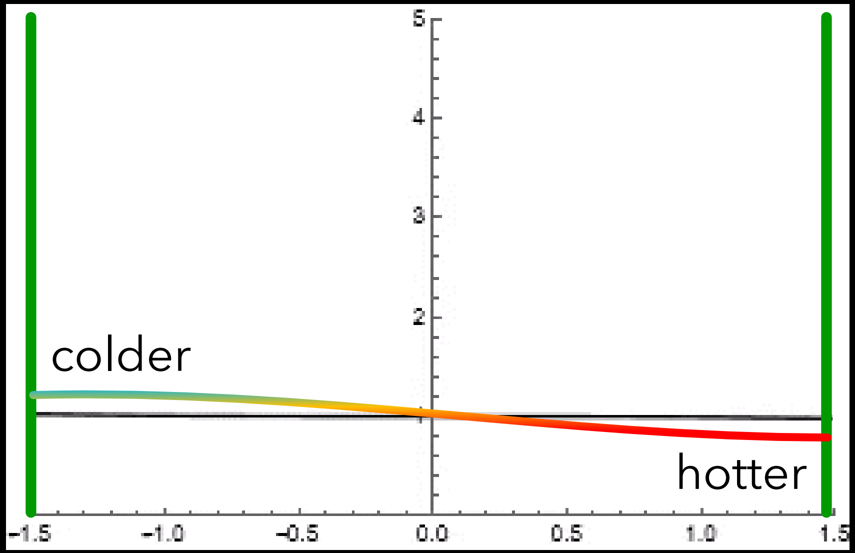
If we start with a small droplet, it's hot, so it needs a colder system into which to evaporate

A small rattle is a small black hole in the bulk – hotter than the droplet!

Need instead a bigger black hole in the bulk so that it's colder – this way the droplet will want to flow its heat into it

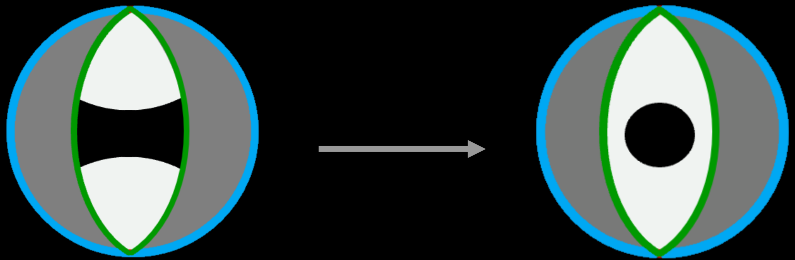


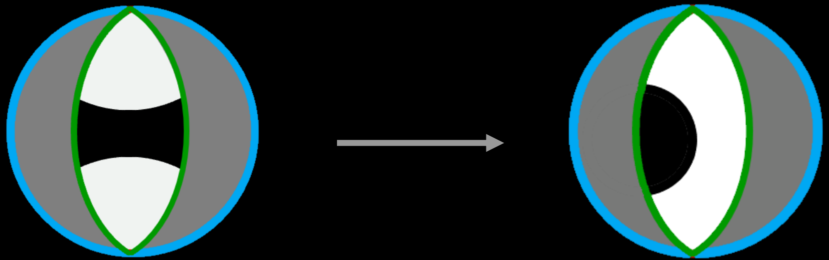
With funnels



$r_0 < L_{AdS}$

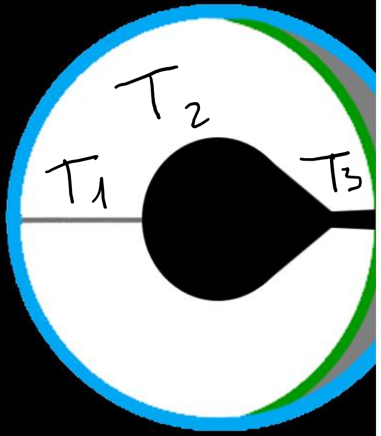
small AdS black hole
hotter when smaller

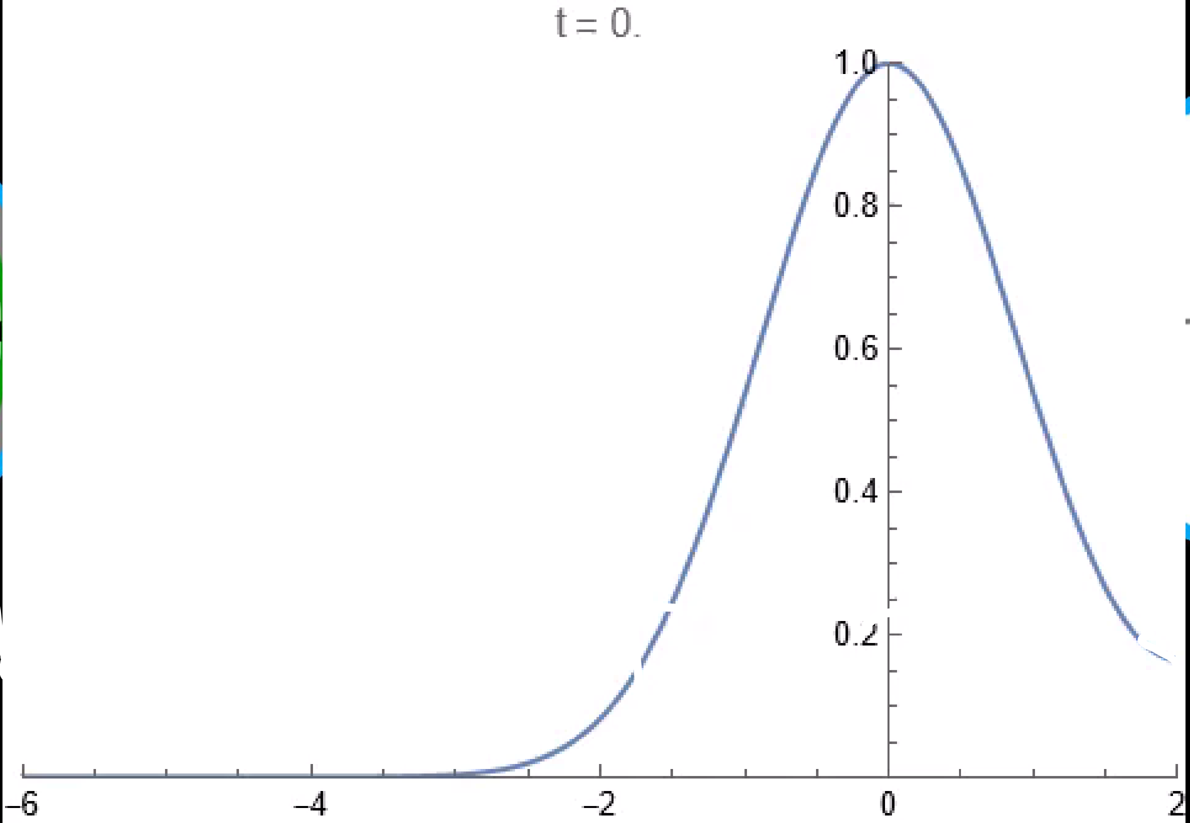




The large *d* method: large brane bhs

Let us just quickly show what happens with large brane black holes





Large AdS … ince T~M

summary, questions

We can study the evaporation of brane black holes using the large *d* limit of General Relativity

Evaporation on the brane is only possible when we have a colder black connection in the bulk – either as a funnel or in the form of a big rattle

Otherwise, the droplets become stable

Can be best understood through the laws of thermodynamics – heat will flow from a hotter system to a colder one

But the more pressing question is how to understand all of these phases through the CFT lens

Thank you!