Black Tsunamis and Naked Singularities in AdS

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ICREA & UBarcelona

HoloTube webinar

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Based on

arXiv 2112.07967 [hep-th]

with

David Licht

Ryotaku Suzuki

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Benson Way

Horizons
&
Singularities

Horizons

smooth places
associated to emergence of geometry

Singularities

rough places
associated to breakdown of geometry

Horizons

limit what can be observed

Singularities

limit what can be predicted

(using classical General Relativity)

Horizons & Singularities

linked by

Cosmic Censorship Conjecture(s) by Penrose

CCCP

Cosmic Censorship Conjecture(s) by Penrose

You can predict everything you can observe

You cannot observe what you couldn’t predict

weak **CCCP**

You can predict everything you can observe from afar

weak **CCCP**

The evolution of initially smooth configurations remains predictable for asymptotic observers

The maximal Cauchy development of initial data possesses a complete $\mathcal{I}^+$

wCCCP

Naked singularities can’t form

If naked singularities could form,

then we could safely learn about

highest-energy/shortest-length physics

$\Rightarrow$ strong quantum gravity regime

w**CCCP**

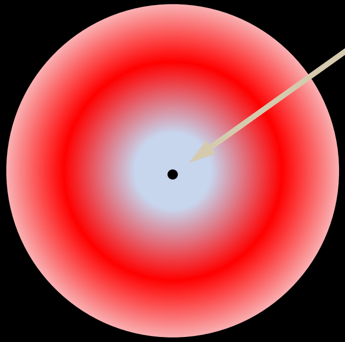
Nature hides Planck-scale physics from us

wCCCP

can be violated!

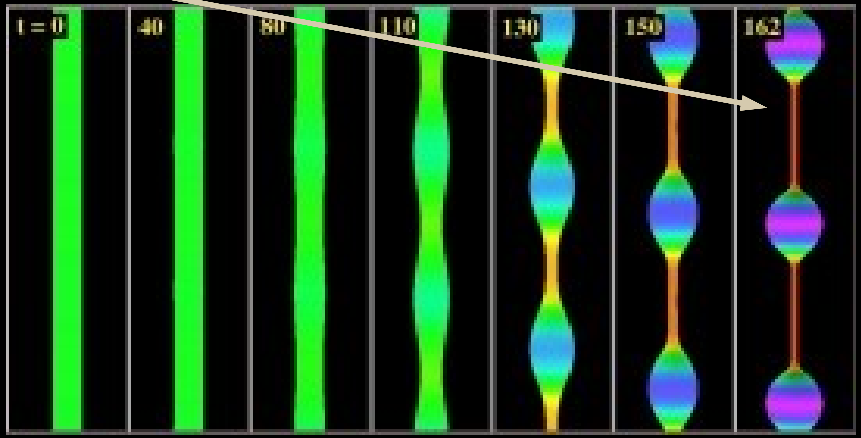
wCCC violations

diverging curvature



Critical collapse

Choptuik 1993



Black string instability

Gregory+Laflamme 1993
Lehner+Pretorius 2011

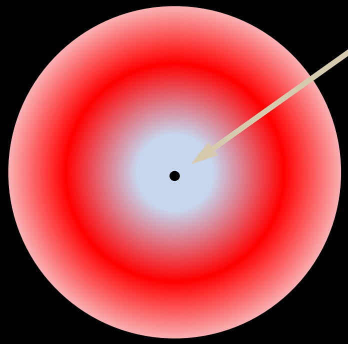
Does Nature give us a chance to probe Planck-scale physics?

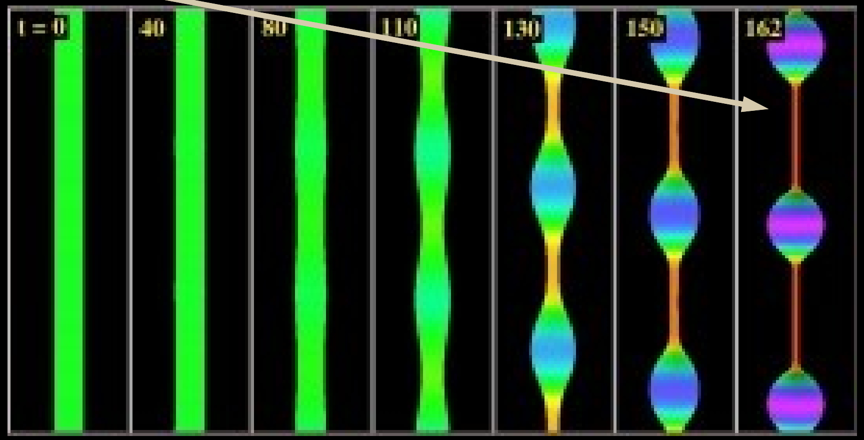
How much of a chance?

How strong the loss of classical predictivity?

wCCC violations

small mass, small extent





Improved wCCC

Predictivity lost, predictivity regained

Only mild naked singularities can form,

small (Planck-scale) mass, size, and duration

They may even be controlled by attractors

Improved wCCC

Predictivity lost, predictivity regained

Only <u>mild</u> naked singularities can form,

so mild that predictivity is lost only for a time

that vanishes as $\hbar \to 0$

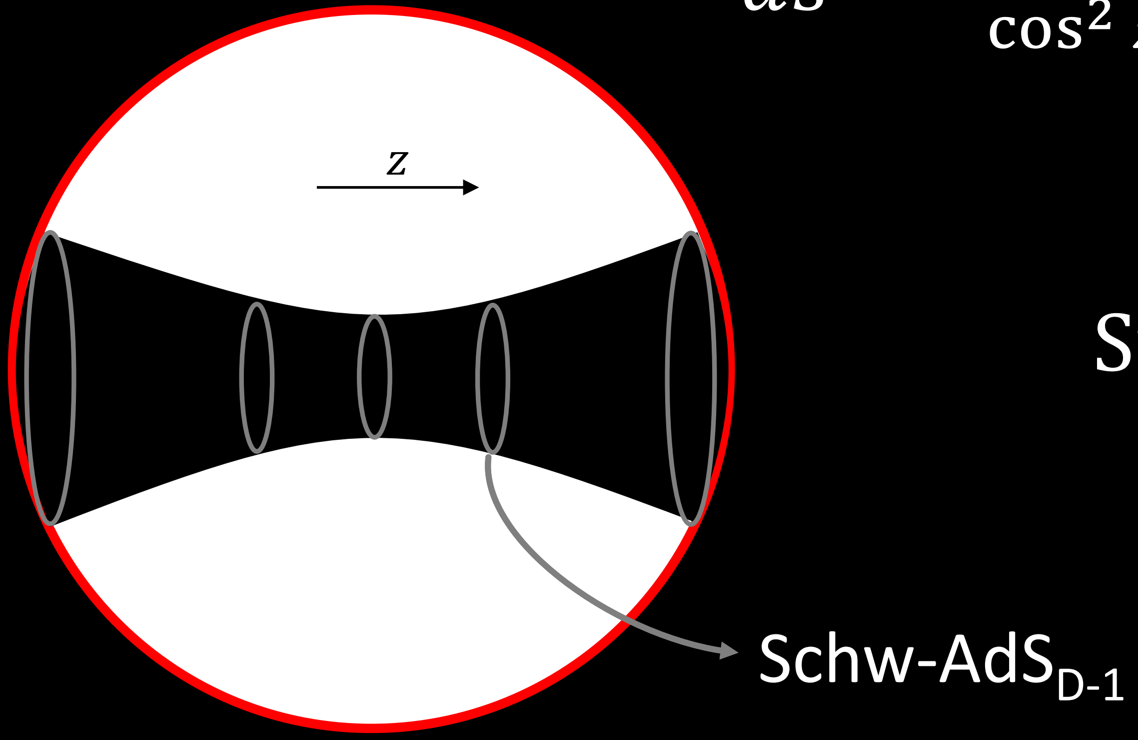
What does AdS/CFT say about this?

What setup?

Black String instability in AdS

Setup

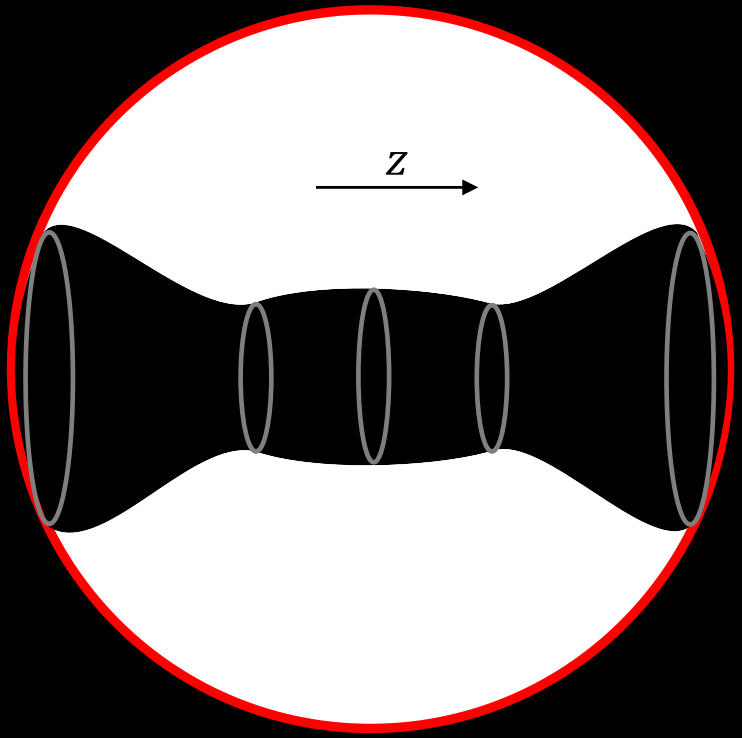
$$ds^2 = \frac{L^2}{\cos^2 z}\left(dz^2 + ds^2(Schw\text{-}AdS_{D-1})\right)$$



Boundary:

Sphere with two black holes at antipodes

fixed geometry



Thin enough black strings are unstable to rippling

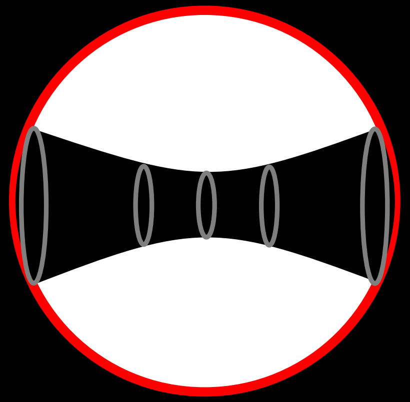
similar to Gregory-Laflamme

Hirayama+Kang 2001

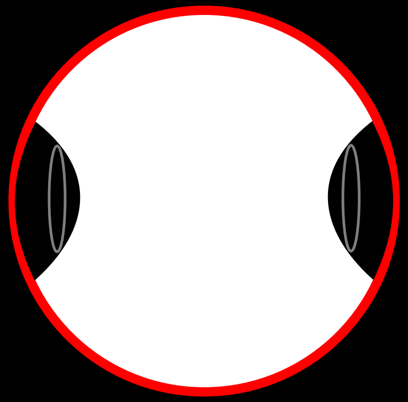
What’s the endpoint of the instability?

Static phases

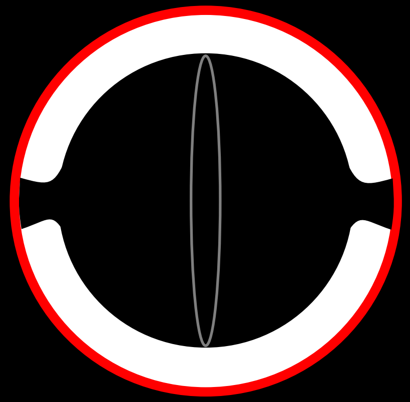
Marolf+Santos 2019



Uniform black string
Black funnel



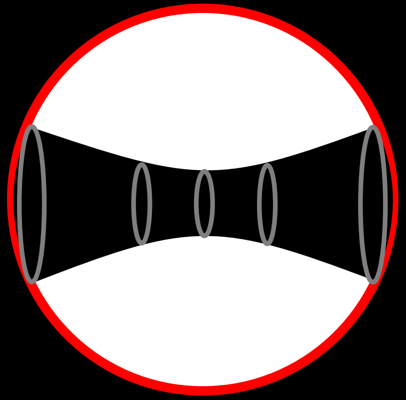
Black droplets



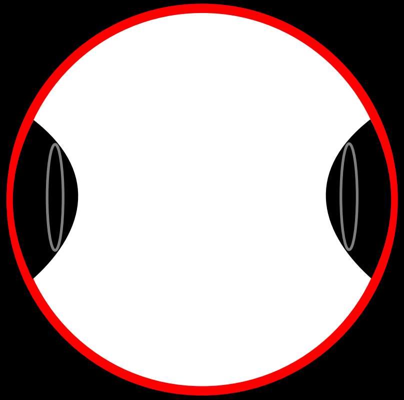
Fat funnels

(other possibilities too)

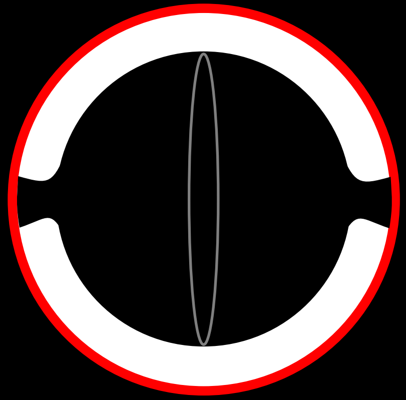
Thermodynamics – canonical



Can dominate for large BH@bdry



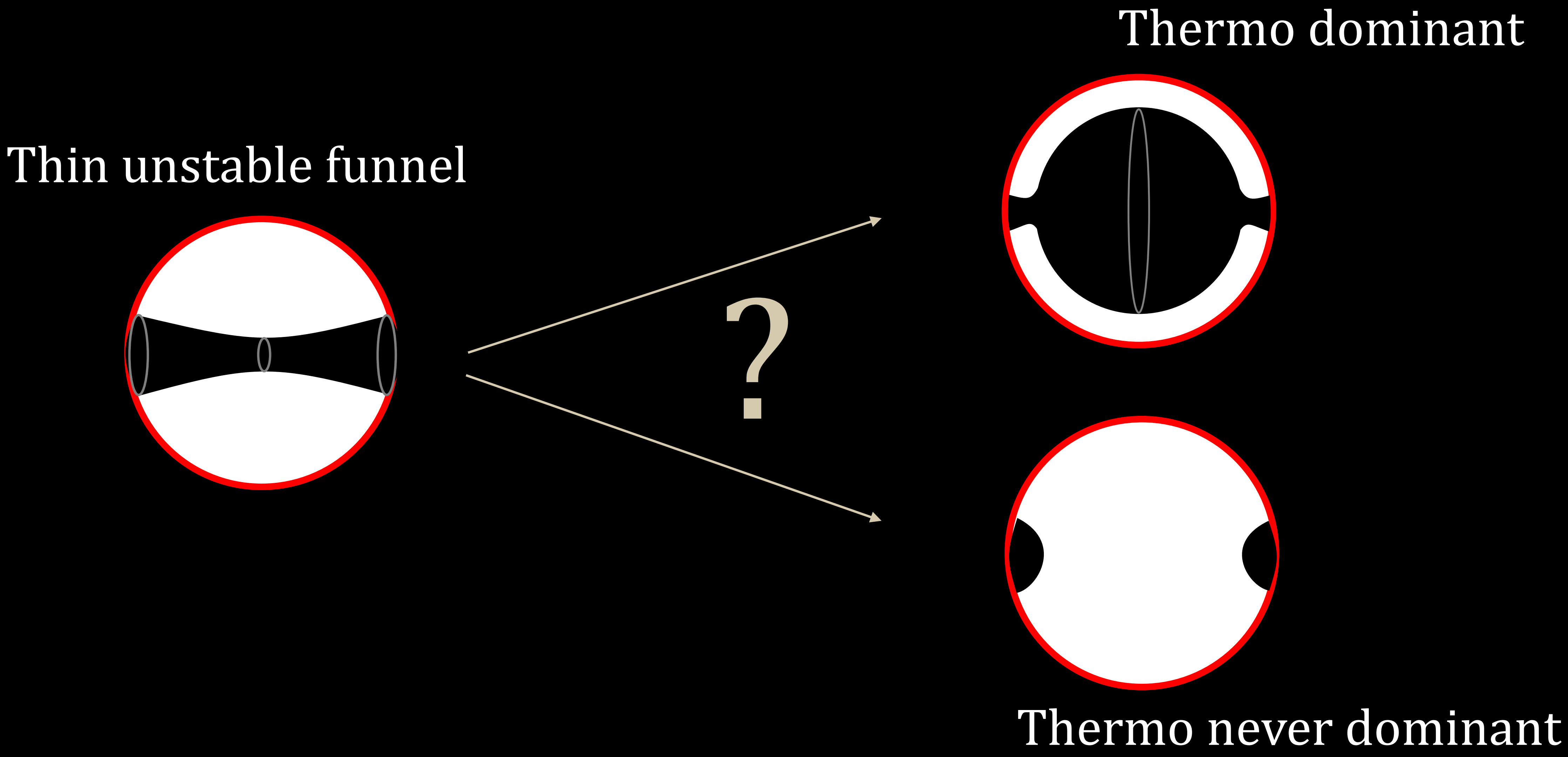
<u>Never dominant</u>



<u>Dominant for small BH@bdry</u>

Can dominate for large BH@bdry

Dynamical evolution?



Black Tsunami flows

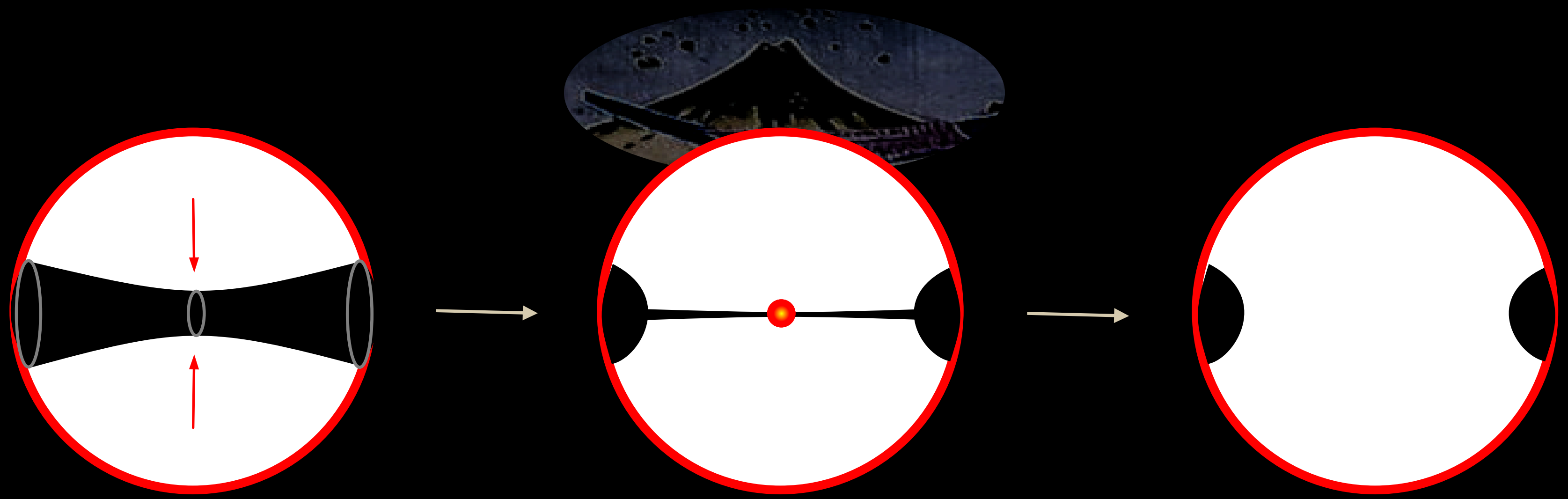
Possible

Fixed black hole@bdry acts as heat source/sink

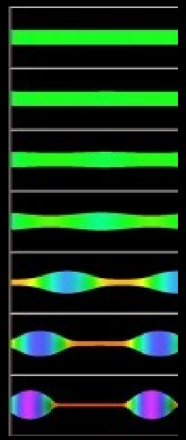
Horizon generators can flow in/out of bdry:

~~Area theorem~~ 'Free energy theorem'

Singular pinch off

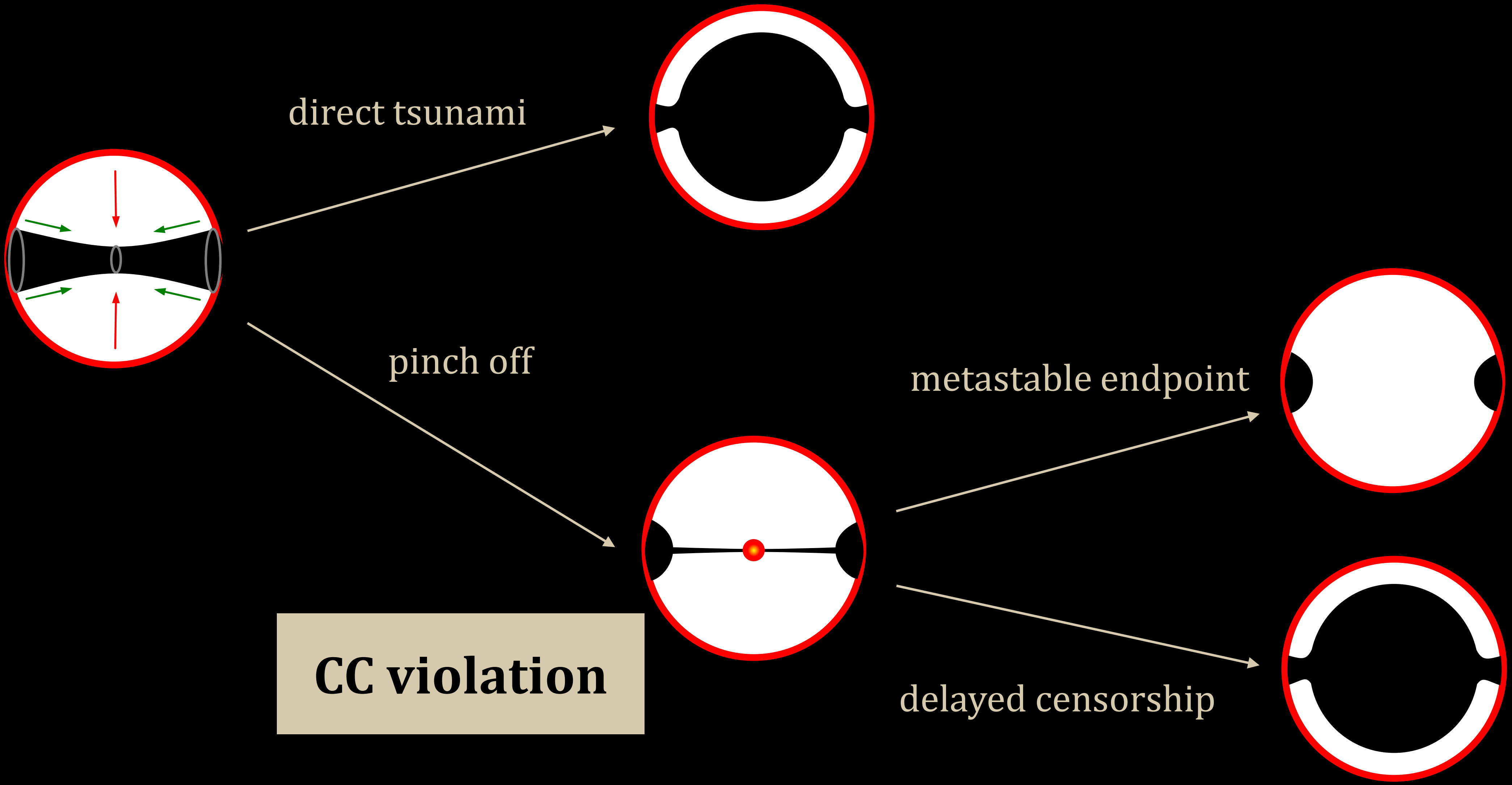


Possible

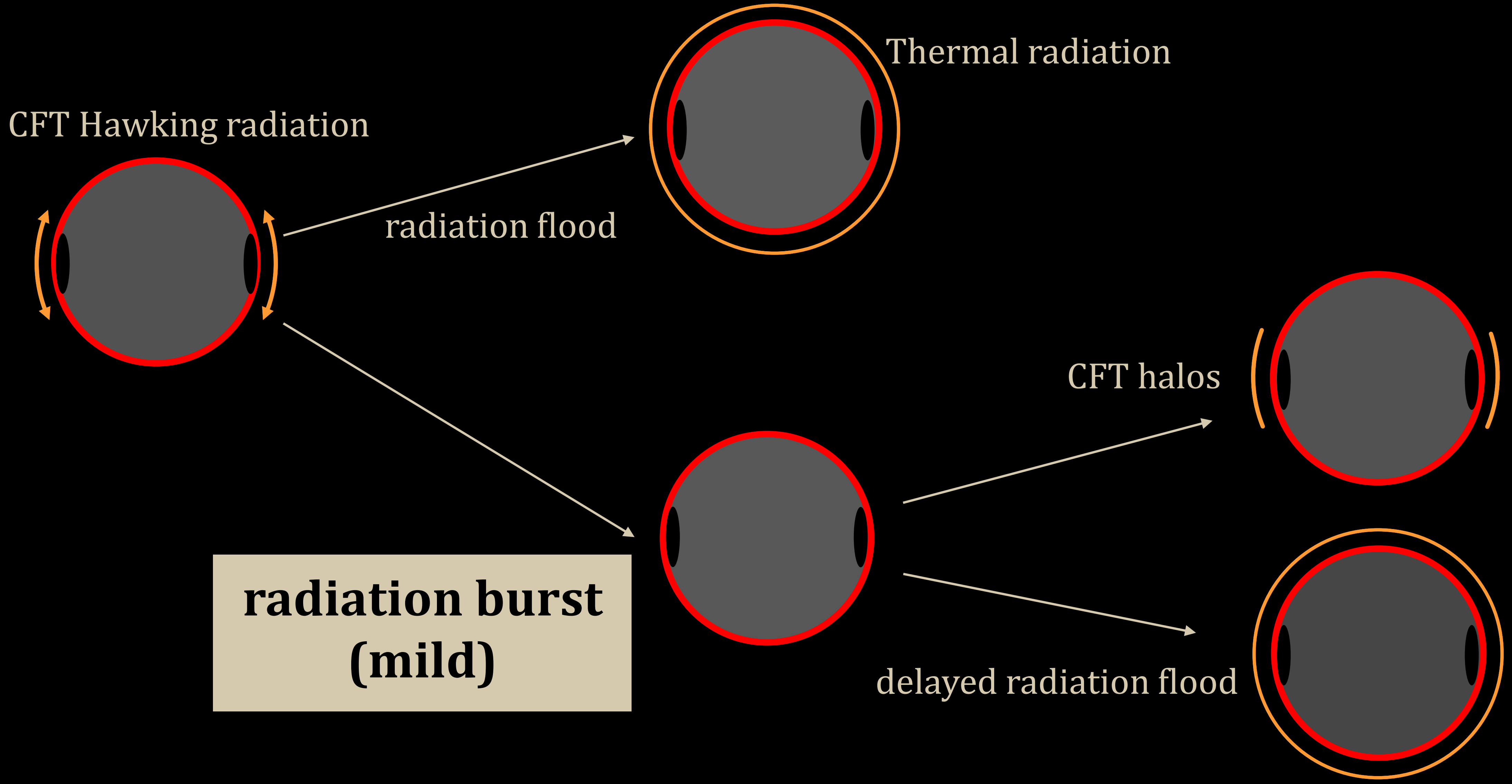
If string thickness ≪ AdS radius ⇒ ~ 

What we have found

+ more complex evolutions



What we have found – dual view



How?

Full numerical GR evolution is difficult and costly

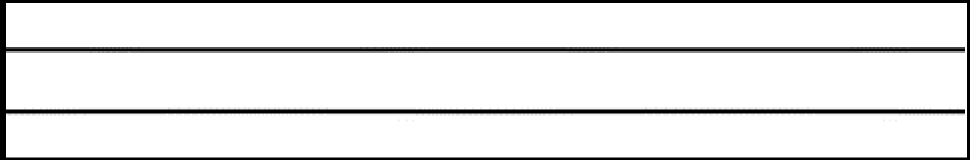
We use

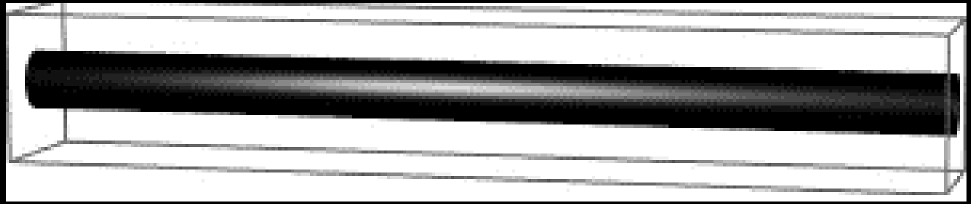
Large-D *effective* theory

Warm up

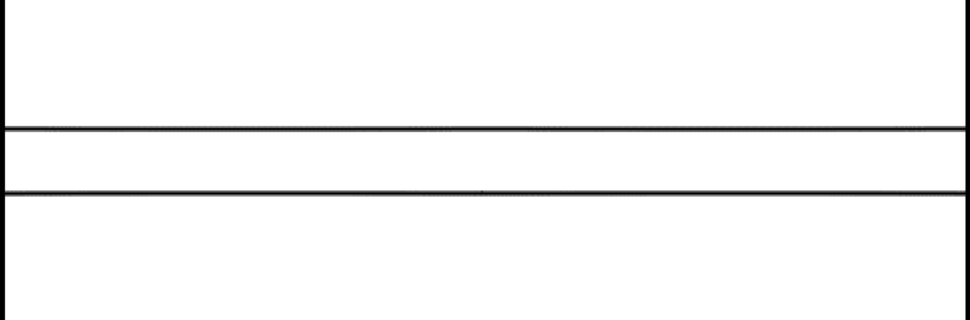
Black strings in AF space @ large D

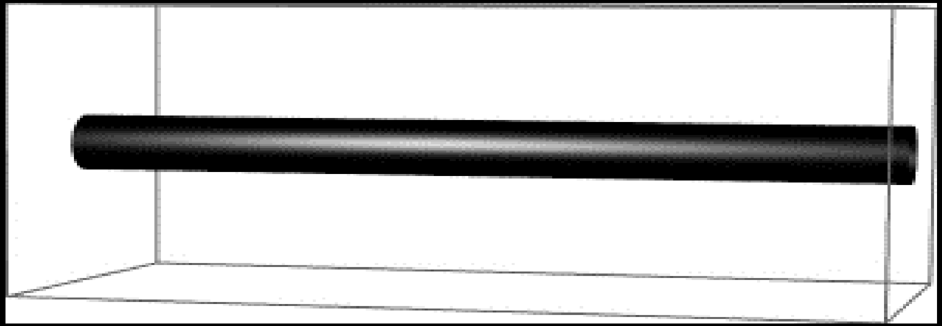
Moderate D





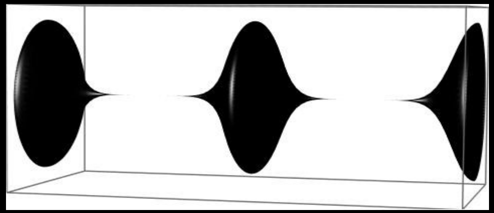
$D \to \infty$ effective theory



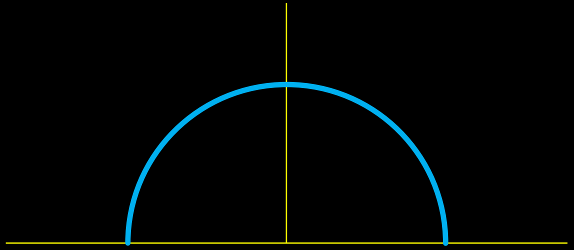


Black holes @ large D: gaussian blobs

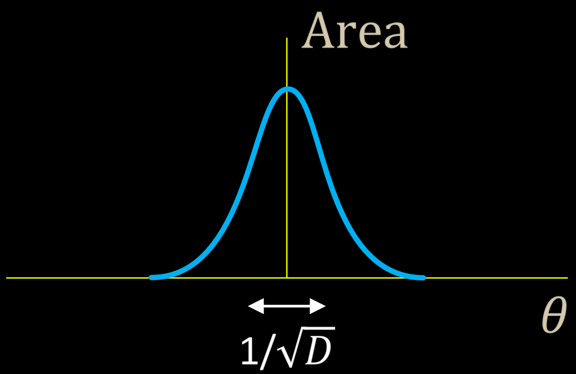
$$d\Omega_{D+1} = \mathrm{d}\theta^2 + \cos^2\theta \, d\Omega_D$$



$$\text{Area}(\theta) = \cos^D\theta \sim e^{D\theta^2/2}$$



$\longrightarrow$

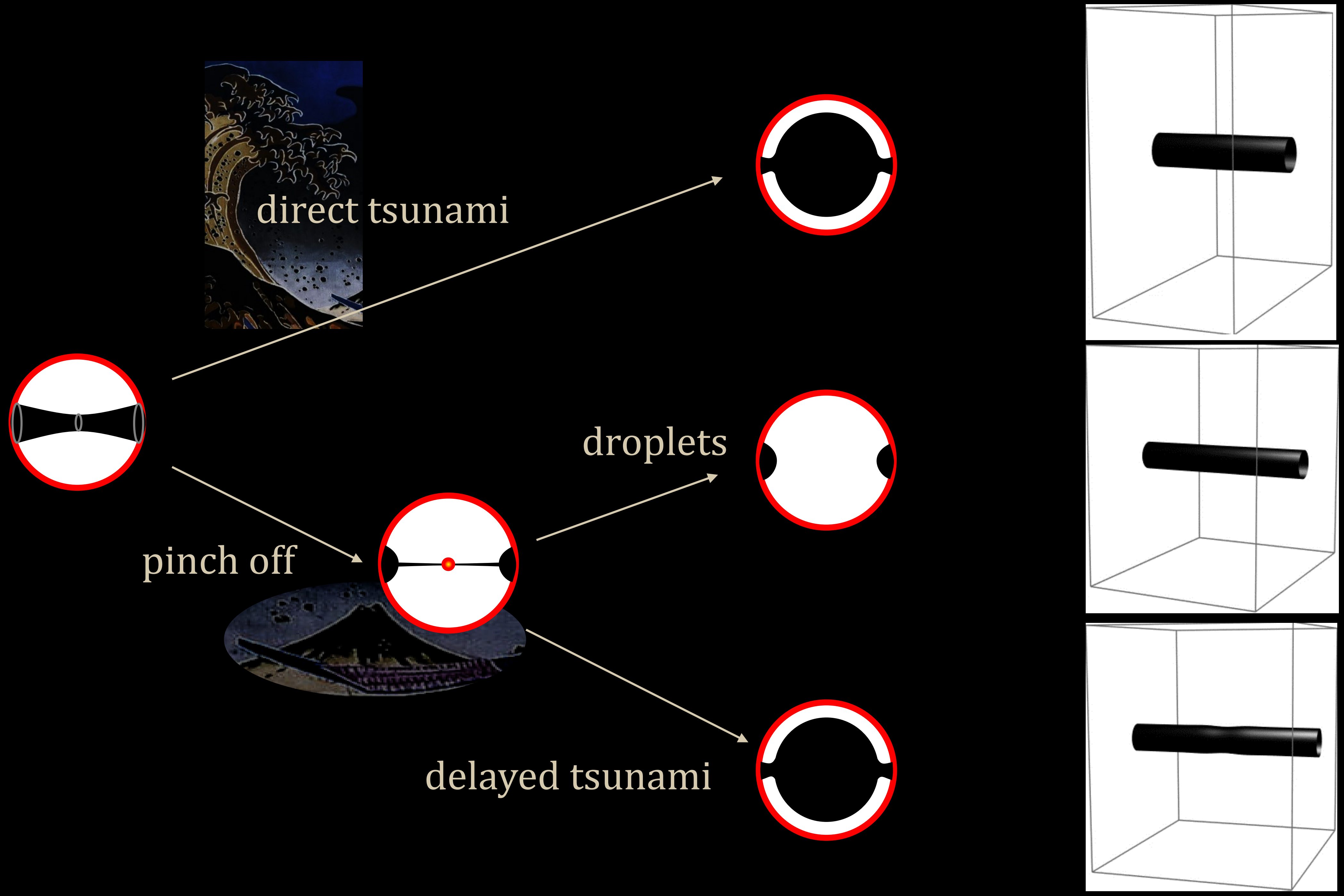


Area strongly localized near equator

Obtain effective equations for AdS black strings

Find linear instability

Evolve non-linear equations


direct tsunami
droplets
pinch off
delayed tsunami

Boundary CFT signal of naked singularity formation

Large D:

Not easy to extract signal at boundary

Non-perturbative in $1/D$

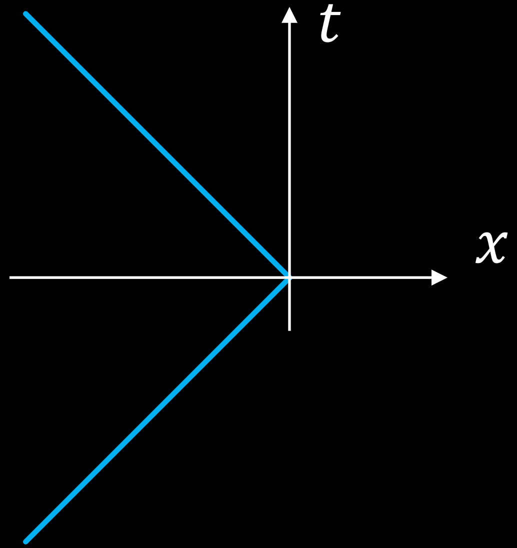
A linearized model

after Chesler+Way 2019

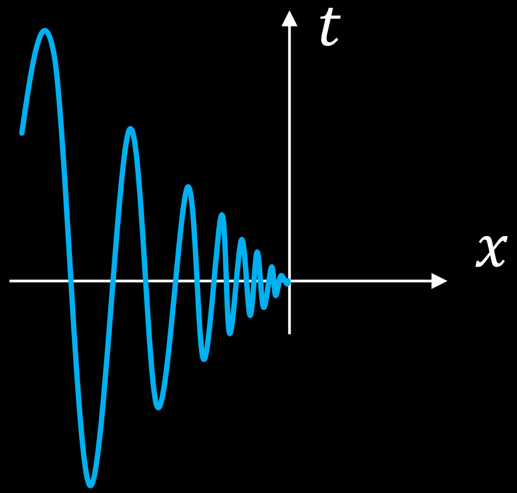
Critical collapse and Black string pinch show Self-Similarity

$$f(t,x) = f(e^{\lambda}t, e^{\lambda}x)$$

$$f(t,x) = f(e^{\lambda}t, e^{\lambda}x)$$



Continuous CSS: $\forall \lambda \in \mathbb{R}$



Discrete DSS: $\lambda = k\Delta \quad k \in \mathbb{N}$

Find solution to *linearized gravity* in AdS that

is Discrete Self-Similar near $r = 0 \quad t = 0$

Extract holographic stress tensor near $r = \infty$

Chesler+Way 2019

For critical scalar field collapse, this gives

$$\langle \mathcal{O}_\varphi \rangle \sim \frac{1}{t - \frac{\pi}{2}}$$

$\frac{\pi}{2}$ = propagation time to bdry

As observed in numerical evolution

For DSS gravitational field

$$\langle T_{tt} \rangle \sim t - \frac{\pi}{2}$$

vanishes!

$$\langle T_{it} \rangle \sim \text{const}$$

$\frac{\pi}{2}$ = propagation time to bdry

$$\langle T_{ij} \rangle \sim \frac{1}{t - \frac{\pi}{2}}$$

(pressures vanish)

Boundary signal is not smooth: it oscillates an infinite number of times before $t = \frac{\pi}{2}$

$\longrightarrow$ It reaches arbitrarily high frequencies

But the energy density vanishes as $t \to \frac{\pi}{2}$

In CFT at large N, we expect

- a few, $\mathcal{O}(1)$ quanta, with energy density $\mathcal{O}(N^2)$
- large localized shears $\mathcal{O}(N^2)$

Not deadly

You don’t notice a few gamma rays hitting you

What have we learned?

- Cosmic Censorship can be violated by AdS black strings
- Evolution is a combination of pinch-offs and tsunamis
- Dual CFT interpretation: Hawking radiation+burst
- Boundary burst: shearing, but mild – a few γ gravitons

Going further

- CFT resolution of singularity at finite N ?

- Hawking radiation + gravitational backreaction

  $\rightarrow$ Black hole evaporation as classical bulk evolution

Thank you

David Licht
Ryotaku Suzuki
Marija Tomašević
Benson Way

Backup material

Large D setup and effective equations

$D = n + 5$

$r_0 =$ thickness

$$ds^2 = \frac{L^2}{\cos^2\left(\frac{x}{\sqrt{n}}\right)}\left(\frac{H dx^2}{n} - (1+r_0^{-2}) A\, dt^2 + u_t \frac{2 dt}{n}\frac{dR}{R} - \frac{2}{n} C\, dt dx + r_0^2\, R^{\frac{2}{n}}\, d\Omega_{n+1}\right)$$

mass (area) density

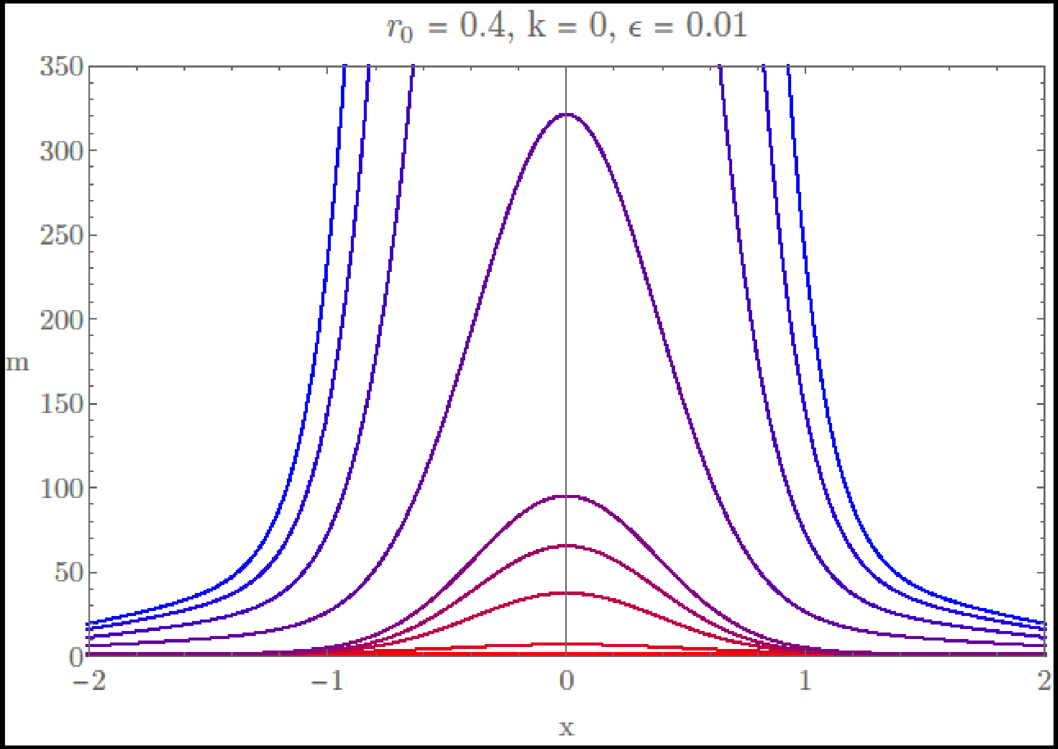
momentum density

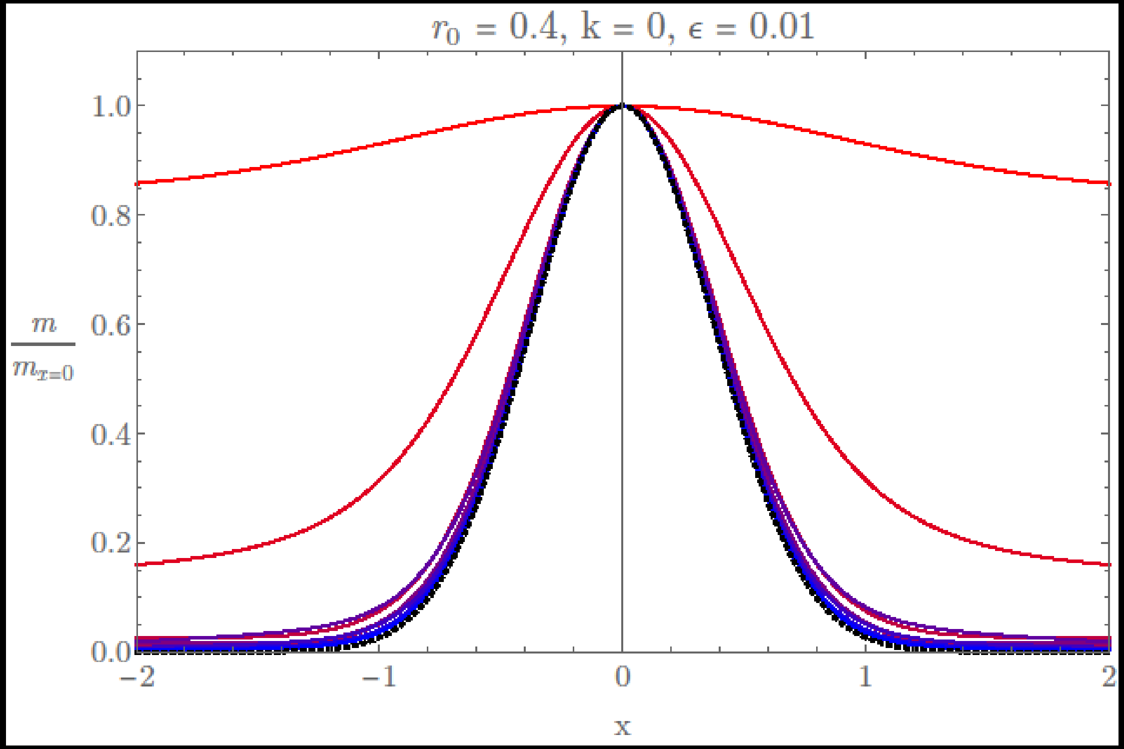
$$A = 1 - \frac{m(t,x)}{R} \qquad C = \frac{p(t,x)}{R}$$

$$\partial_t m + (\partial_x + x)(p - \partial_x m) = 0$$

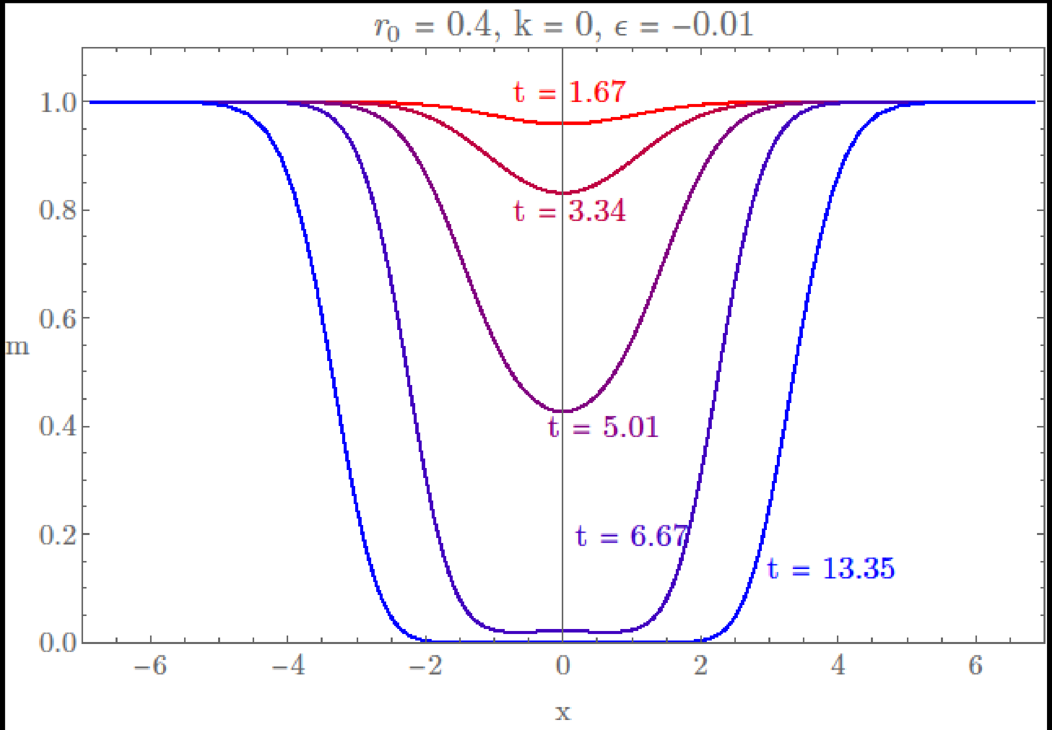
$$\partial_t p - (\partial_x + x)\left(\partial_x p - \frac{p^2}{m}\right) - (1 + r_0^{-2})\partial_x m = 0$$

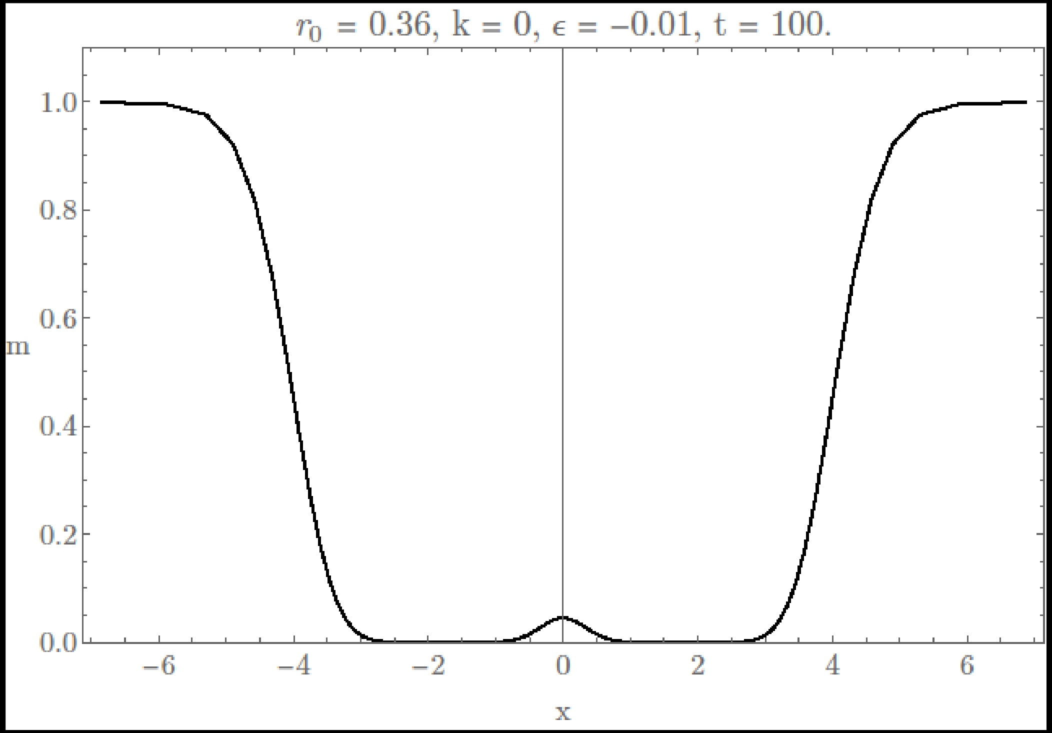
Tsunami to Fat funnel



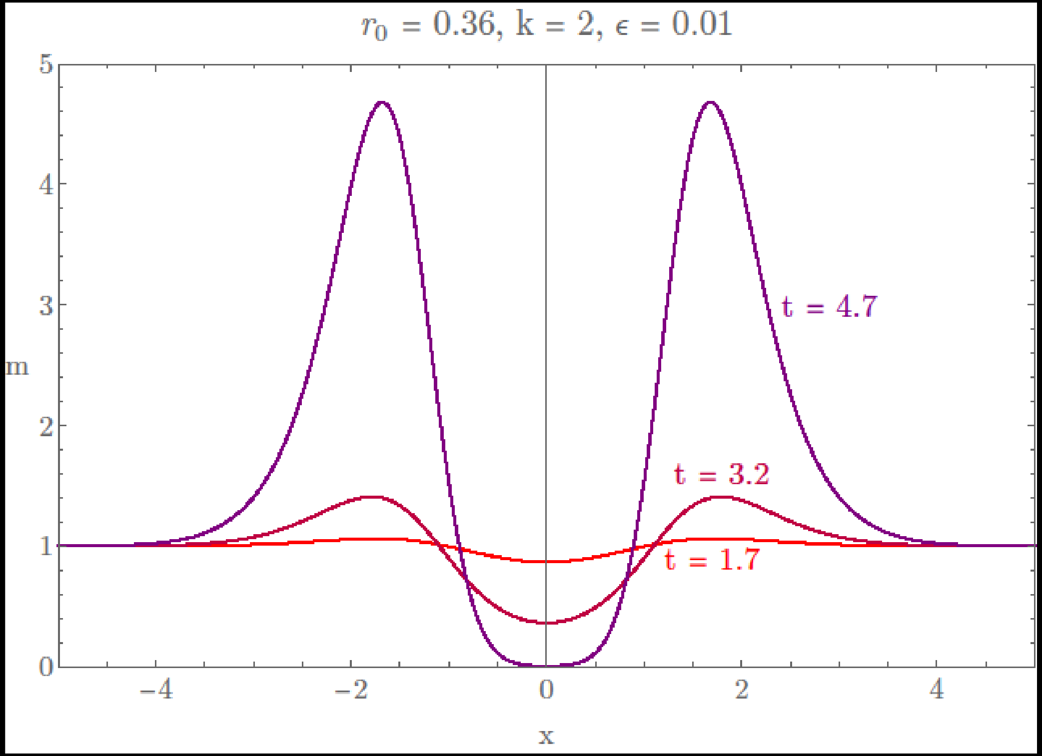


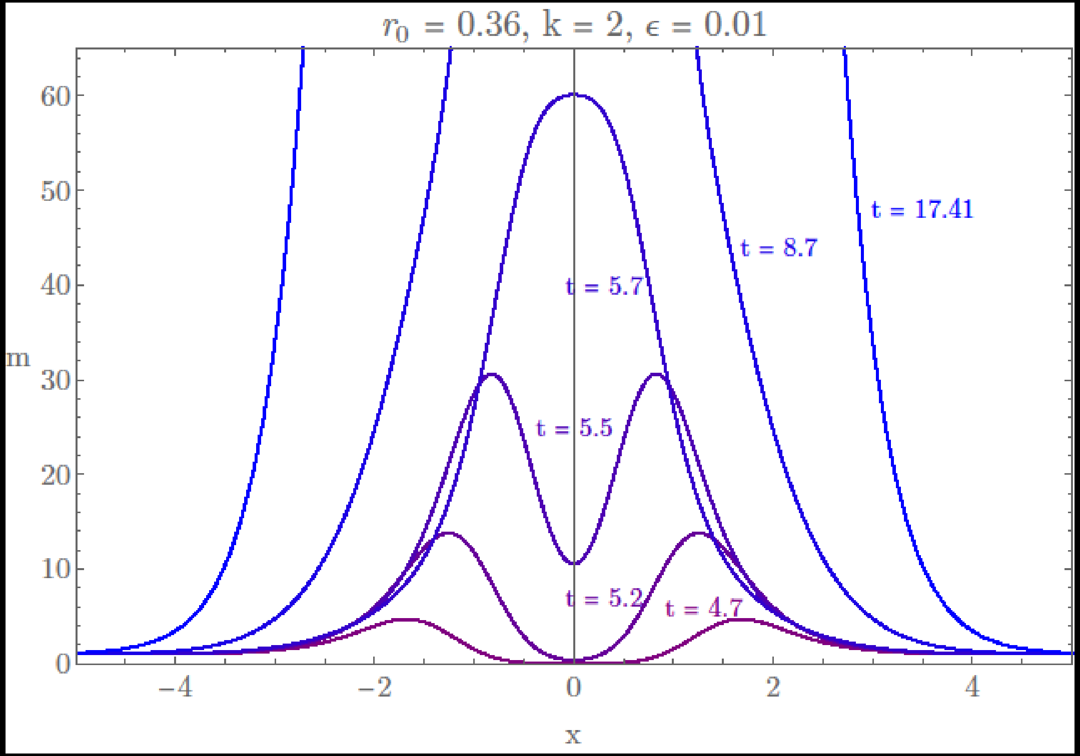
Pinch-off to Droplets





Pinch+Tsunami





Linearized SS solution (scalar field)

sum over AdS normal modes

$$\varphi \sim \sum_n a_n F(nt, nx)$$

self-similarity (high n)

$$a_n = a_{n/\lambda}$$

$$\langle \mathcal{O}_\varphi \rangle \sim \partial_t \overbrace{\sum_n a_n G\left(n\left(t - \frac{\pi}{2}\right)\right)}^{\text{self-similar about } t = \frac{\pi}{2}} \sim \frac{1}{t - \frac{\pi}{2}}$$

$$\langle \mathcal{O}_\varphi \rangle \sim \partial_t F \left[\log \left(t - \frac{\pi}{2} \right) \right] \sim \frac{1}{t - \frac{\pi}{2}}$$

DSS

$\frac{\pi}{2}$ = propagation time to bdry

For a DSS function of $\log(t - t_*)$

$$\partial_t \sim \frac{1}{t - t_*}$$

A CSS function of only t must be constant

- Stress-energy conservation:

$$\partial_t \langle T_{tt} \rangle = \nabla^i \langle T_{it} \rangle \qquad \partial_t \langle T_{ti} \rangle = \nabla^j \langle T_{ji} \rangle$$

- DSS: $\partial_t \sim \frac{1}{t - t_*}$

$$\Rightarrow \quad \langle T_{tt} \rangle \sim (t - t_*) \langle T_{it} \rangle \sim (t - t_*)^2 \langle T_{ij} \rangle$$

Conservation:

$$\langle T_{tt}\rangle \sim (t-t_*)\,\langle T_{it}\rangle \sim (t-t_*)^2\langle T_{ij}\rangle$$

Shear mode (tensor) ~ scalar field:

$$\langle T_{ij}\rangle \sim \frac{1}{t-t_*}$$

$$\Rightarrow \quad \langle T_{tt}\rangle \sim t-t_* \quad \text{vanishes!}$$

$$\langle T_{it}\rangle \sim \text{const}$$

$$\langle T_{ij}\rangle \sim \frac{1}{t-t_*}$$

(explicit solution bears this out)

David Licht
Ryotaku Suzuki
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Thank you