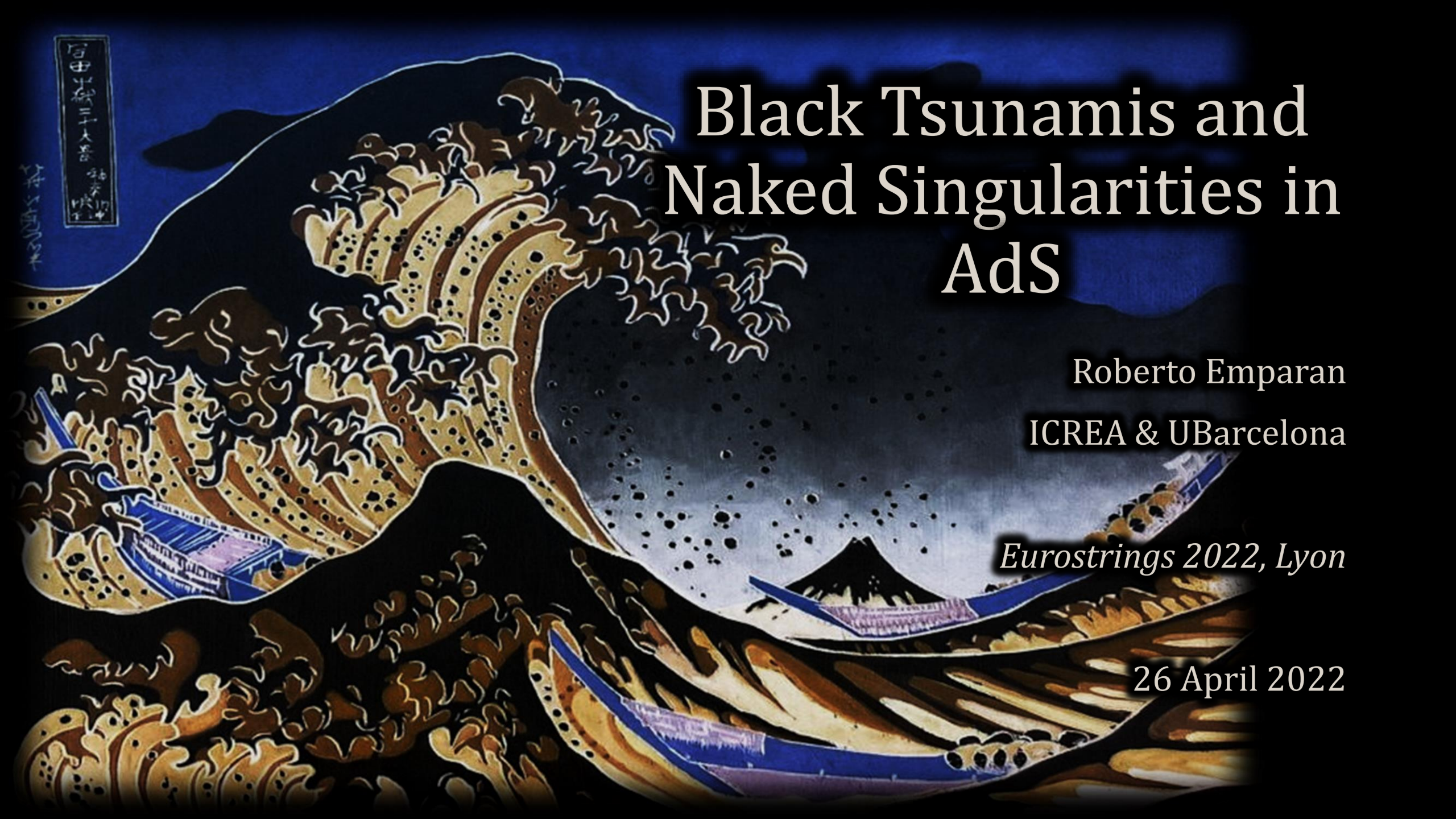


Black Tsunamis and Naked Singularities in AdS

Roberto Emparan

ICREA & UBarcelona

Eurostrings 2022, Lyon

26 April 2022

Based on

arXiv 2112.07967 [hep-th]

with

David Licht

Ryotaku Suzuki

Marija Tomašević

Benson Way

Horizons & Singularities

Horizons

limit what can be observed

Singularities

limit what can be predicted

(using classical General Relativity)

weak **Cosmic Censorship Conjecture**

You can predict everything you can observe from afar

weak **Cosmic Censorship**

Naked singularities can’t form

weak **Cosmic Censorship**

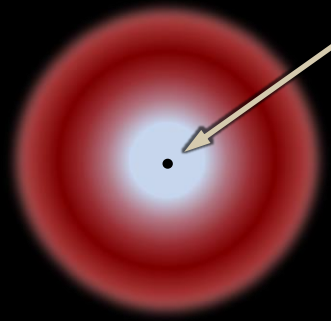
Nature hides Planck-scale physics from us

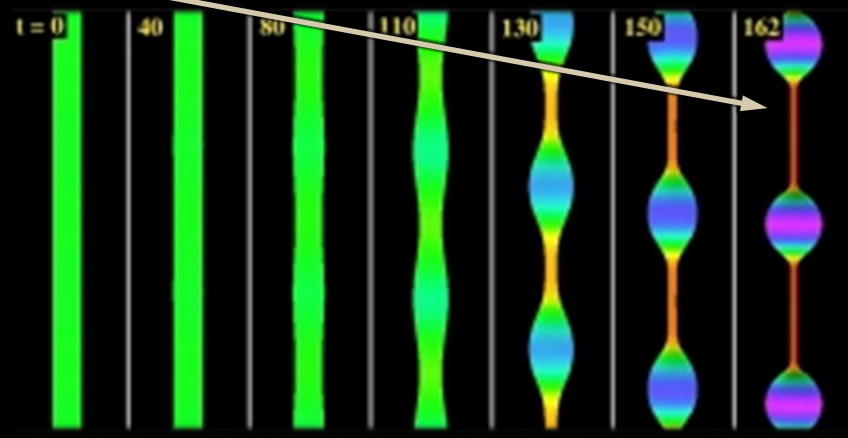
weak **Cosmic Censorship**

can be violated!

wCC violations

diverging curvature





Critical collapse

Choptuik 1993

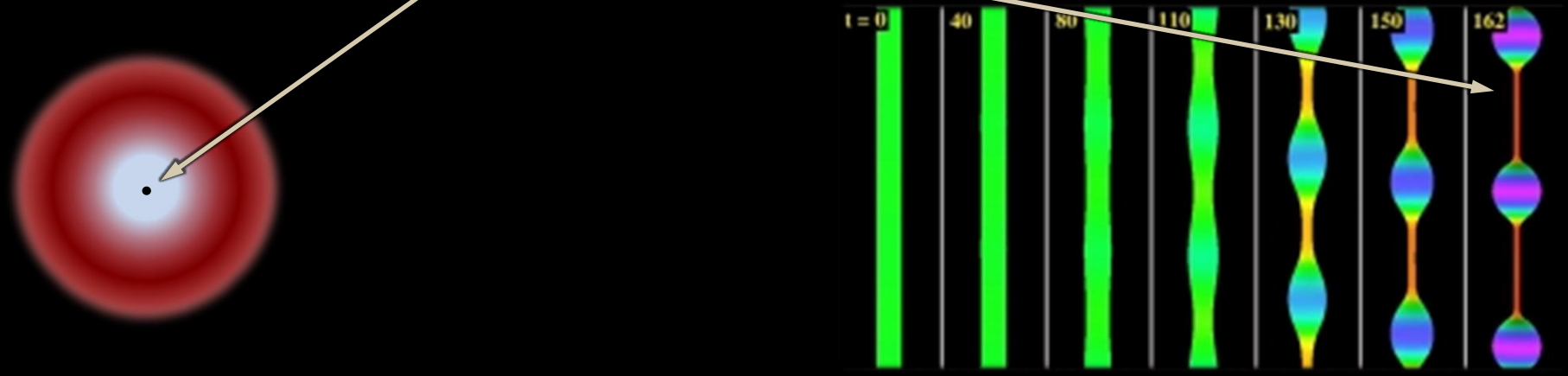
Black string instability

Gregory+Laflamme 1993
Lehner+Pretorius 2011

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

wCC violations

small mass, small extent



Improved weak Cosmic Censorship

Predictivity lost, predictivity regained

Only mild naked singularities can form,

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

They may even be controlled by attractors

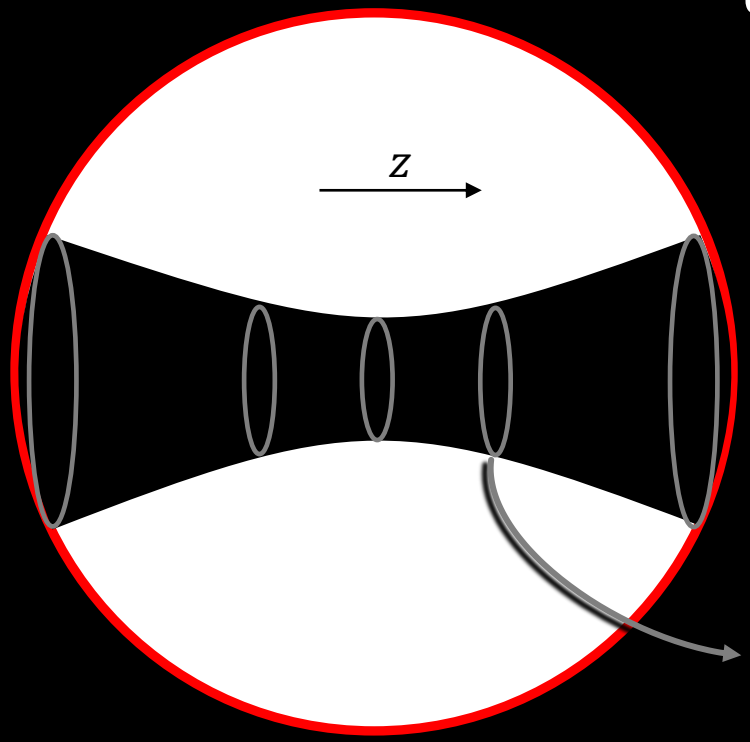
What does AdS/CFT say about this?

What setup?

Black String instability in AdS

Setup

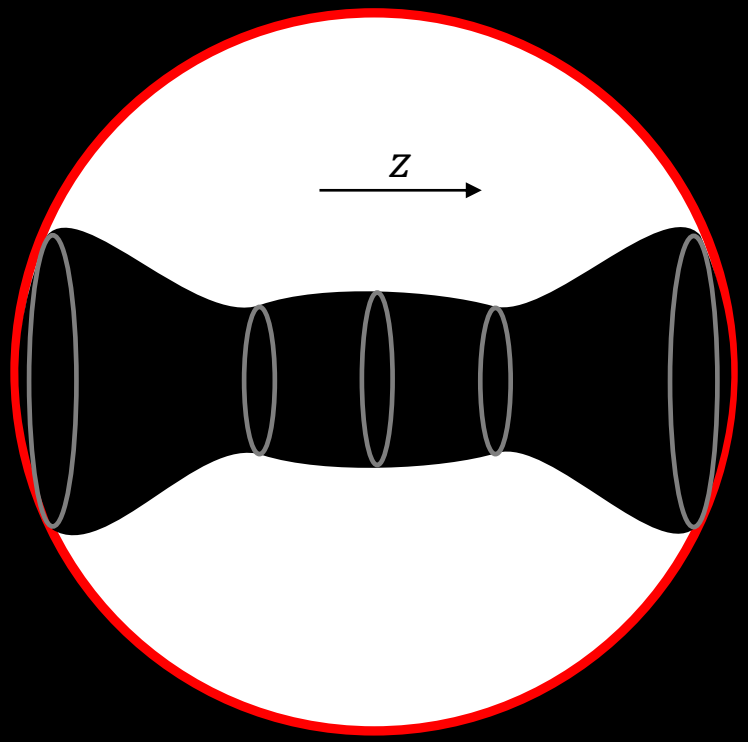
$$ds^2 = \frac{L^2}{\cos^2 z}\left(dz^2 + ds^2(\text{Schw}-\text{AdS}_{D-1})\right)$$



Boundary:

Sphere with two black holes at antipodes

fixed geometry



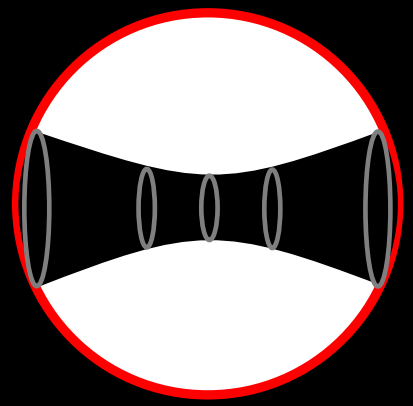
Thin enough black strings are unstable to rippling

similar to Gregory-Laflamme

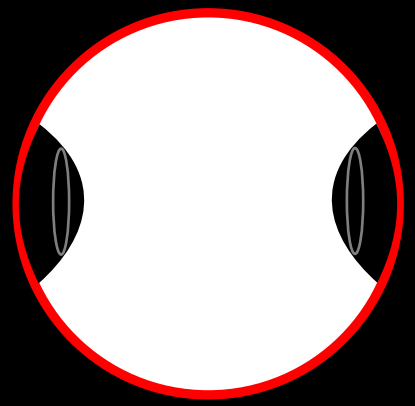
Hirayama+Kang 2001

What's the endpoint of the instability?

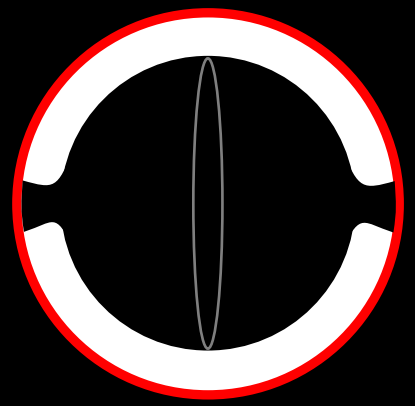
Static phases



Uniform black string
Black funnel



Black droplets



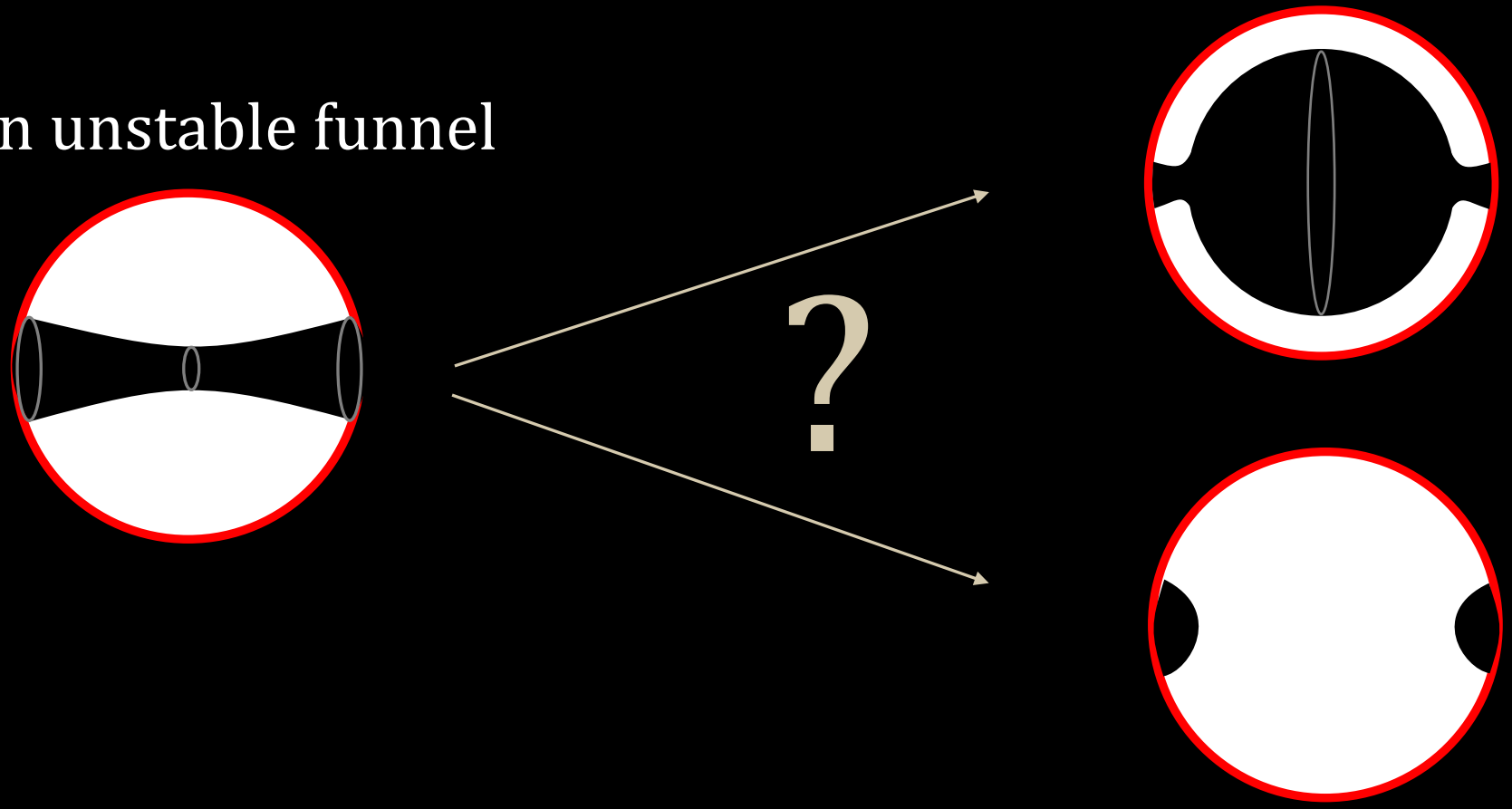
Fat funnels

Marolf+Santos 2019

(other possibilities too)

Dynamical evolution?

Thin unstable funnel



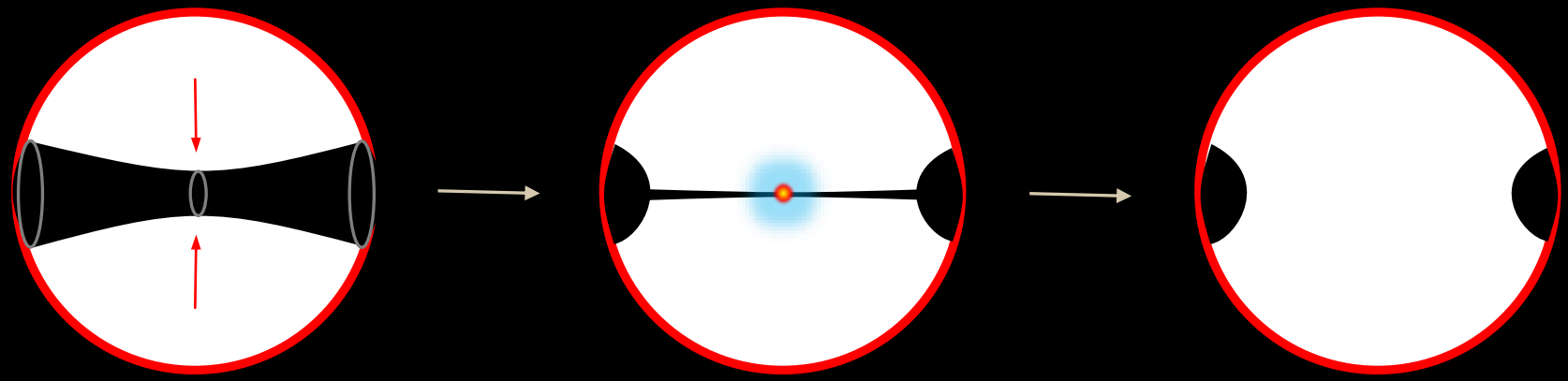
Black Tsunami flows

Possible

Fixed black hole @bdry acts as heat source/sink

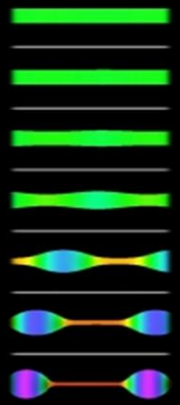
Horizon generators can flow in/out of bdry: **Black Tsunami**

Singular pinch off



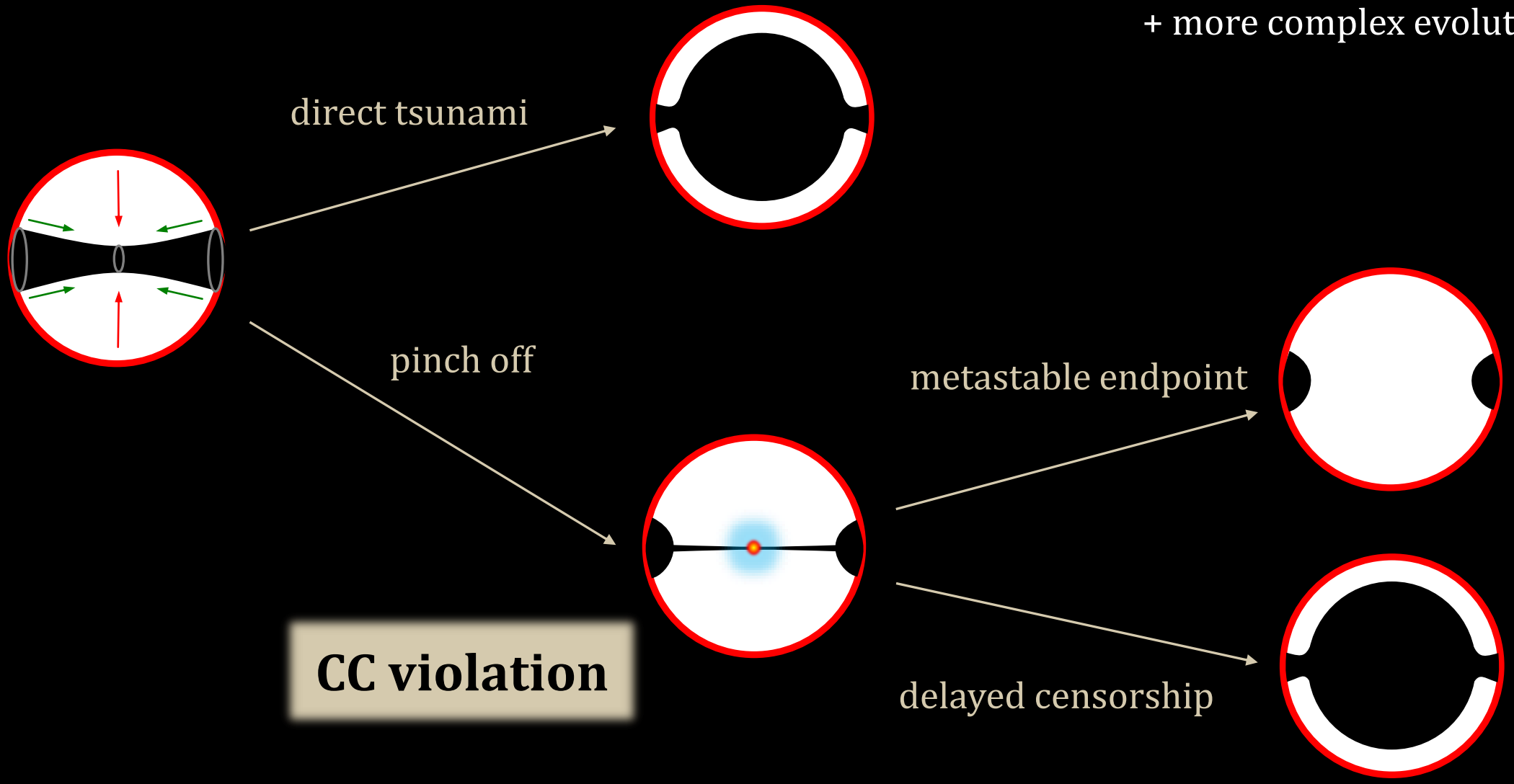
Possible

If string thickness ≪ AdS radius ⇒ ~

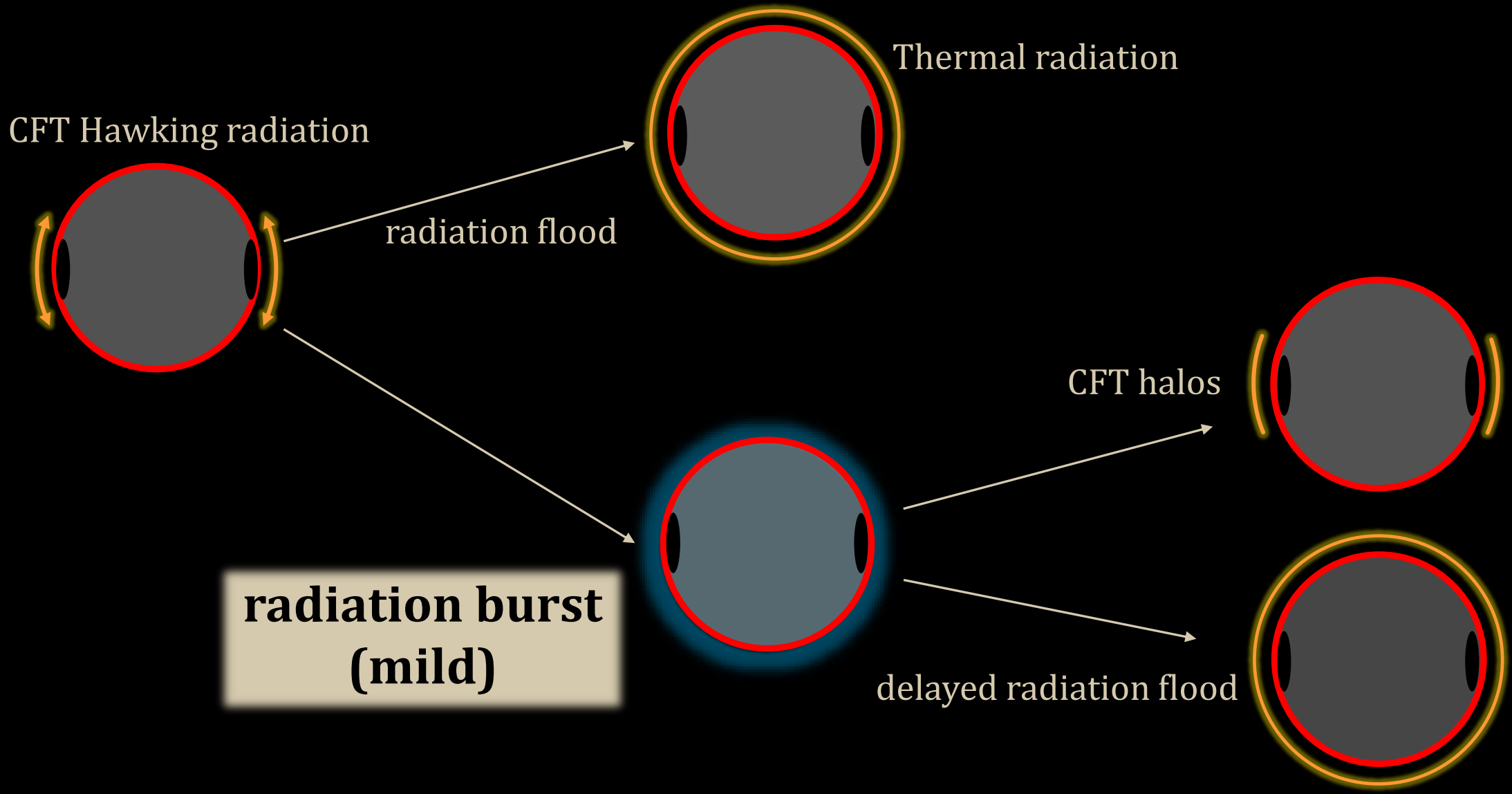


What we have found

+ more complex evolutions



What we have found – dual view

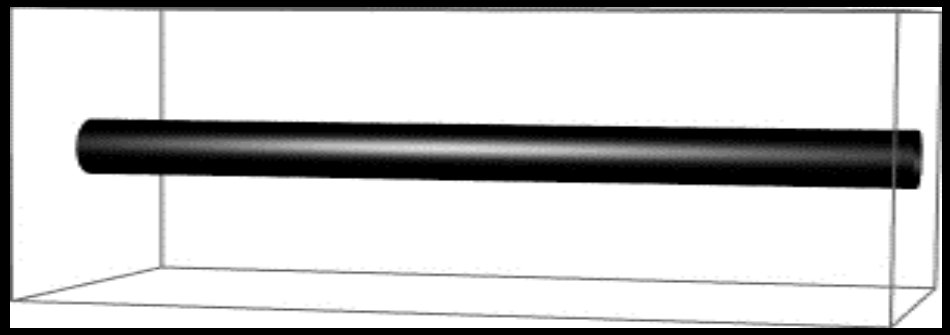


How?

Large-*D effective* theory

Black string instability in AF space

$D \to \infty$ effective theory



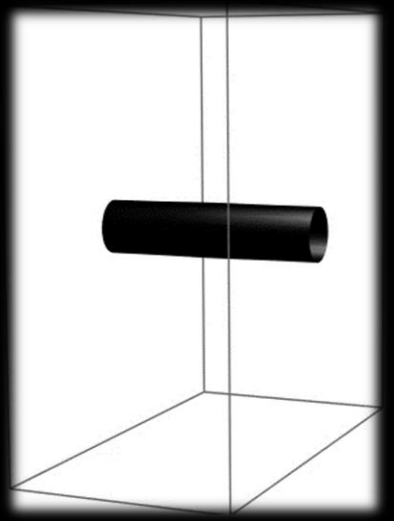
Non-linear evolution of AdS black strings

direct tsunami

droplets

pinch off

delayed tsunami



Boundary CFT signal of naked singularity formation

Large D:

Not easy to extract signal at boundary

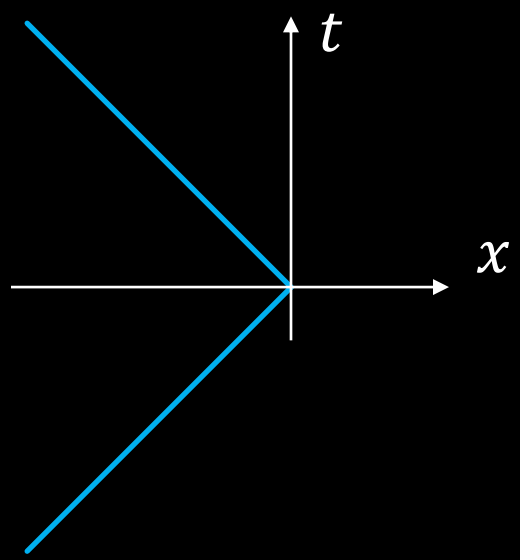
Non-perturbative in $1/D$

A linearized model

after Chesler+Way 2019

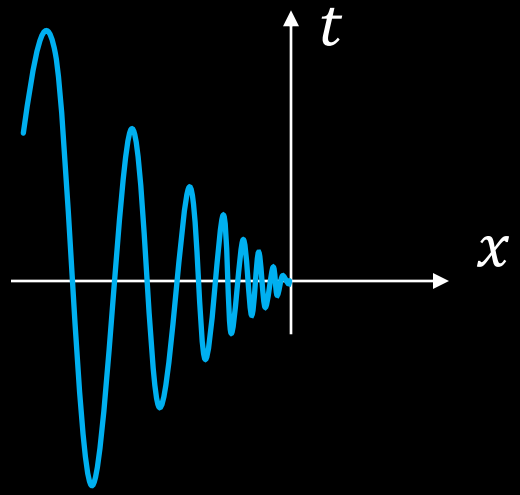
Critical collapse and Black string pinch show Self-Similarity

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



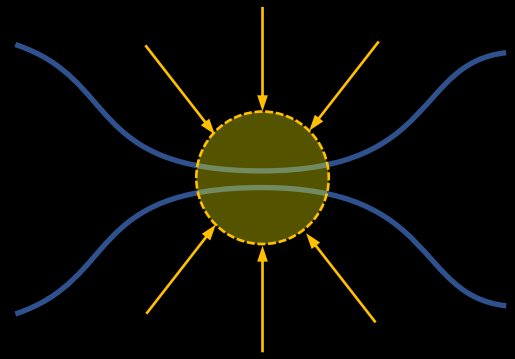
$$f(t,x) = f(e^{\lambda}t, e^{\lambda}x)$$

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



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

Assume that



- naked singularity formation occurs through **self-similar shrinking**
- self-similar region is largely **independent of smoother surroundings**
- in a sizable part of it, **gravity is approx linear**

Find solution to *linearized gravity* in AdS that

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

Extract holographic stress tensor near $r = \infty$

For DSS gravitational field

dual CFT stress tensor

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

(pressures vanish too)

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

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

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

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 $\mathcal{O}(N^2)$ each
- large localized shears

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 ?

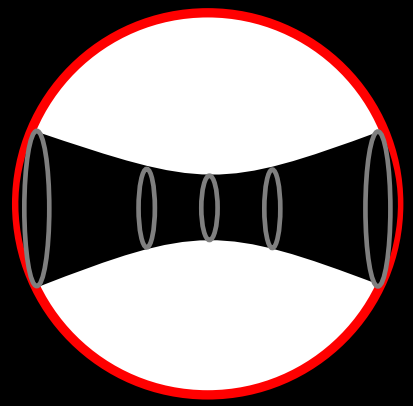
- Hawking radiation + gravitational backreaction

  → Black hole evaporation as classical bulk evolution

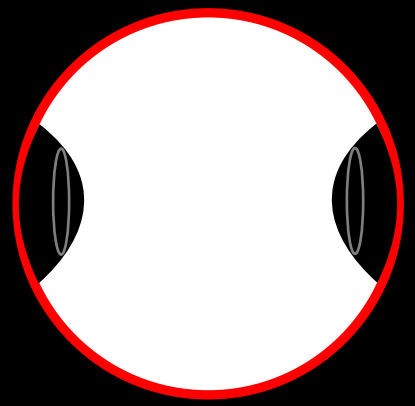

Thank you
David Licht
Ryotaku Suzuki
Marija Tomašević
Benson Way

Backup material

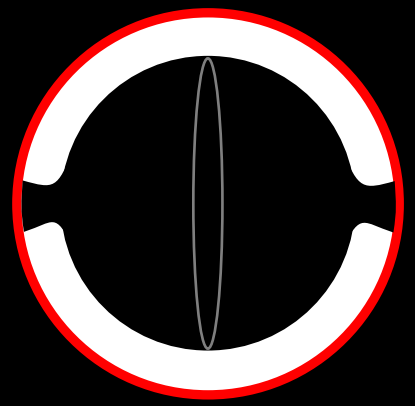
Thermodynamics – canonical



Can dominate for large BH@bdry



Never dominant



Dominant for small BH@bdry

Can dominate for large BH@bdry

Large D setup and effective equations

$D = n + 5$

r_0 = thickness in AdS units

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

mass (area) density

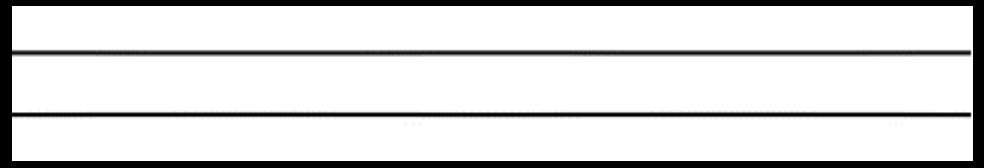
momentum density

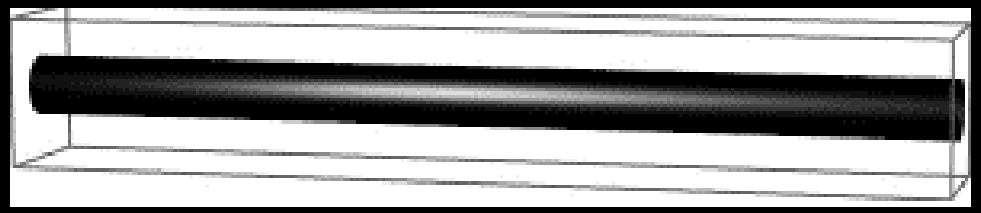
$$A = 1 - \frac{m(t,x)}{\mathrm{R}} \qquad C = \frac{p(t,x)}{\mathrm{R}}$$

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

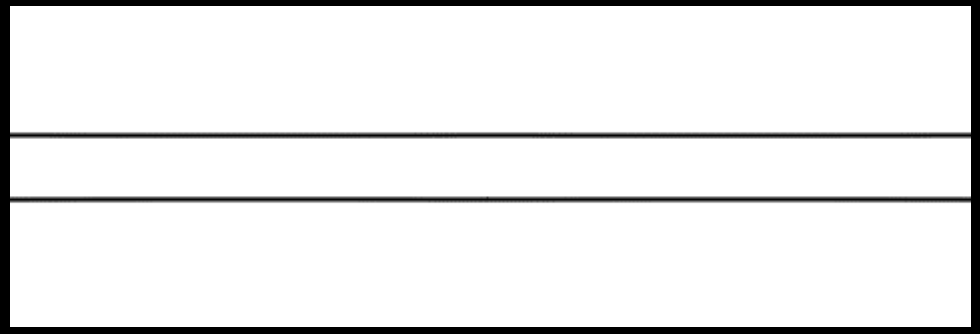
$$\partial_t p - (\partial_x + x)\left(\partial_x p - \frac{p^2}{m}\right) - (1 + r_0^{-2})\partial_x m = 0$$

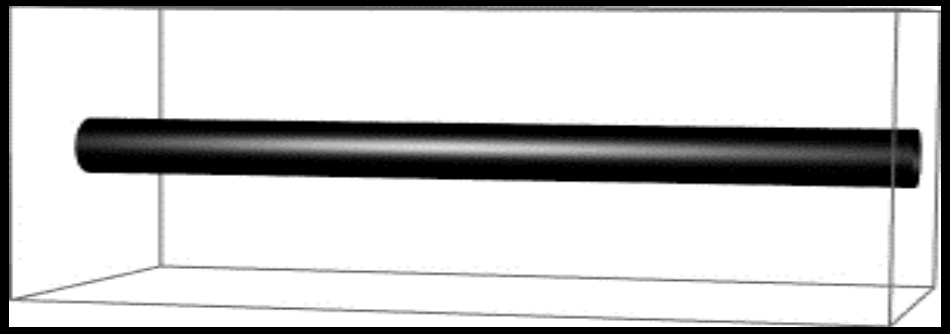
Moderate D





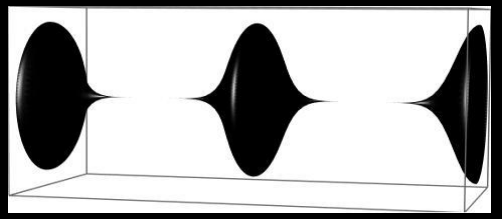
$D \to \infty$ effective theory



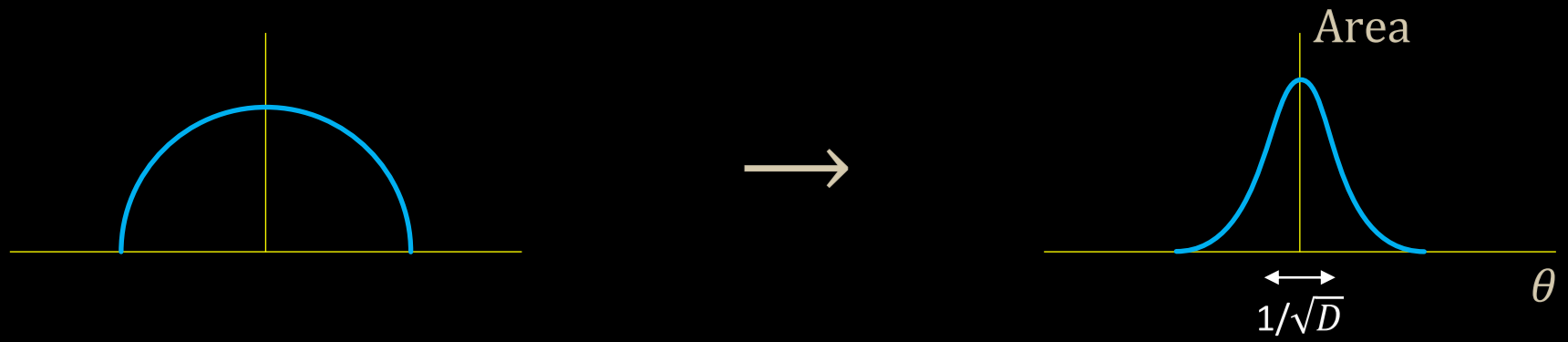


Black holes @ large D: gaussian blobs

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

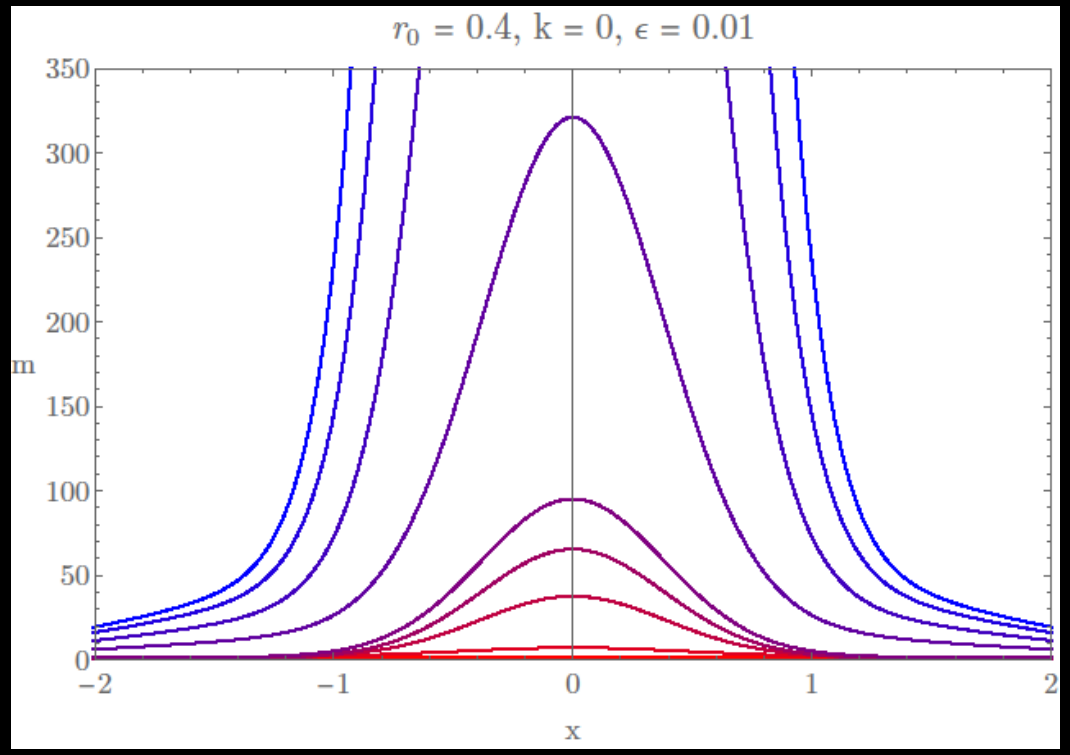


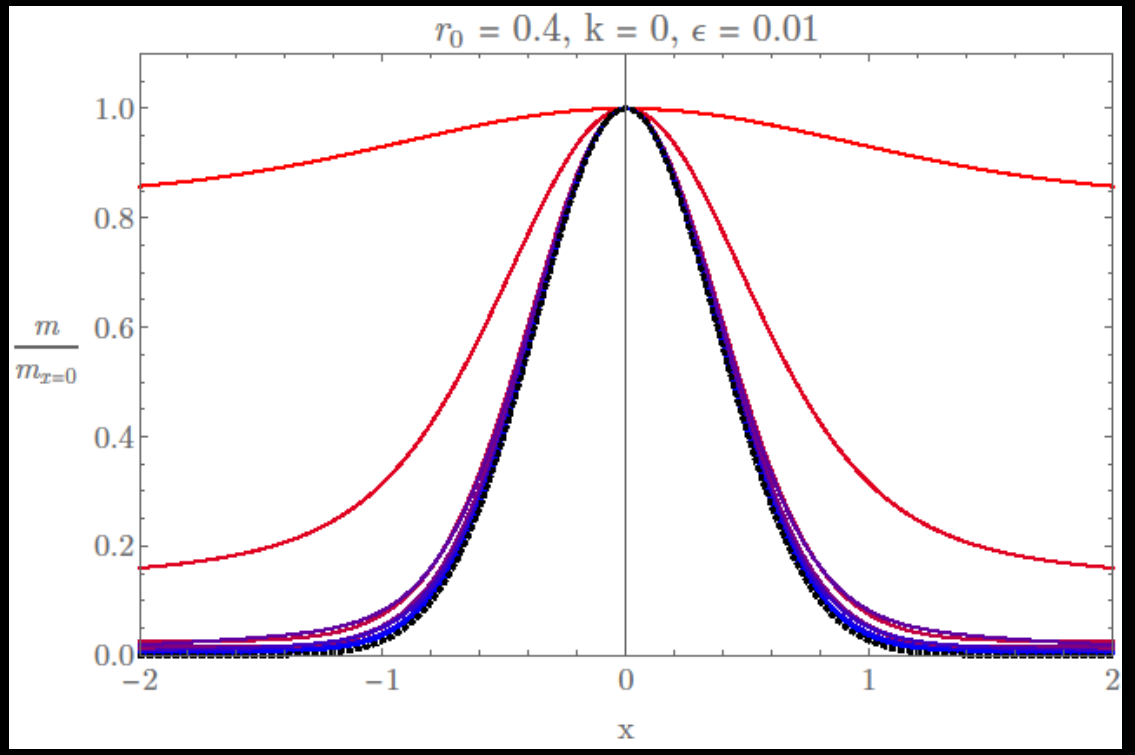
$$\mathrm{Area}(\theta) = \cos^D\theta \sim e^{D\theta^2/2}$$



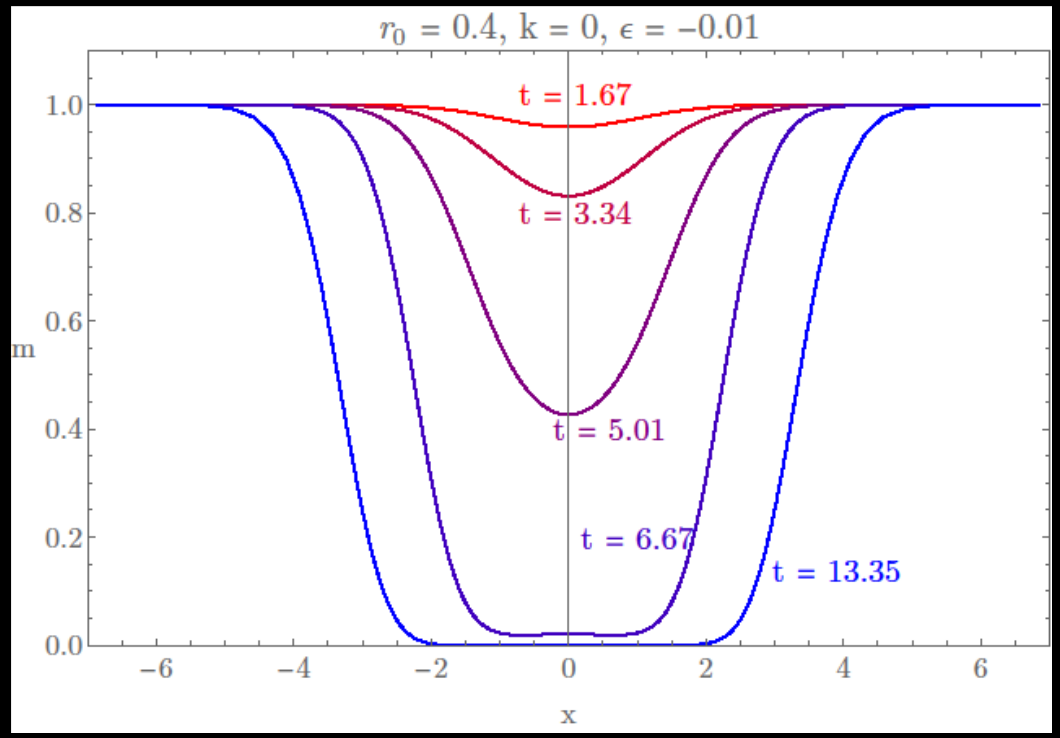
Area strongly localized near equator

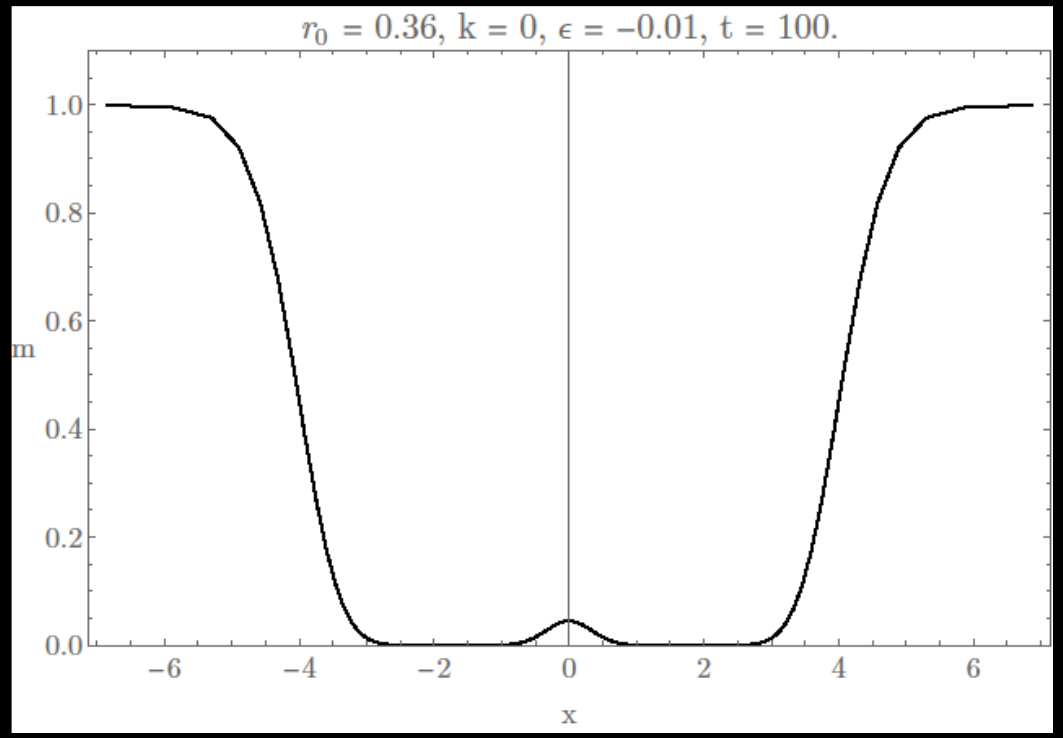
Tsunami to Fat funnel



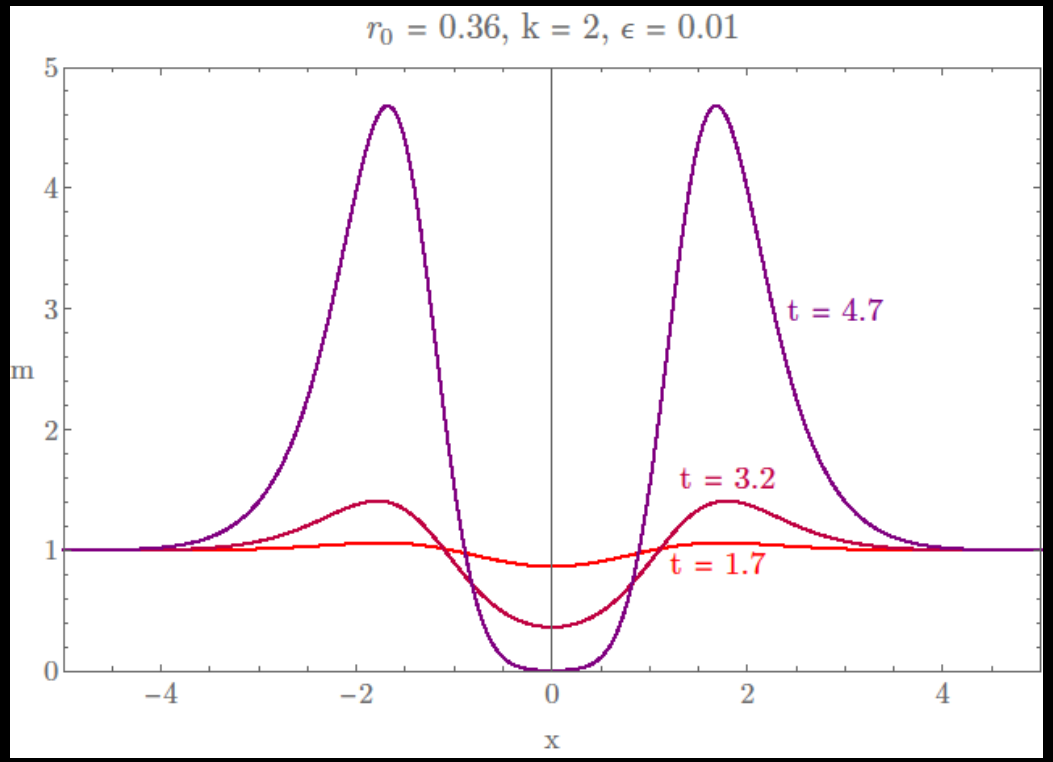


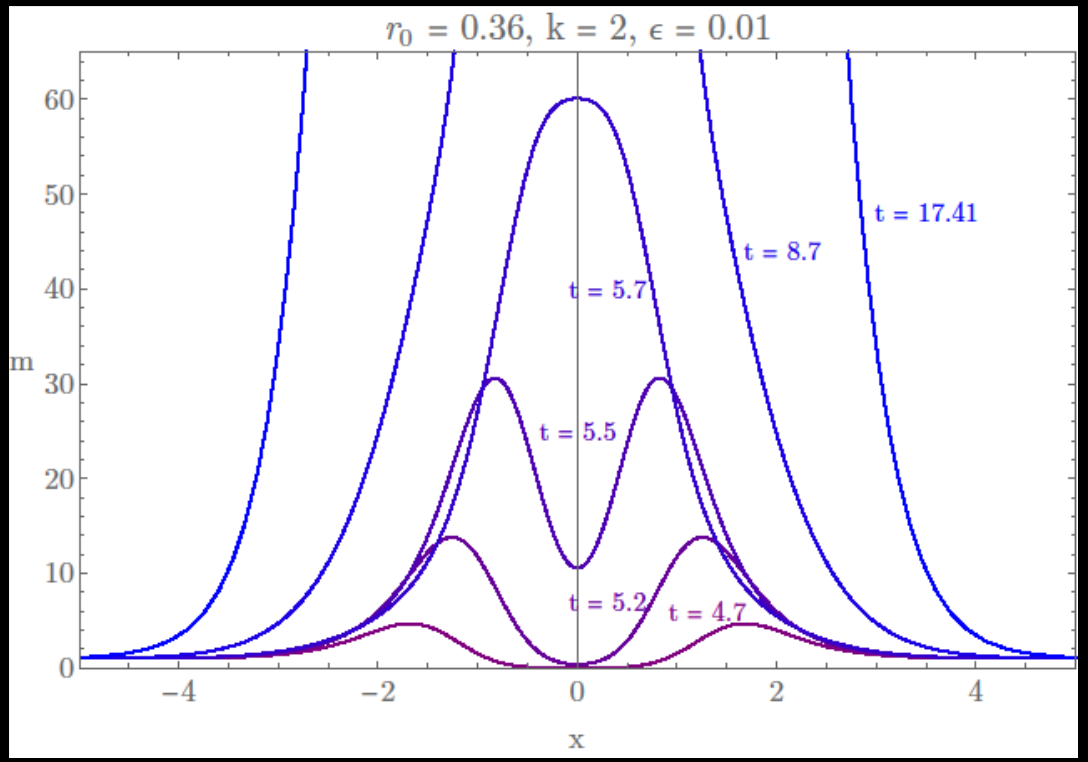
Pinch-off to Droplets





Pinch+Tsunami





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

Linearized SS solution (scalar field)

sum over AdS normal modes

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

self-similarity (high n)

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

self-similar about $t = \frac{\pi}{2}$

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

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

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:

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

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

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

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

(explicit solution bears this out)