Black hole-Wormhole collisions

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Black hole- Wormhole collision and the emergence of islands
arXiv:2304.06098
In collaboration with:
João Dias (IST)
Valentin Paccoia (Perugia U.)
Jorge Rocha

INTERNATIONAL CONFERENCE
DARK MATTER AND STARS
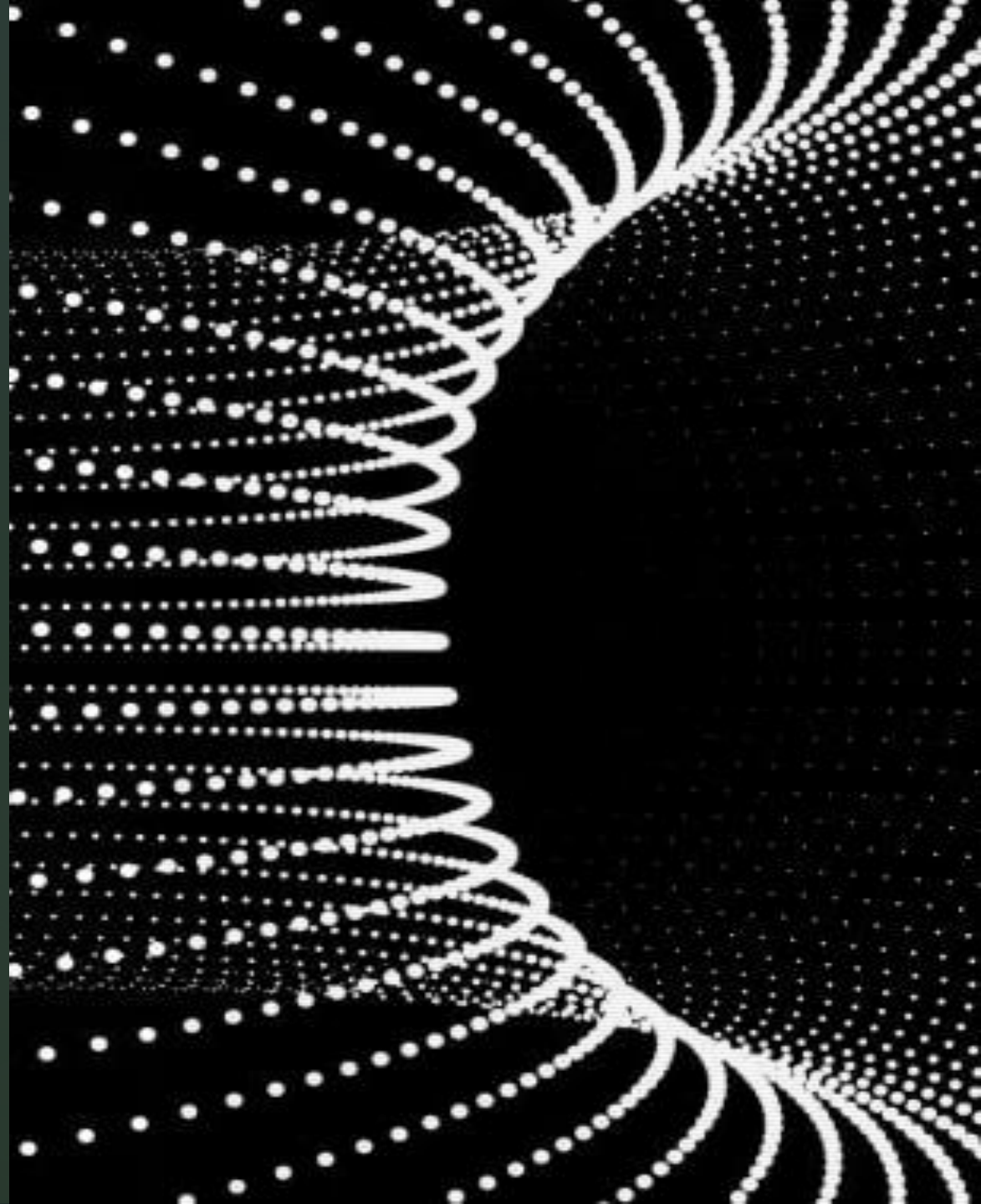Multi-Messenger probes of Dark Matter and Modified Gravity
3-5 MAY 2023

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BH- WH collision and the emergence of islands

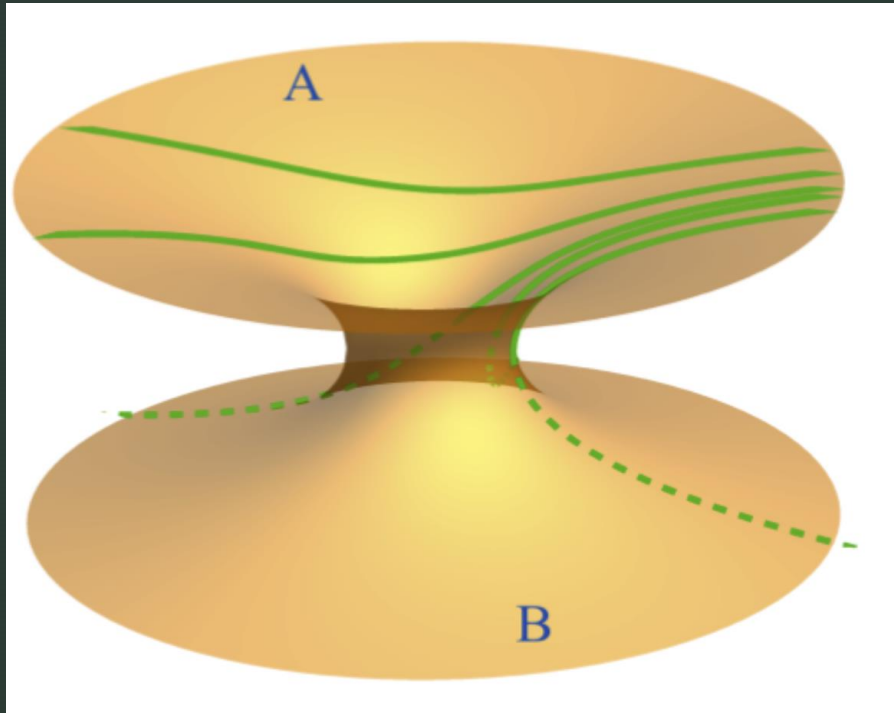arXiv:2304.06098

Outline

Motivation

Strategy

Inter-universe WH
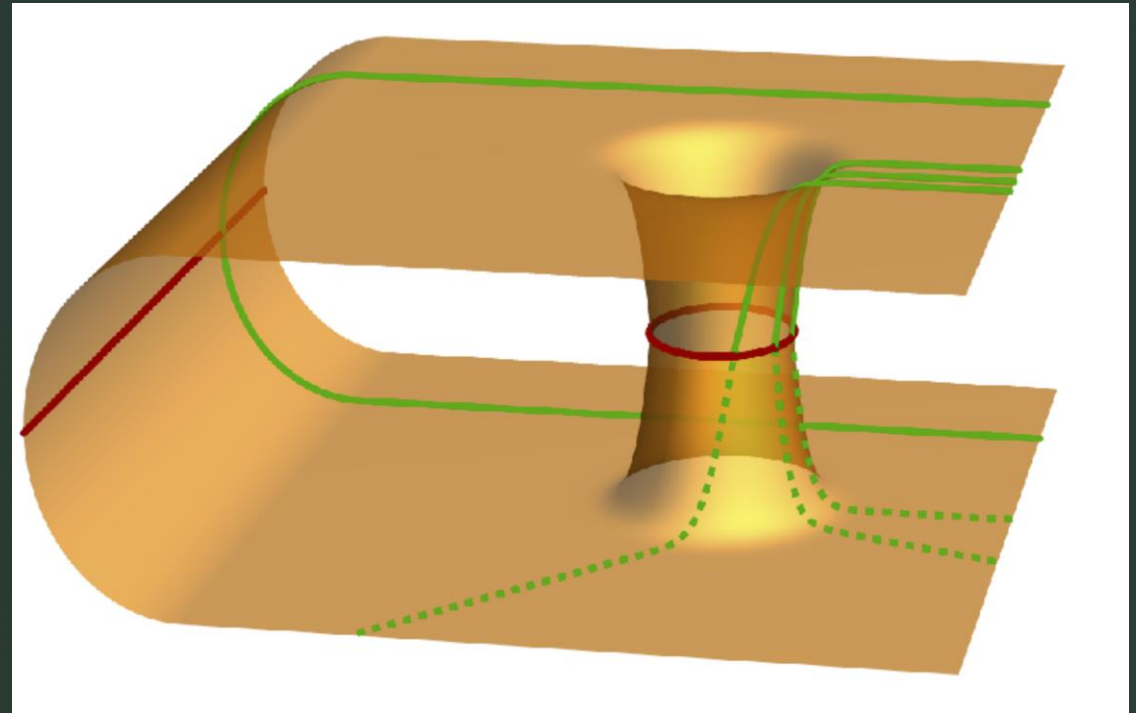
Intra-universe WH

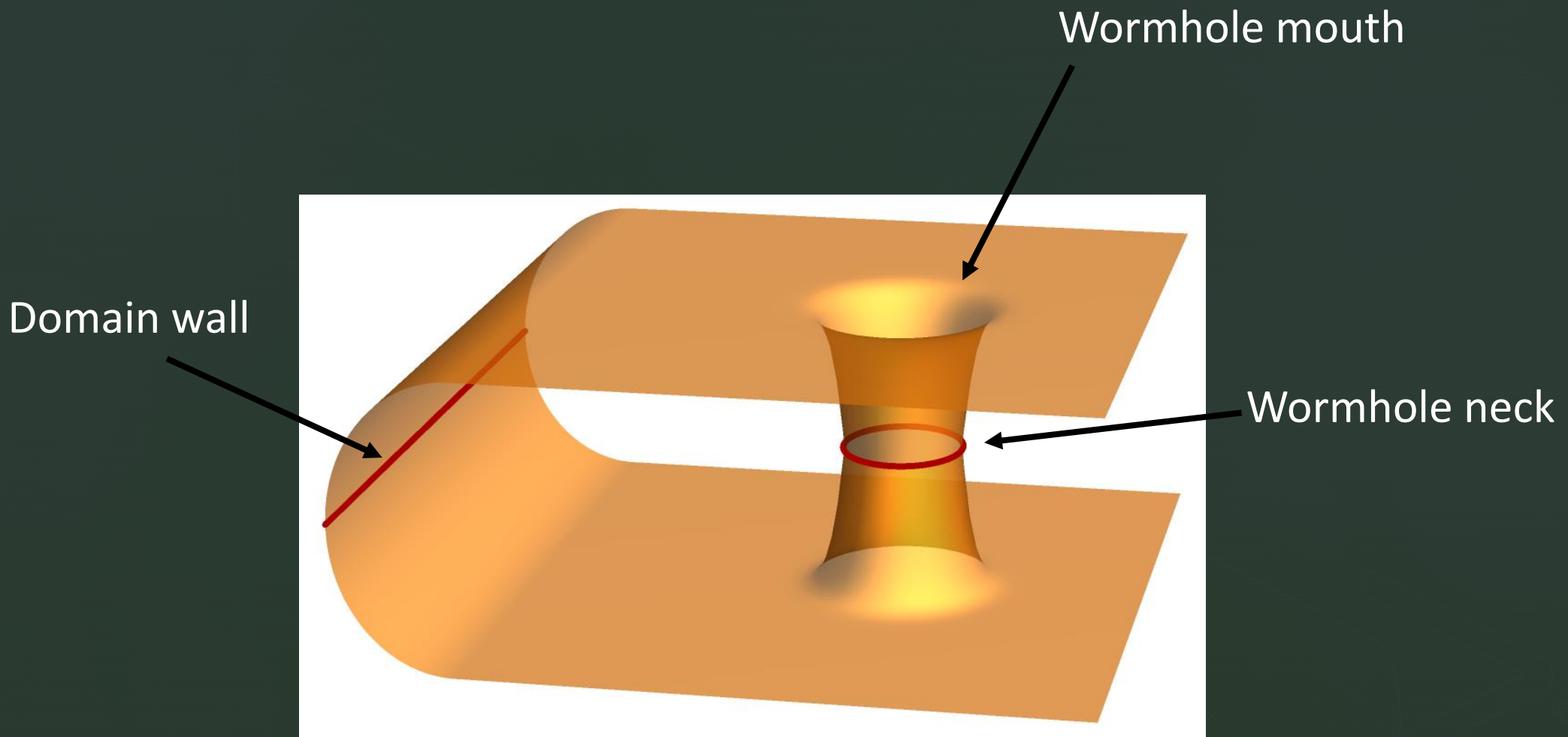## Results

Inter-universe wormhole

Wormholes are spacetime bridges connecting separate universes

Intra-universe wormhole

They can also be used to connect distant regions within the same universe

Wormhole mouth

Domain wall

Wormhole neck

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BH- WH collision and the emergence of islands

Motivation

Study of solutions of modified gravity

- Exotic matter / Casimir energy
- Horizonless compact object with particular properties/topology
- Energy conditions: AANEC

What happens when a wormhole falls into a black hole?

- Intuitively:
  if there is a mouth of the WH inside the BH connecting to another mouth outside
  ➡ Then one might escape the BH by traversing the WH
  ➡ If so, the BH interior gets modified

Motivation

What happens when a wormhole falls into a BH?

- This was studied long ago by Frolov and Novikov
  [wormhole as a device to study black hole's interior (1993)]
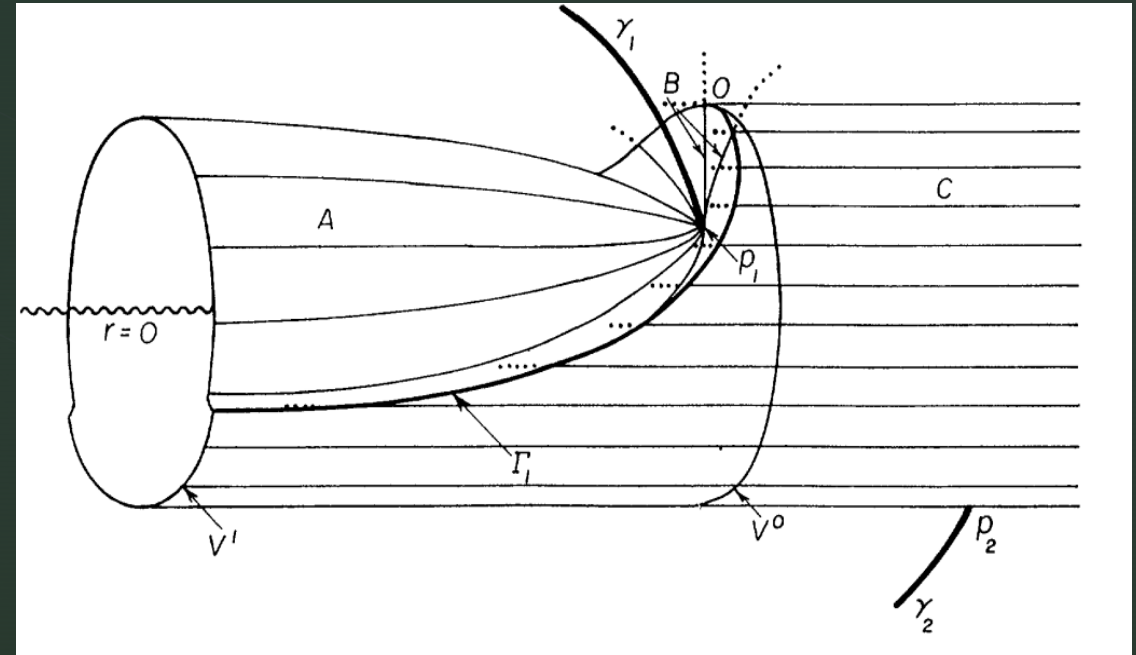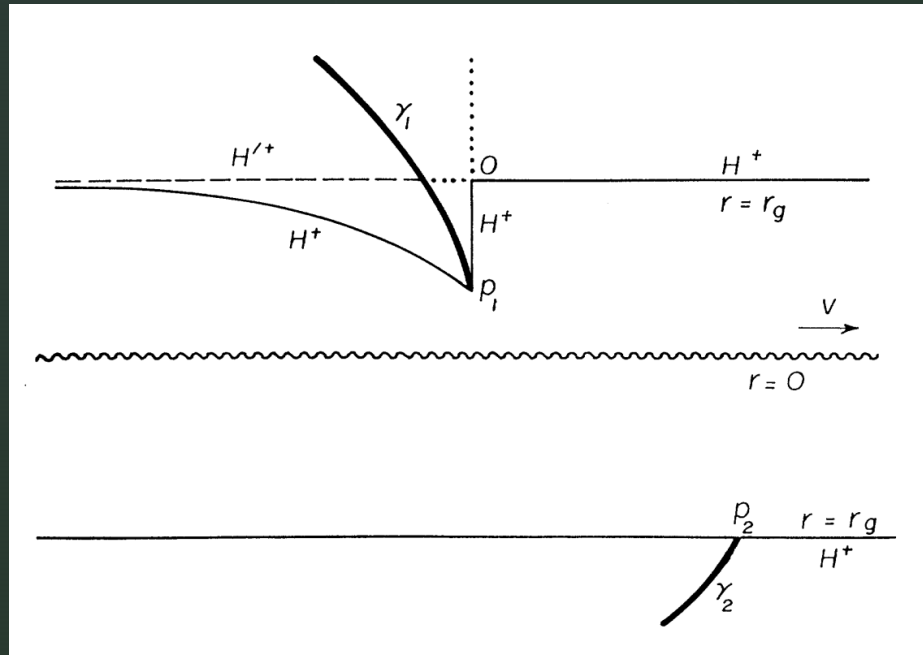
Motivation

What happens when a wormhole falls into a BH?

- This was studied long ago by Frolov and Novikov
  [wormhole as a device to study black hole's interior (1993)]

  - The study mostly considered a point-like WH and a finitely sized BH

  - It used a quasi-Newtonian approximation to describe the gravitational field near the wormhole

  - Found that the event horizon recedes (for some time) when a wormhole falls into a black hole

In order to determine the evolution of the event horizon at the scales of the wormhole, while retaining the EMR regime,
we must keep the WH finite and consider an infinitely large BH

Strategy

1 Consider a WH-BH collision in the EMR regime,
keeping the size of the WH finite (while R_{BH} to infinity):

2 Use light ray-tracing to determine the entire event horizon
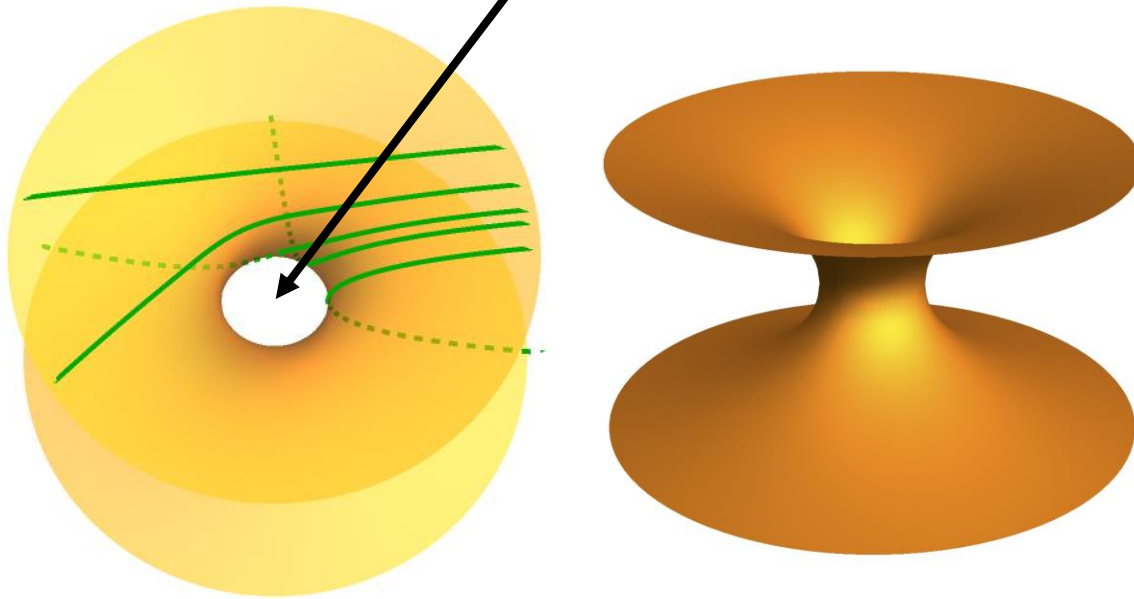
To this end, all that is required is <u>a specific background</u> on which to compute the desired geodesics

We chose one of the simplest traversable WH geometries known: <u>the Ellis-Bronnikov solution</u>

3 By taking constant time slices and then showing them in succession one obtains the time evolution of the event horizon

Ellis-Bronikov metric

$$ds^2 = -dt^2 + \frac{r^2}{r^2 - a^2}dr^2 + r^2 d\Omega^2$$

② Light ray-tracing

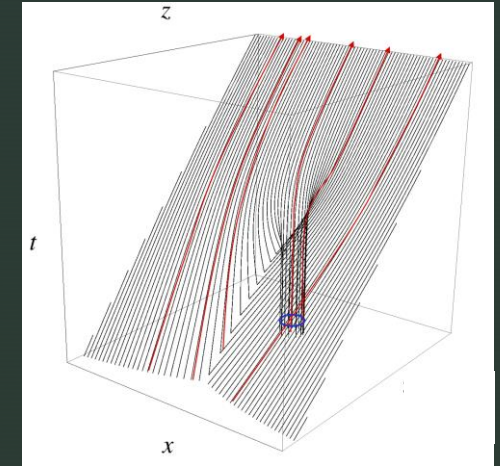To find the evolution of the event horizon:

Trace a family of null geodesics in the EB solution that approaches a null hyper-plane at infinity (and integrate back in time)

All the equations you need to solve (for EB):

$$t_q(r) = \int \frac{r^2 dr}{\sqrt{(r^2 - q^2)(r^2 - a^2)}}$$

$$\phi_q(r) = -\int \frac{q dr}{\sqrt{(r^2 - q^2)(r^2 - a^2)}}$$

[Emparan, Martínez 2016 Emparan, Martínez, Zilhão 2018]]

q = impact parameter of light rays at infinity

With the appropriate final conditions: null plane at infinity

➡ in this case can be even solved analytically
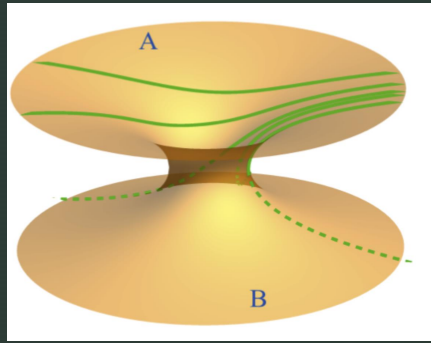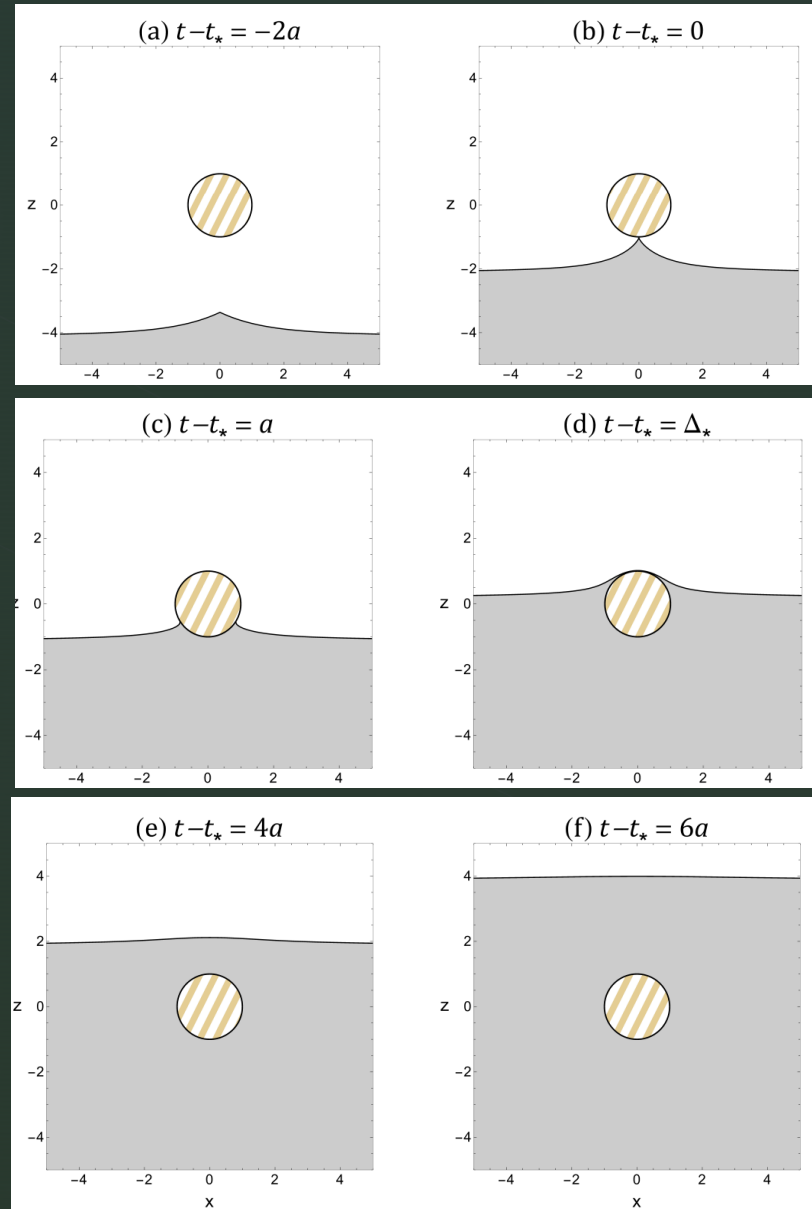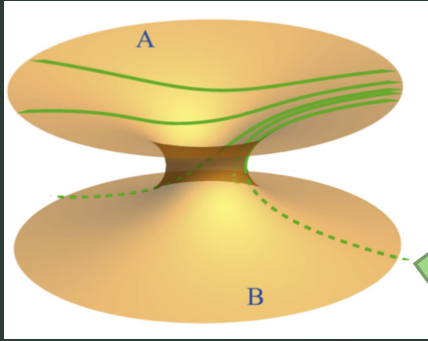
➡ general solution

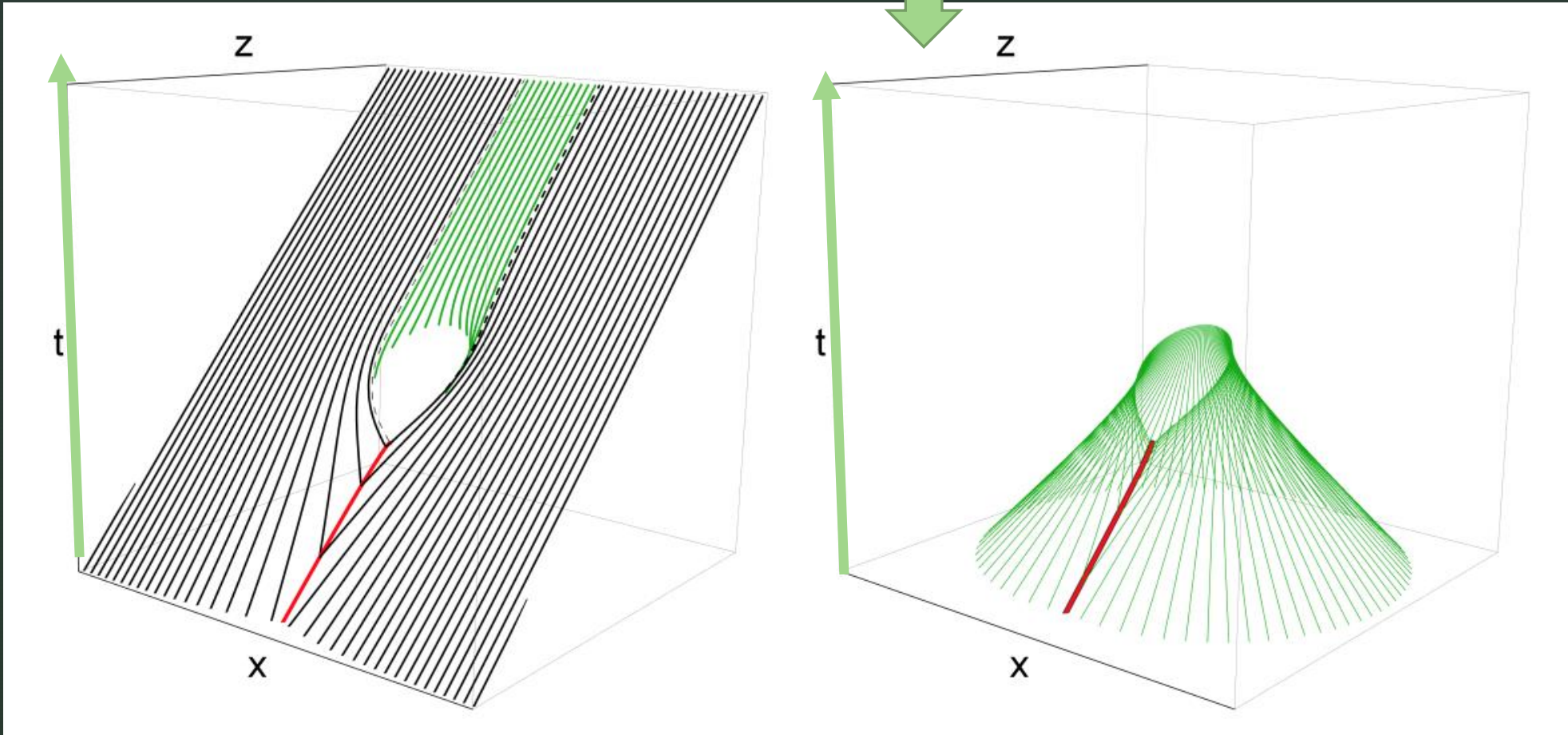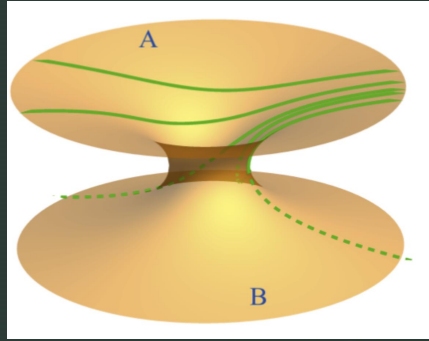# Time evolution of the event horizon
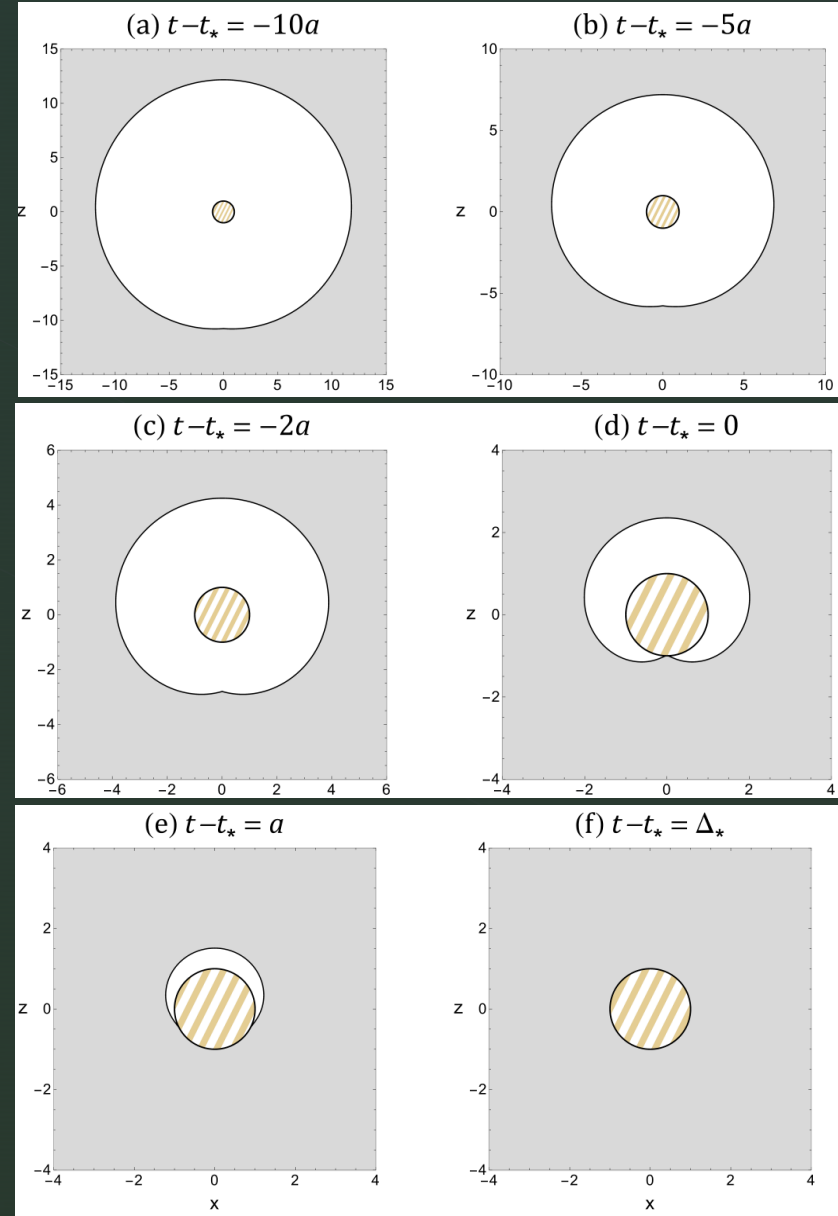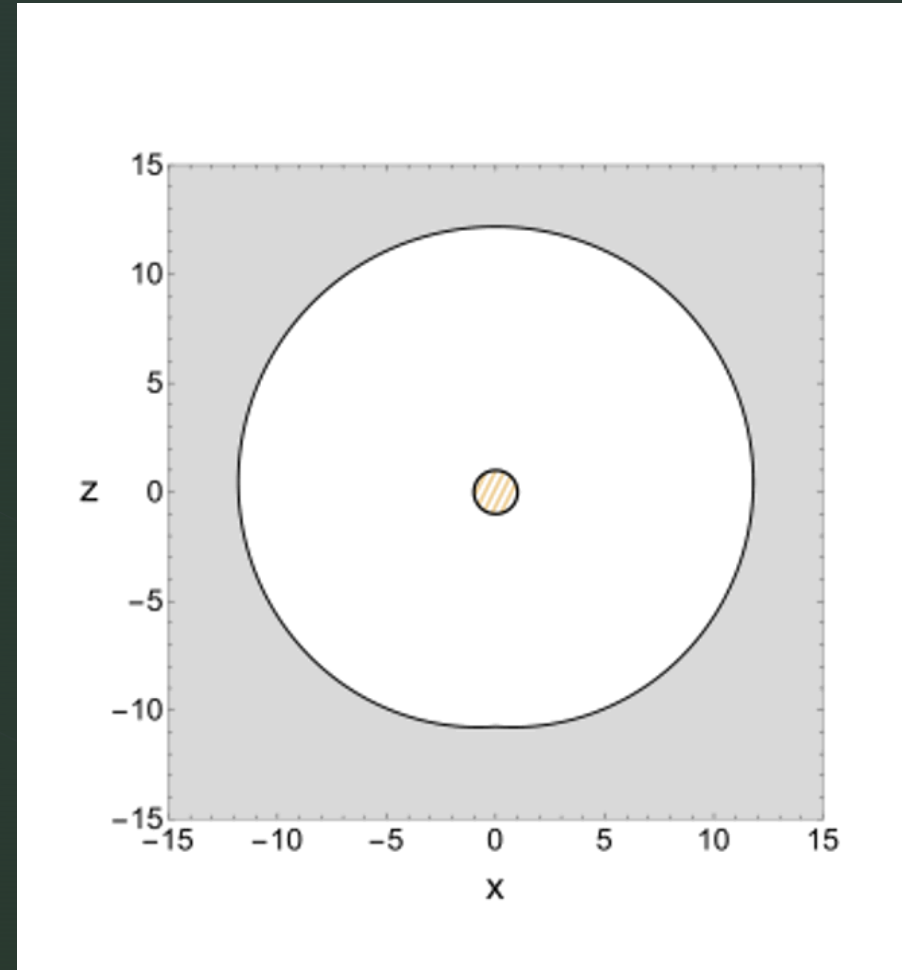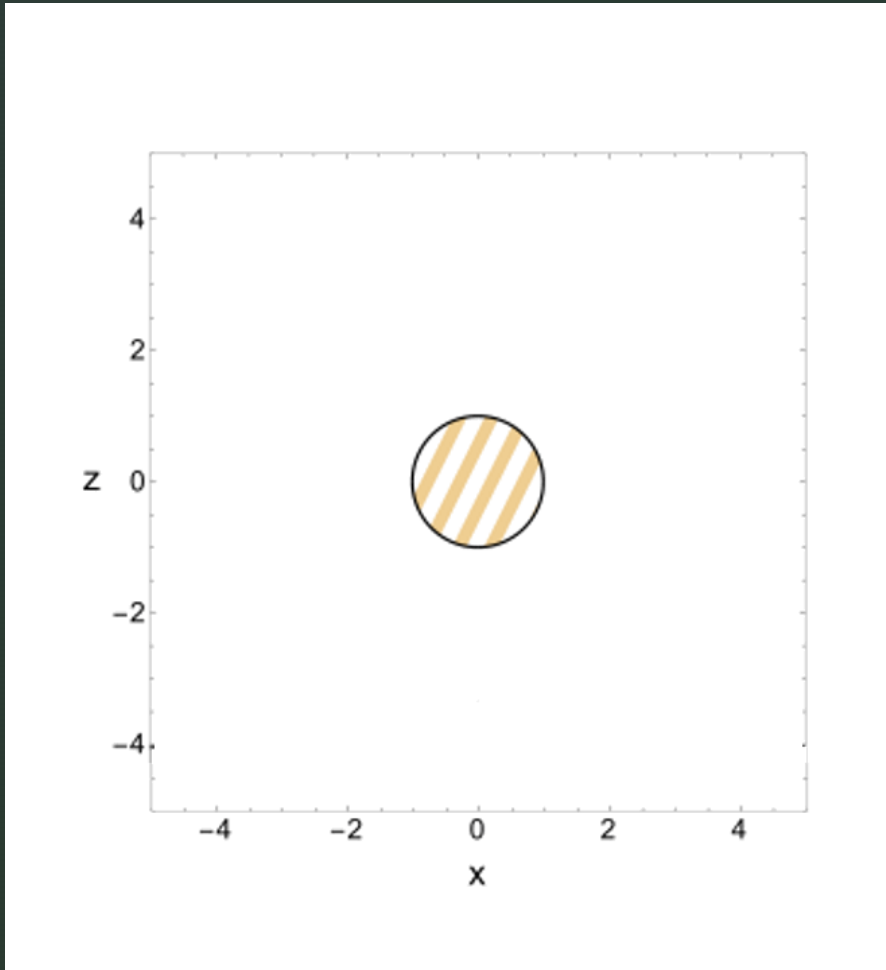## side A
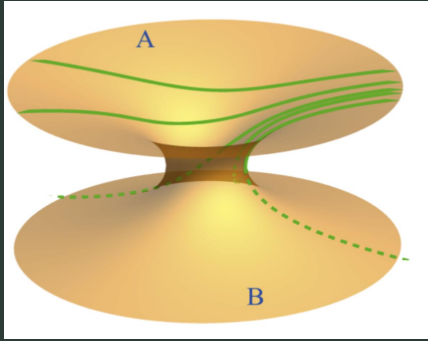
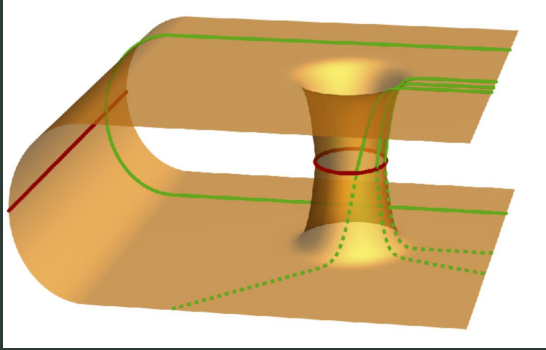③ Time evolution of the event horizon
side A
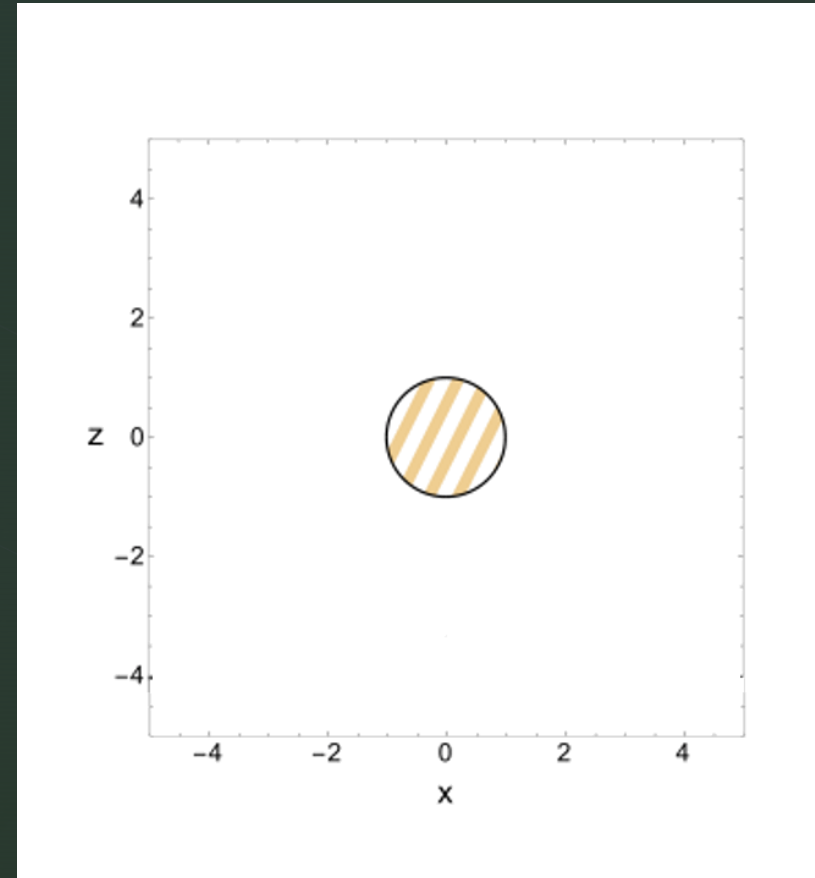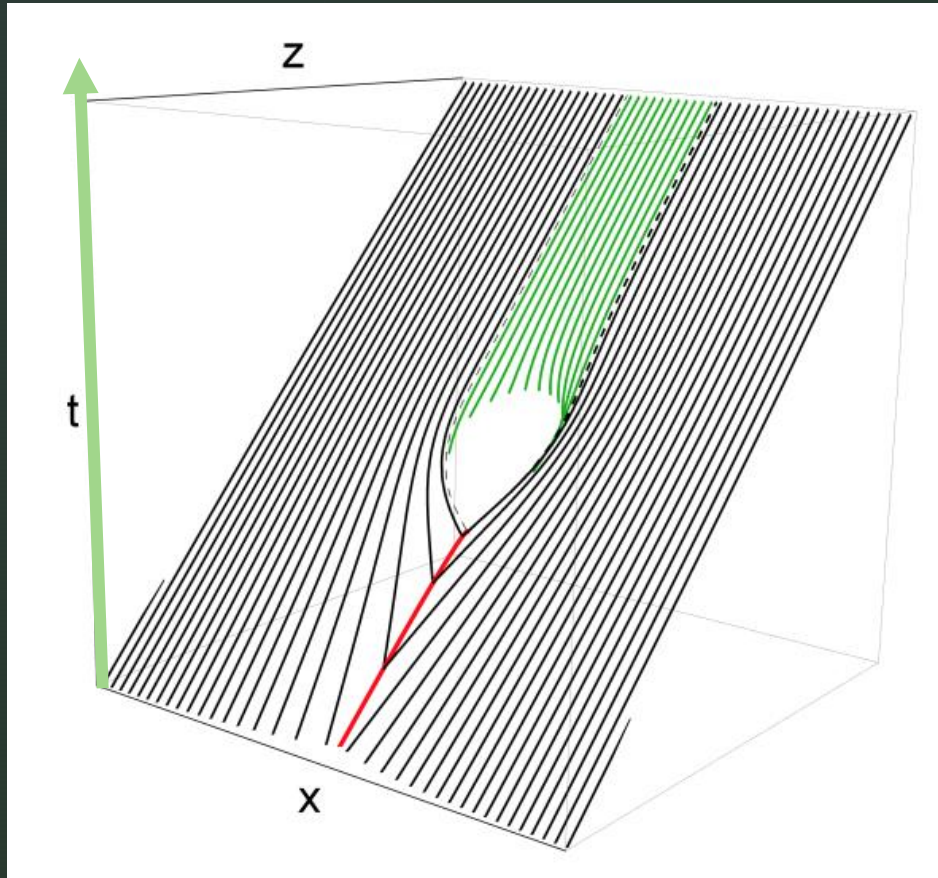
2 Light-ray tracing
side A & side B

③ Time evolution of the event horizon
side B
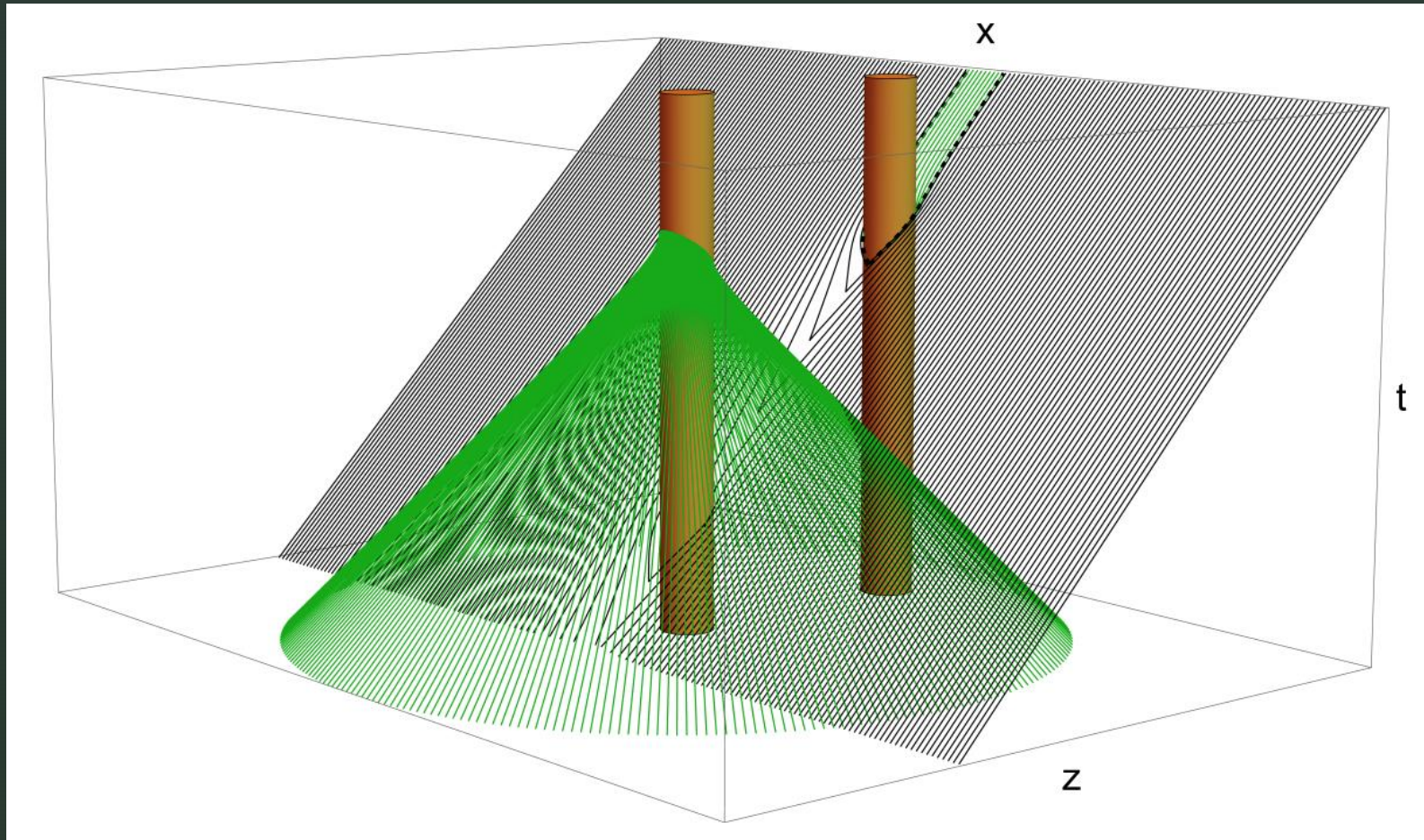

(a) $t - t_* = -10a$

(b) $t - t_* = -5a$

(c) $t - t_* = -2a$

(d) $t - t_* = 0$

(e) $t - t_* = a$

(f) $t - t_* = \Delta_*$

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BH- WH collision and the emergence of islands

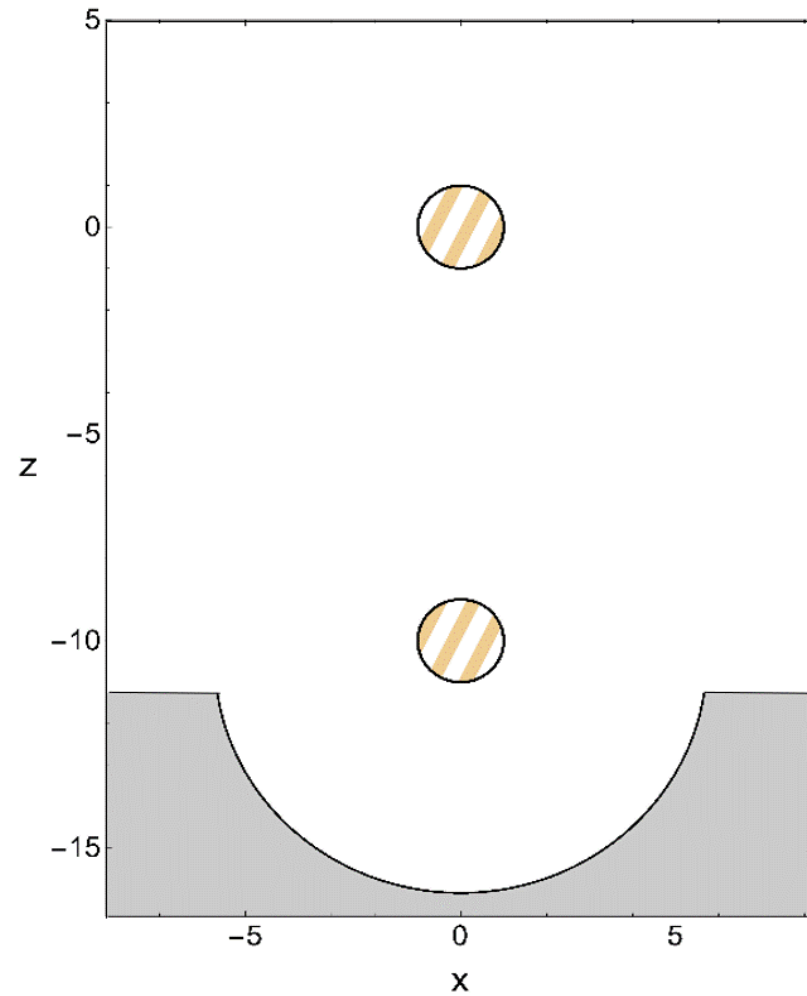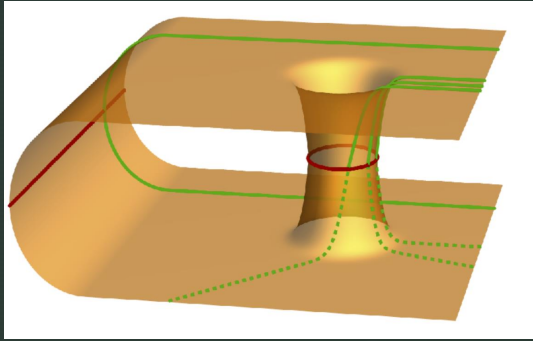arXiv:2304.06098

❸ Time evolution of the event horizon
side A & side B

② Light-ray tracing

Time evolution of the event horizon

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③ # Time evolution of the event horizon
inter-universe WH

(a) $t - t_* = -10a$

(b) $t - t_* = -3.8762a$

(c) $t - t_* = -3.70a$

(d) $t - t_* = -2a$

(e) $t - t_* = a$

(f) $t - t_* = 4a$
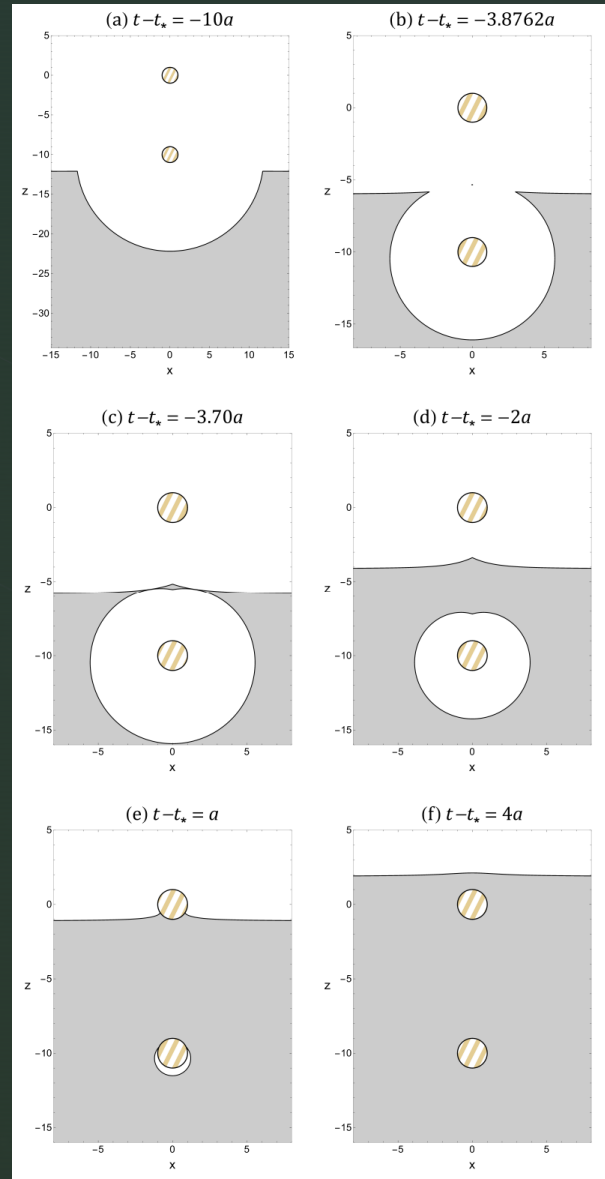
1. The formation of a precursor
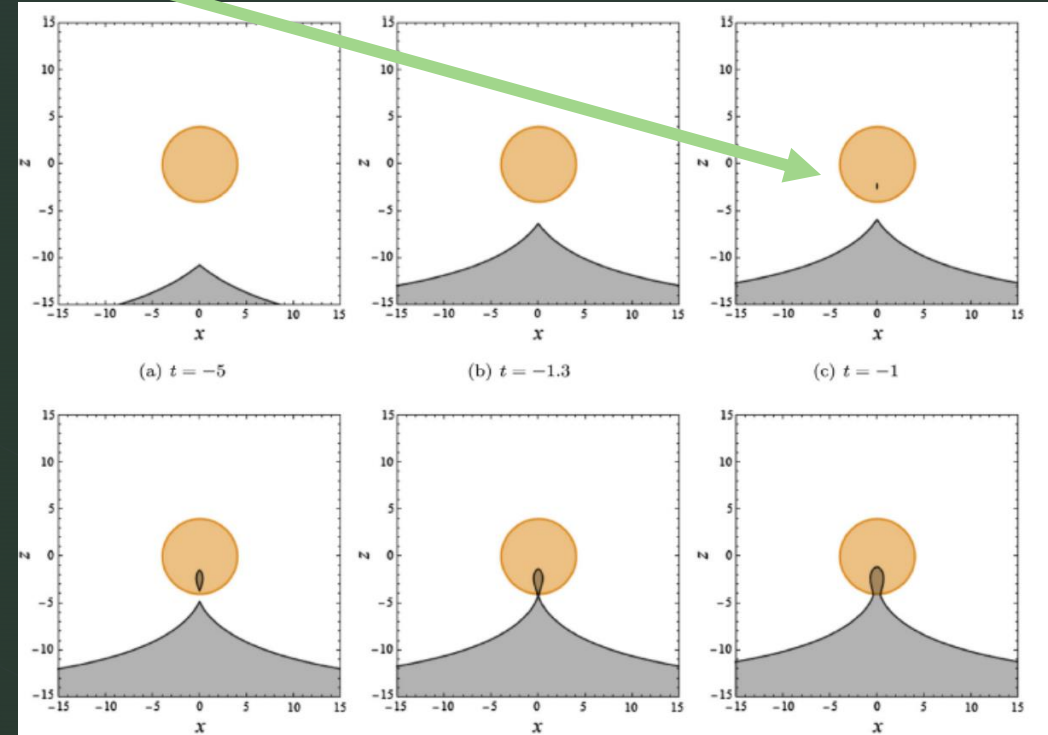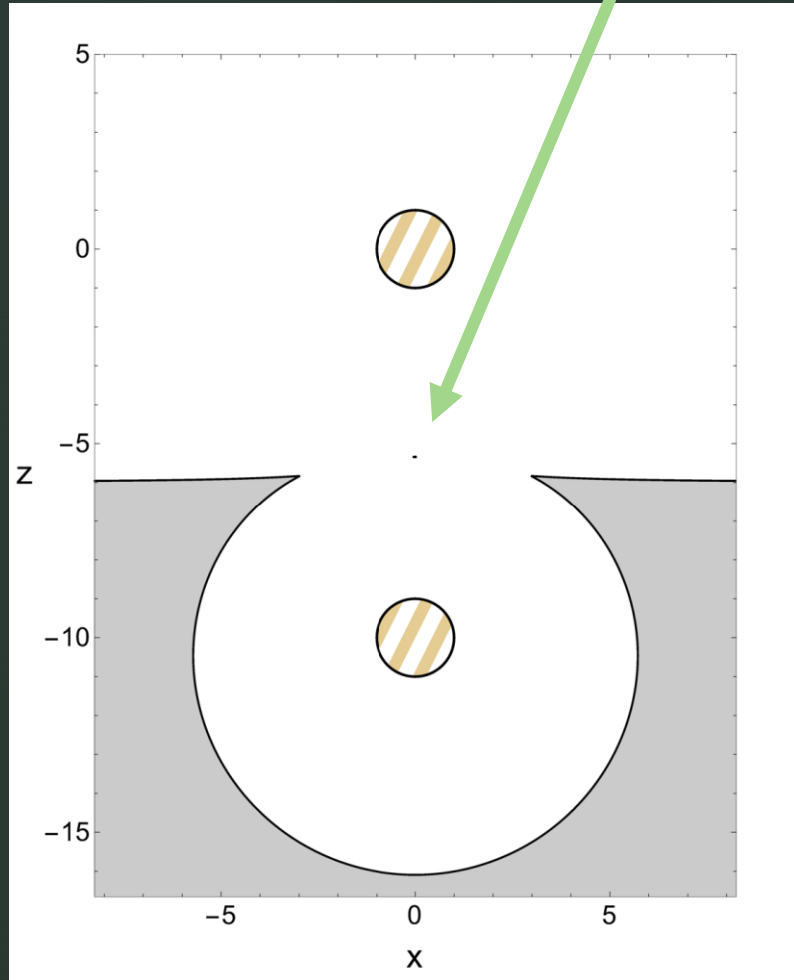
[Emparan & Marín 2020 BH-NS merging]

1. The formation of a precursor
2. The presence of an island & duration of the island

- The characteristic lifetime of the island can then be defined:
  $$\Delta_0 = t_f - t_i$$
- Once d is fixed relative to a, the lifetime can be computed numerically.

$$\Delta_\circ = a + \frac{1}{2}d$$

$$\Delta_\circ = a + \frac{1}{2}d - L$$

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Summary and conclusions

What happens when a wormhole falls into a BH?

Evolution of the event horizon

Intra-universe WH
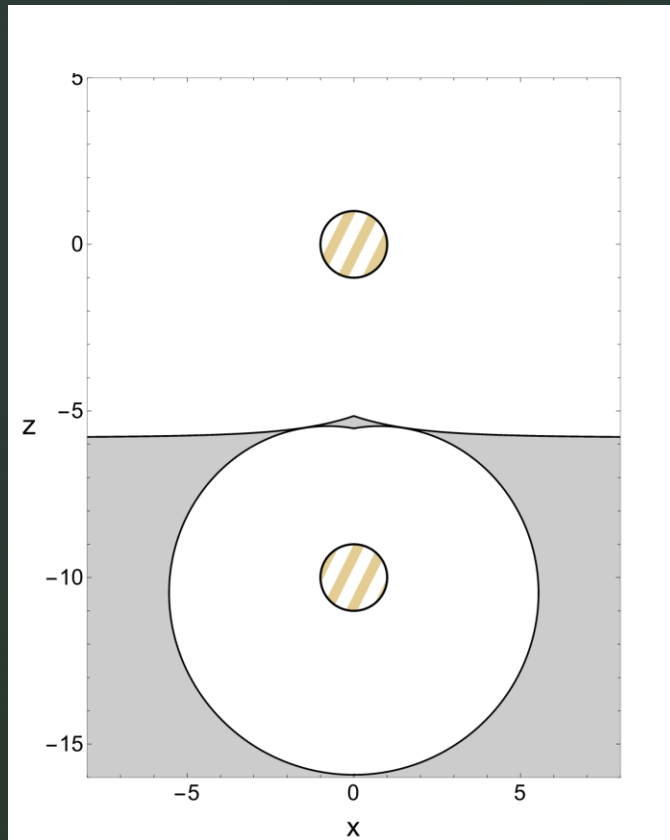
- Merging of two horizons

Inter-universe WH

- Emergence of islands
- Precursor
- Energy conditions

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