Black hole instabilities and violation of the weak cosmic censorship in higher dimensions

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THE ROYAL SOCIETY

Why gravity in higher *D*?

- Study fundamental aspects of gravity in new settings
- String theory, AdS/CFT
- GR simplifies in the large *D* limit
- New gravitational physics in *D*>4:

  1. Gravitational instabilities [Gregory and Laflamme]

  2. New black hole topologies [Emparan and Reall; Schoen and Galloway]

Outline of the talk

- Motivation: the weak cosmic censorship conjecture
- Black ring instabilities
- Rotating spherical black hole instabilities
- Summary and conclusions

The weak cosmic censorship conjecture

- GR has a well-posed initial value problem [Choquet-Bruhat; Choquet-Bruhat and Geroch; Sbierski]

- Singularity theorems in GR: singularities form generically [Penrose; Hawking and Penrose]

- If singularities form generically, does GR have any predictive power at all?

- What kind of singularities form generically in dynamical evolution?

The weak cosmic censorship conjecture

*"**Generic** asymptotically flat initial data have a maximal future development possessing a complete future null infinity"*

[Penrose; Geroch and Horowitz;Christodoulou]

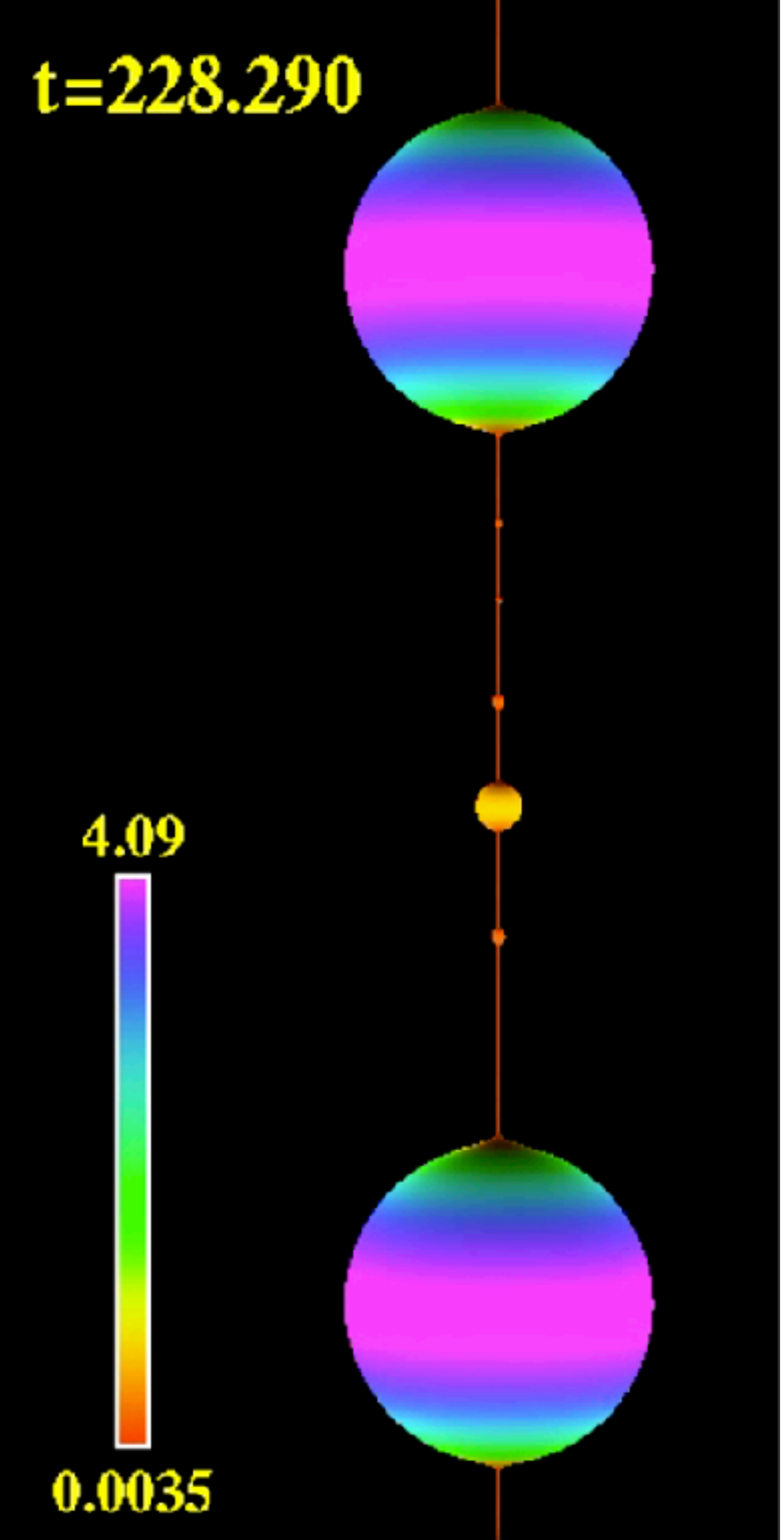
- If a black hole is unstable, can the singularity inside become visible during the evolution?

The Gregory-Laflamme instability for black strings

- Black strings: black hole solution of the Einstein vacuum equations in $M_4 \times S^1$

$$ds^2 = -\left(1 - \frac{2\,M}{r}\right) dt^2 + \frac{dr^2}{1 - \frac{2\,M}{r}} + r^2\, d\Omega^2_{(2)} + dz^2 \qquad z \sim z + L$$

- If $M/L \lesssim O(1)$ black strings are unstable to develop ripples along the compact extra dimension [Gregory and Laflamme]



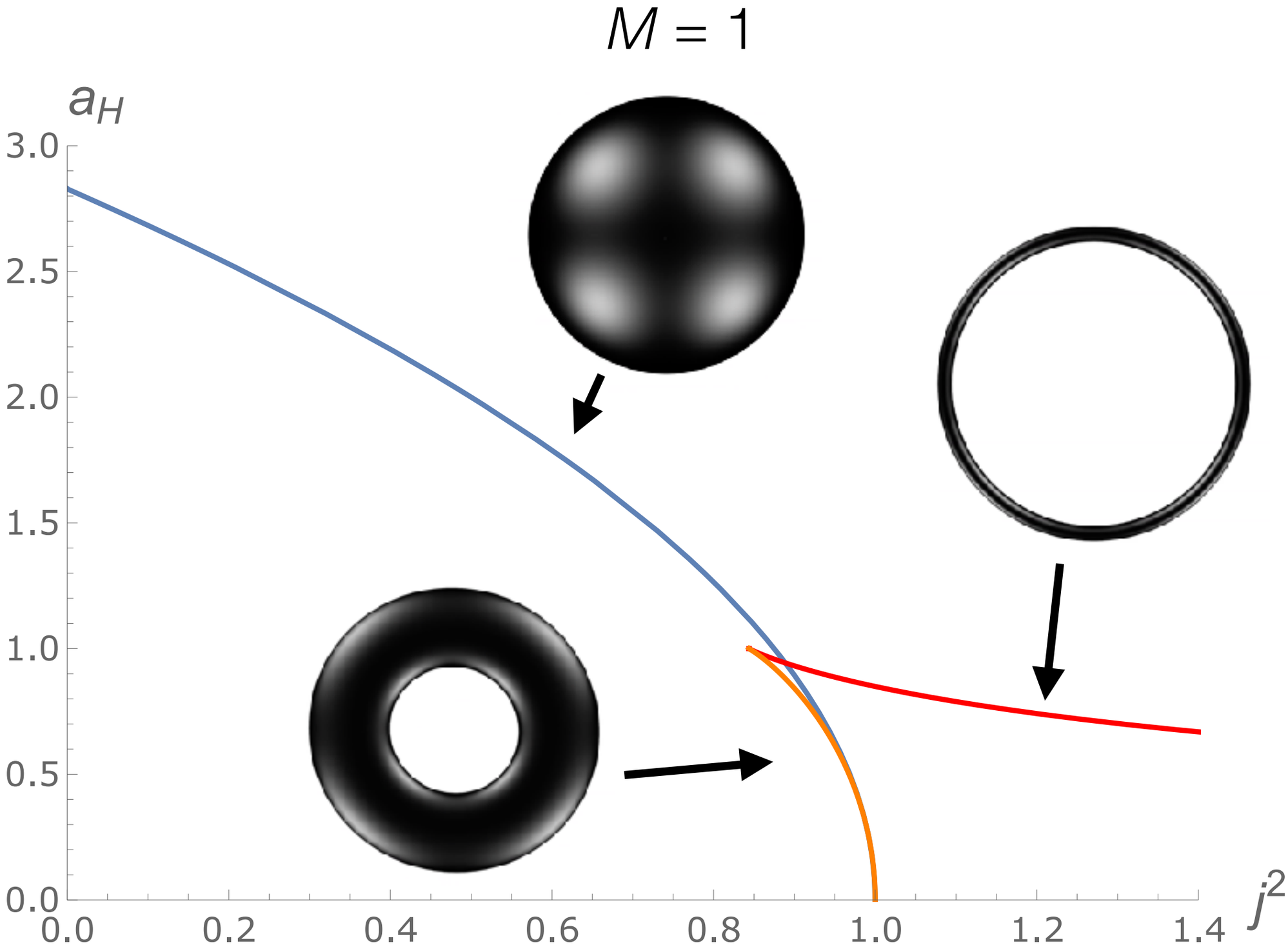
- The horizon develops a fractal structure
- Self-similar process
- The black string breaks in finite asymptotic time
- No fine-tuning is required
- The weak cosmic censorship conjecture may be false in spaces with compact extra dimensions

[Lehner and Pretorius]

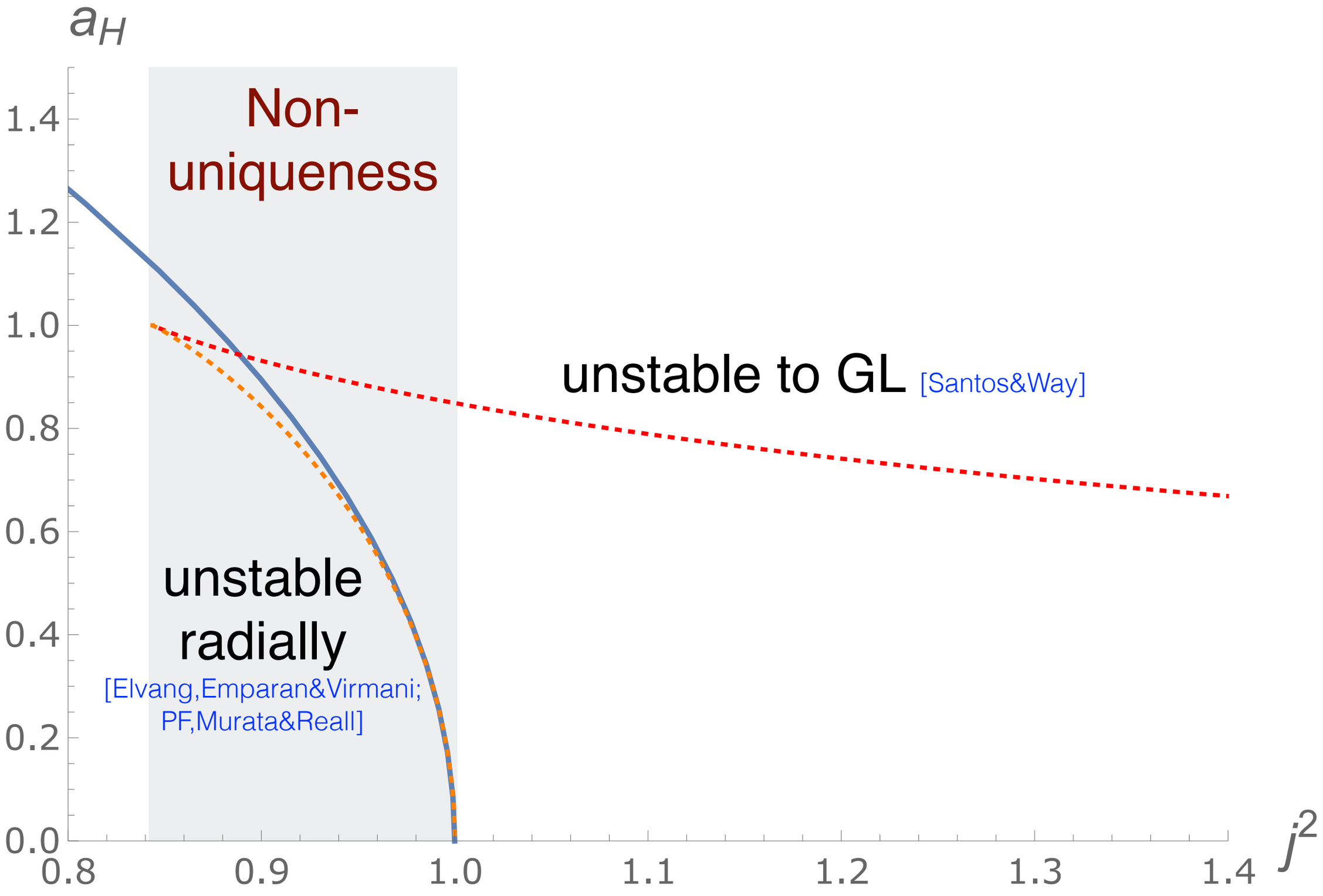
Can the weak cosmic censorship conjecture be violated around higher dimensional asymptotically flat black hole spacetimes?

Black ring instabilities

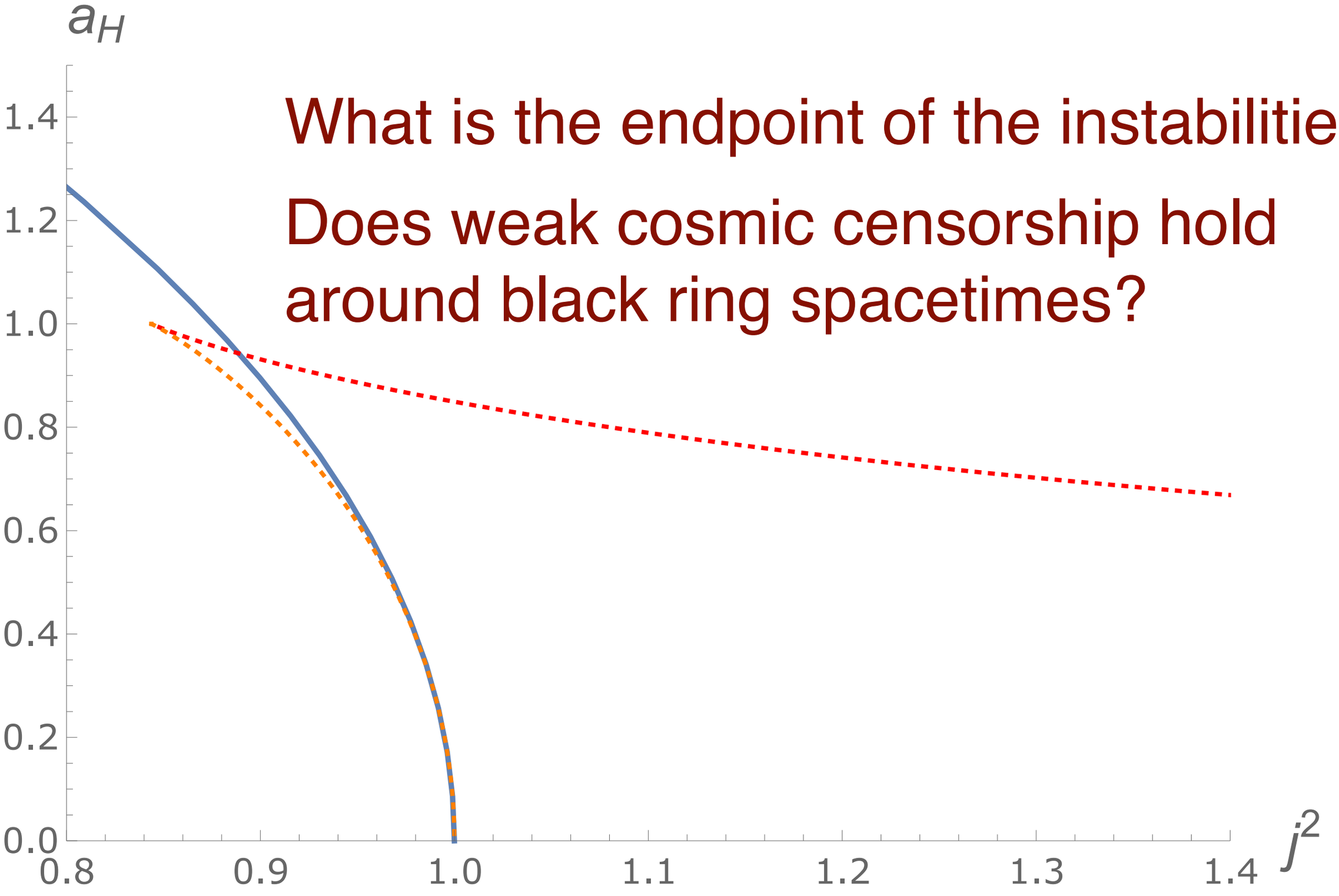
Black hole phases in 5D



Black hole phases in 5D

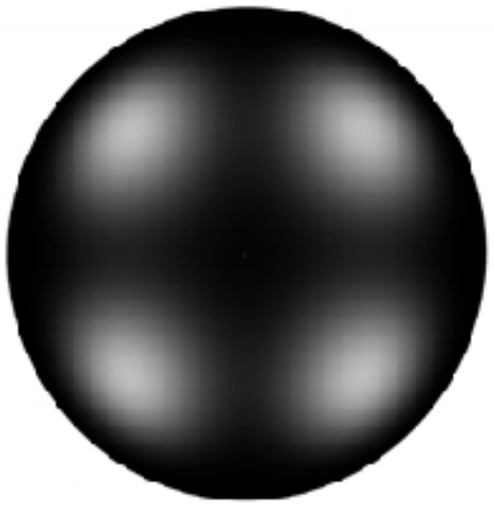


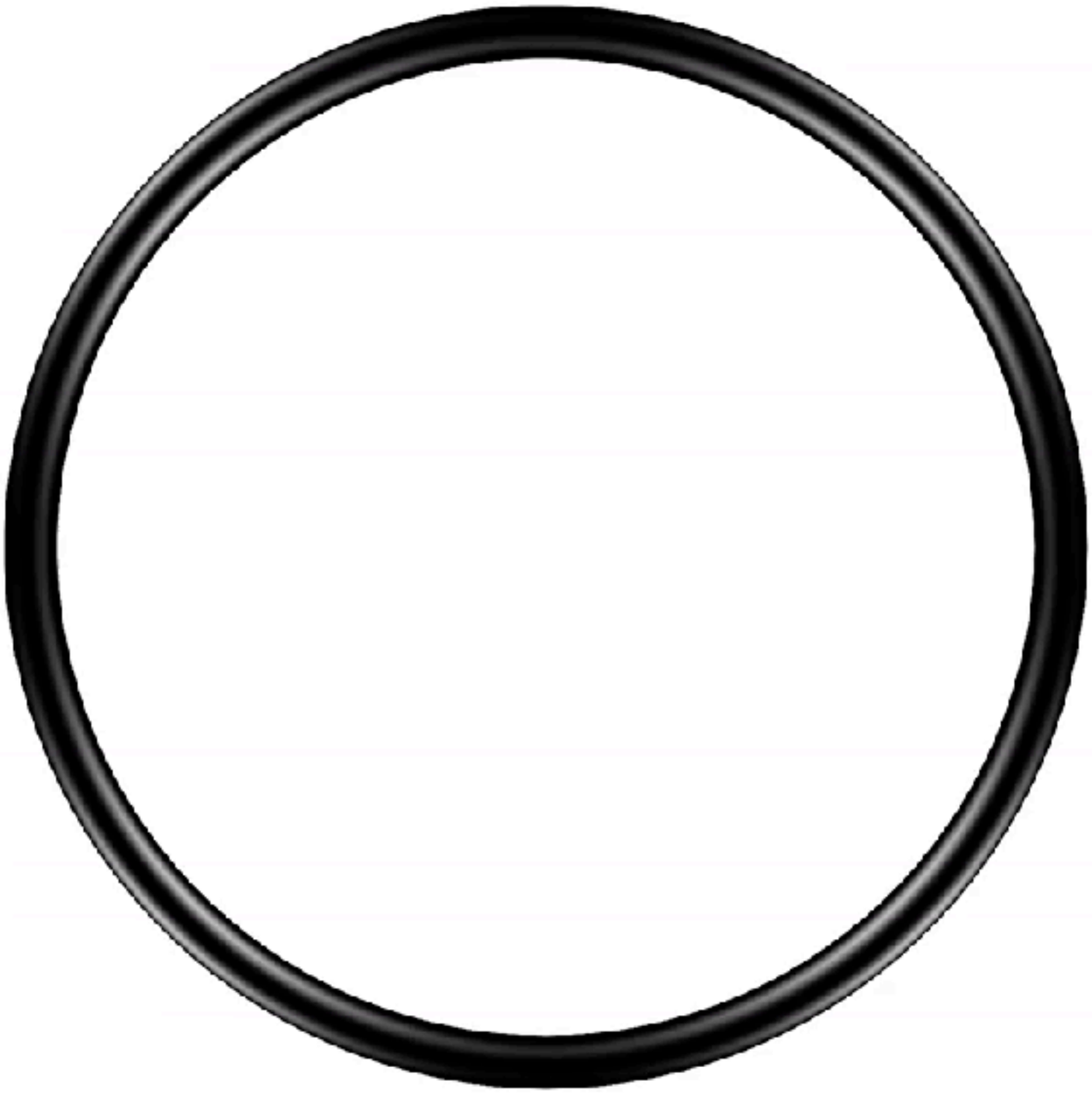
Black hole phases in 5D

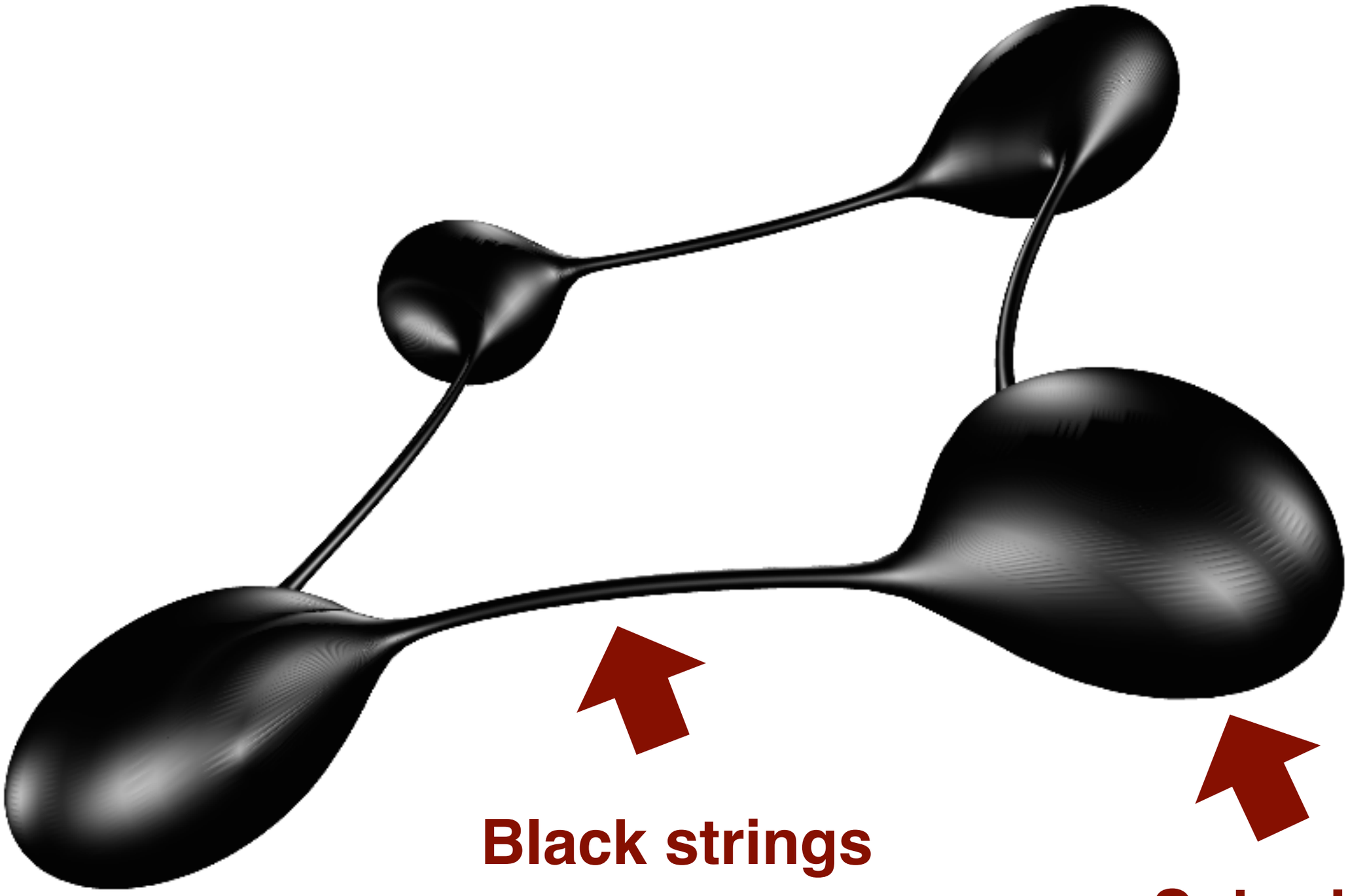


What is the endpoint of the instabilities?

Does weak cosmic censorship hold around black ring spacetimes?






Black strings
Spherical
black holes

- However the computations were very expensive (it's a 3+1 problem) and the understanding of the endpoint was limited:

  - Time-scale of the pinch-off could not be estimated

  - Is the process self-similar as in black strings?

Can we understand the details of the Gregory-Laflamme instability in asymptotically flat spaces?

Rotating spherical black hole instabilities

Myers-Perry BHs in $D \geq 6$

- The higher dimensional analogues of the Kerr BH:

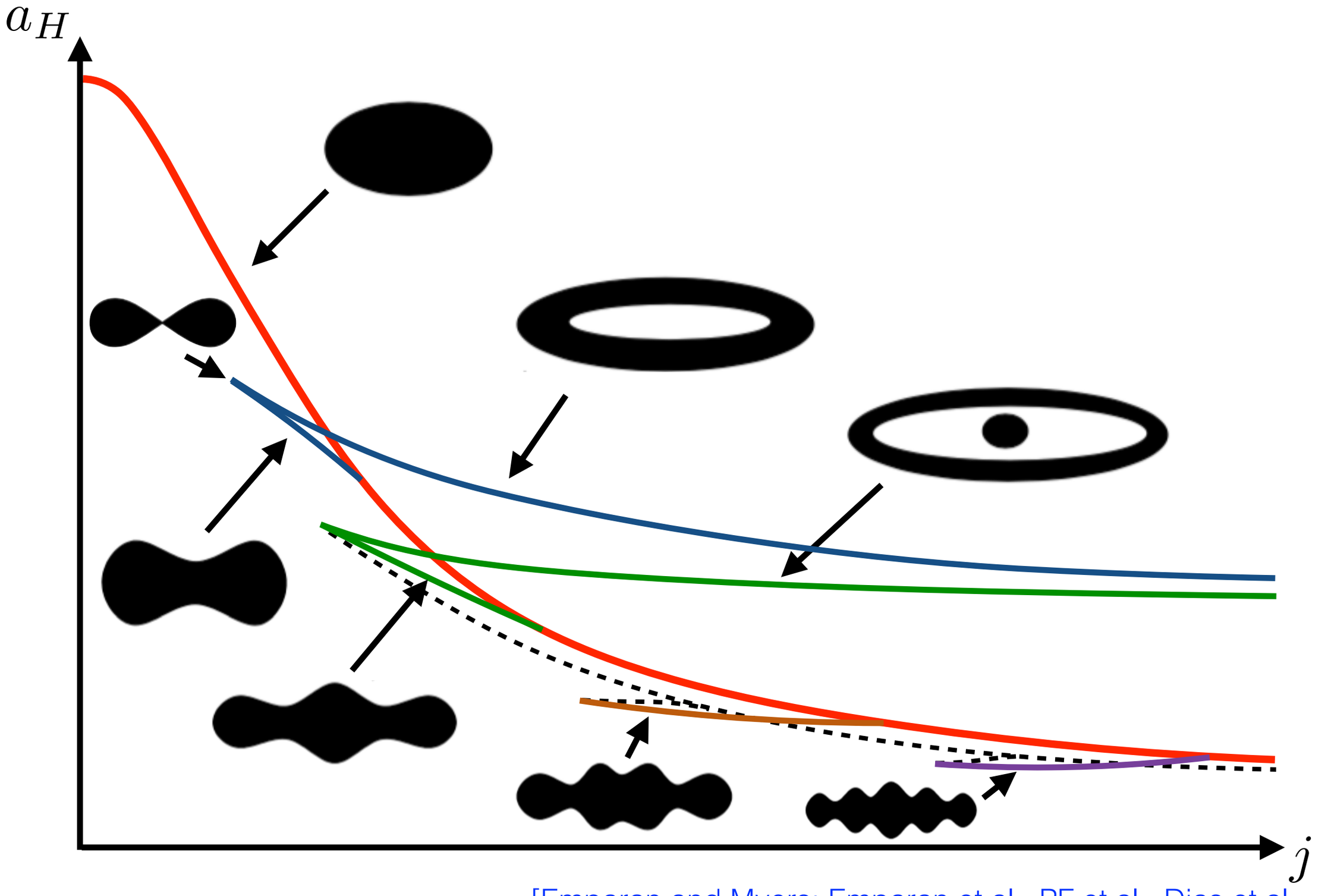
$$ds^2 = -\,dt^2 + \frac{\mu}{r\,\Sigma}(dt - a\,\sin^2\theta\,d\phi)^2 + \frac{\Sigma}{\Delta}\,dr^2 + \Sigma\,d\theta^2$$
$$+ (r^2 + a^2)\,\sin^2\theta\,d\phi^2 + r^2\,\cos^2\theta\,d\Omega^2_{(D-4)}$$

$$\Sigma = r^2 + a^2\,\cos^2\theta \qquad \Delta = r^2 + a^2 - \frac{\mu}{r^{D-5}}$$ [Myers and Perry]

- In $D \geq 6$ MP black holes can rotate arbitrarily fast

- In the limit $a \to \infty$, MP black holes resemble black membranes, which are unstable under the Gregory-Laflamme instability [Emparan and Myers]

Black hole phases in D≥6

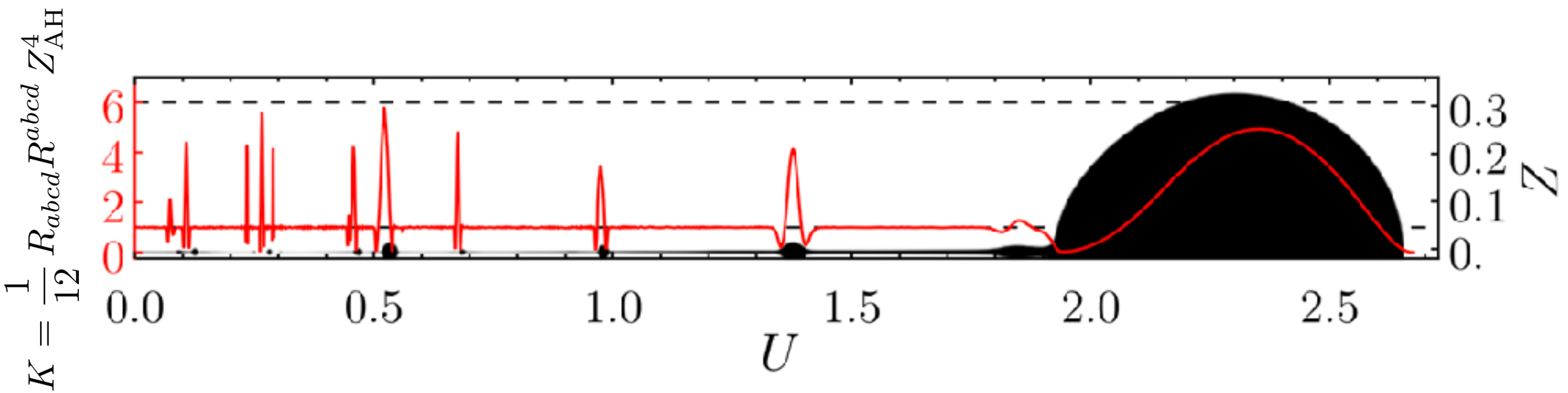


[Emparan and Myers; Emparan et al., PF et al., Dias et al.,…]

$t/\mu^{\frac{1}{3}} = 30.0000$

10,000 thinner than the original black hole!!!

Evolution



- The local geometry is well approximated by a sequence of black rings connected by black membranes

- The outermost ring carries most of the mass and angular momentum

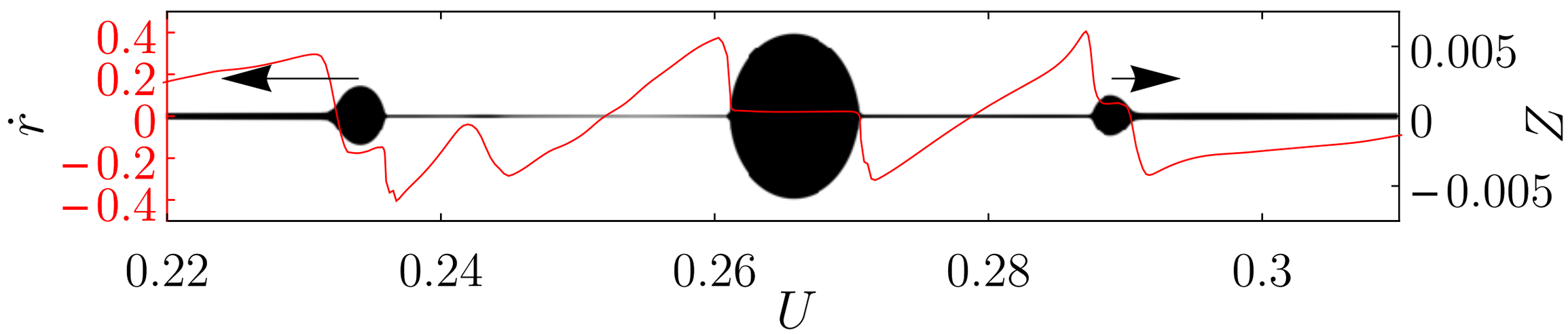
Evolution

- Differences between the dynamics of black strings and ultra spinning MP black holes:

- Boundary effects are important initially

- Centrifugal force: non-uniform membrane sections

- Motion of higher generation rings

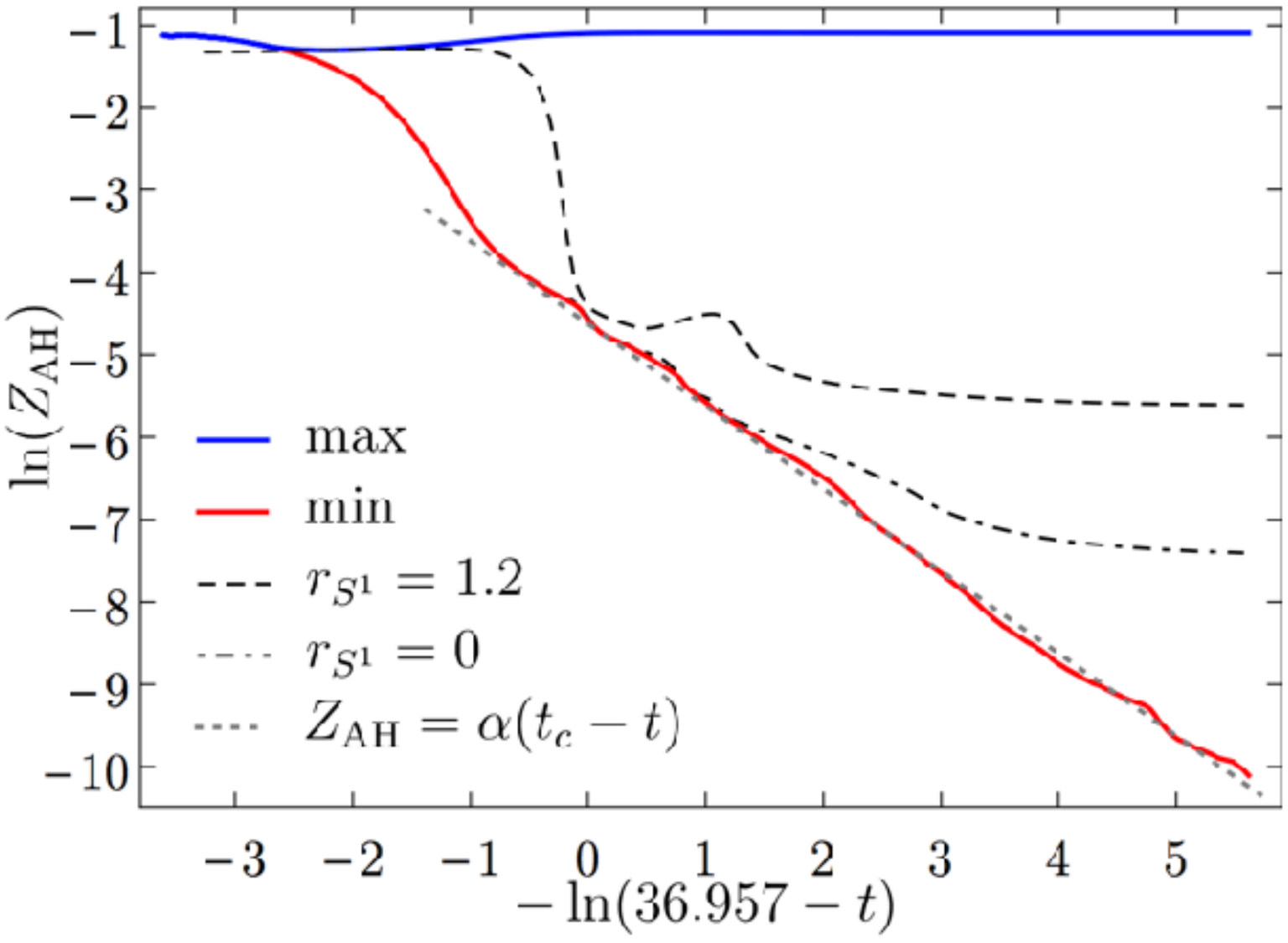


Evolution

The evolution of the ultra spinning instability of MP black holes is NOT self-similar

Evolution

- The minimum thickness follows a scaling law: $Z_{\mathrm{AH}} = \alpha(t_c - t)$



Summary and Conclusions

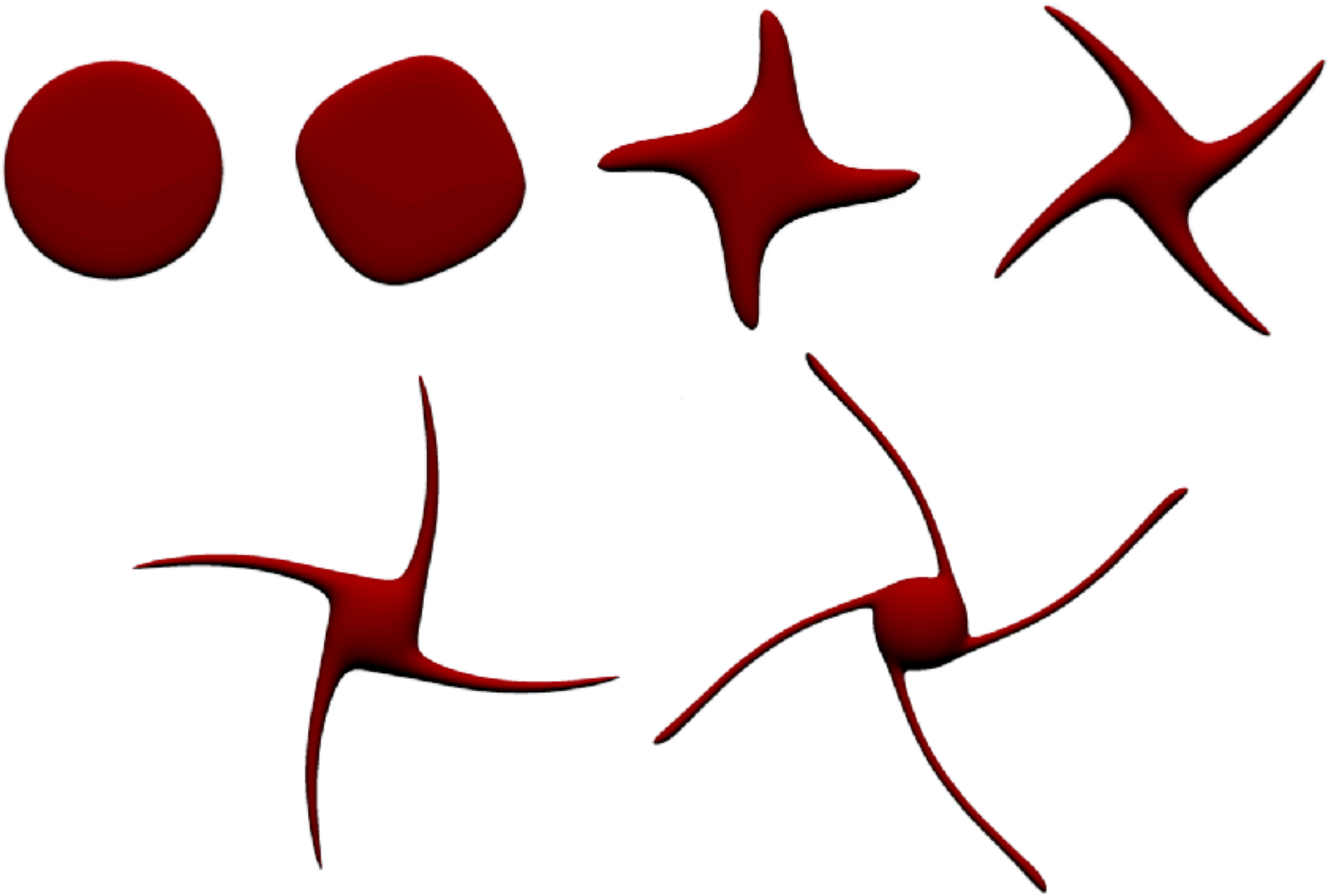
Summary and Conclusions

- Black rings and ultraspinning MP black holes are unstable and the instability evolves into a naked singularity in finite asymptotic time

- The weak cosmic censorship conjecture around ultraspinning MP black holes and black rings may be false

- This is generic in higher dimensions

- Evolution of non-axisymmetric instabilities of spherical black holes



- **Conjecture 1**

  The Gregory-Laflamme instability is the only mechanism that GR has to change the horizon topology

- **Conjecture 2**

  The only stable black hole in $D>4$ is the Myers-Perry solution with $J/M^{D-3} \lesssim O(1)$

Thank you for your attention!