Cosmic inflation prevents black hole singularity formation

Michał Bobula

University of Wrocław

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Classical Oppenheimer-Snyder collapse scenario

Homogeneous dust ball collapse [Oppenheimer, Snyder, 1939]

- Interior: FRW metric

$$\mathrm{d}s^2_{\mathrm{int}} = -\mathrm{d}T^2 + a(T)\mathrm{d}r^2 + a(T)^2 r^2 \mathrm{d}\Omega^2$$

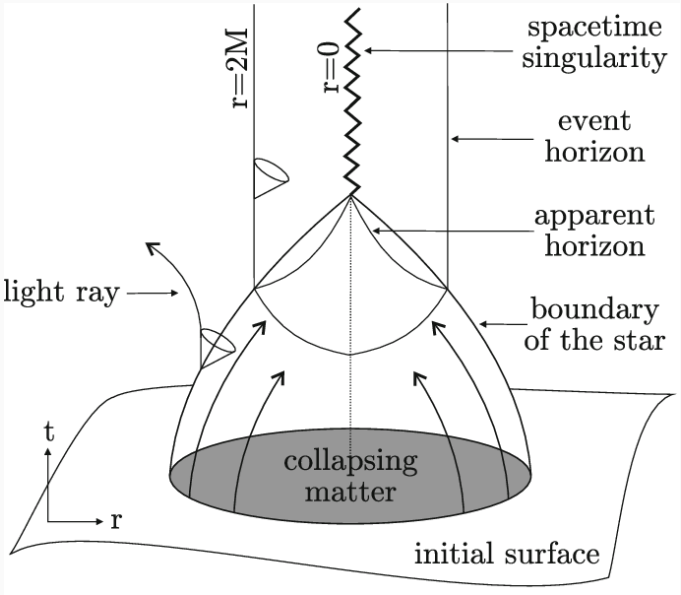
$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G\rho}{3} \quad \rightarrow \quad a(T) \sim T^{2/3}$$

- Exterior: Schwarzschild solution (due to Birkhoff theorem)

$$\mathrm{d}s^2_{\mathrm{ext}} = -F(X)\mathrm{d}t^2 + \frac{1}{F(X)}\,\mathrm{d}X^2 + X^2\mathrm{d}\Omega^2$$

with $F(X) = 1 - \frac{2M}{X}$

Two metrics smoothly join at the boundary (the surface of the dust ball) $r = r_b$



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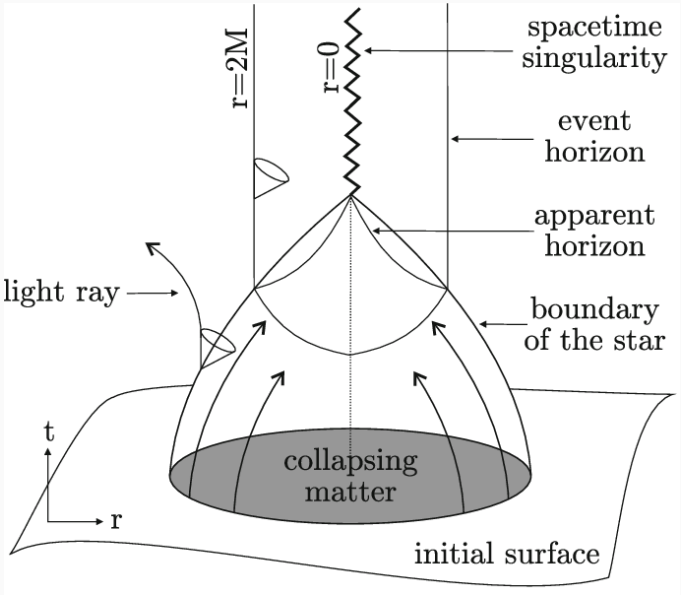

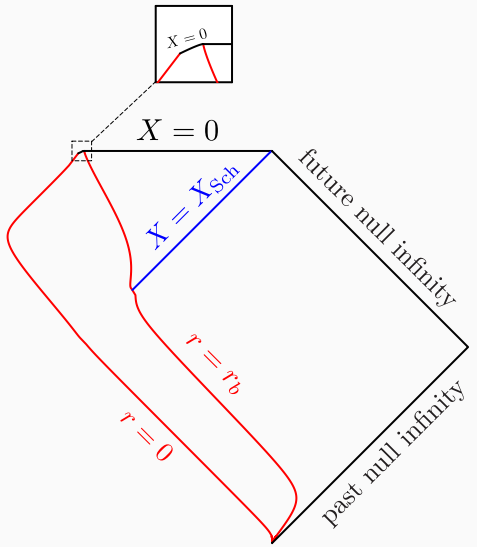

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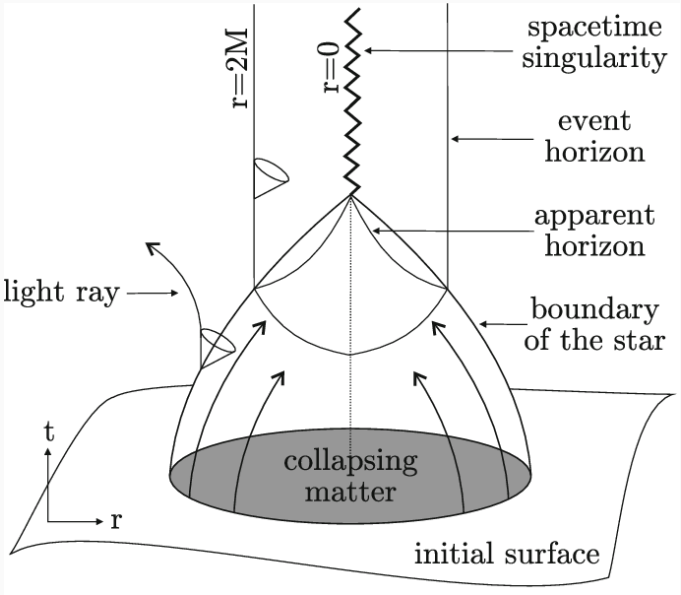
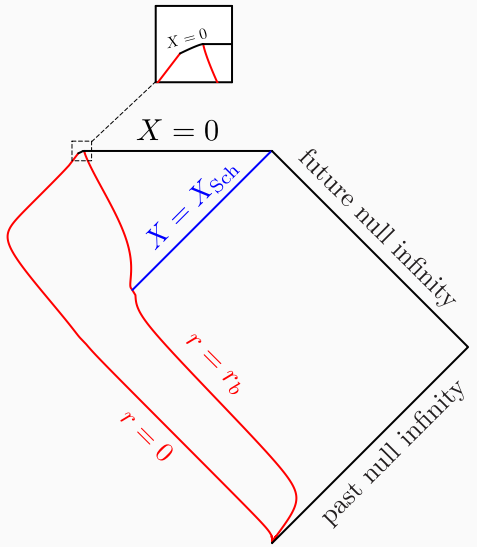
In this talk

Singularities are unacceptable. GR is wrong.
How to find a consistent picture?





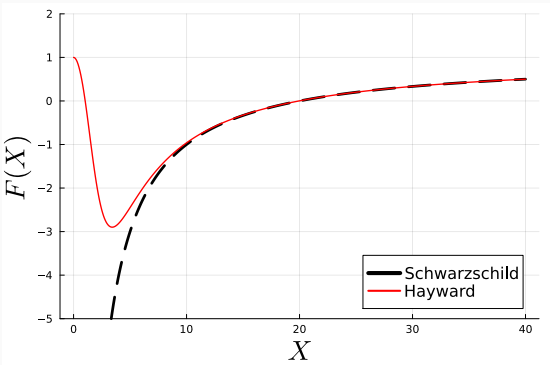
In this talk

- OS collapse. **Exterior → regular Hayward BH**
- What is the interior? How well the corresponding FRW geometry describe Universe?

Quantum-corrected Schwarzchild metric – Hayward black hole [Hayward, 2005], **No BH information paradox**:

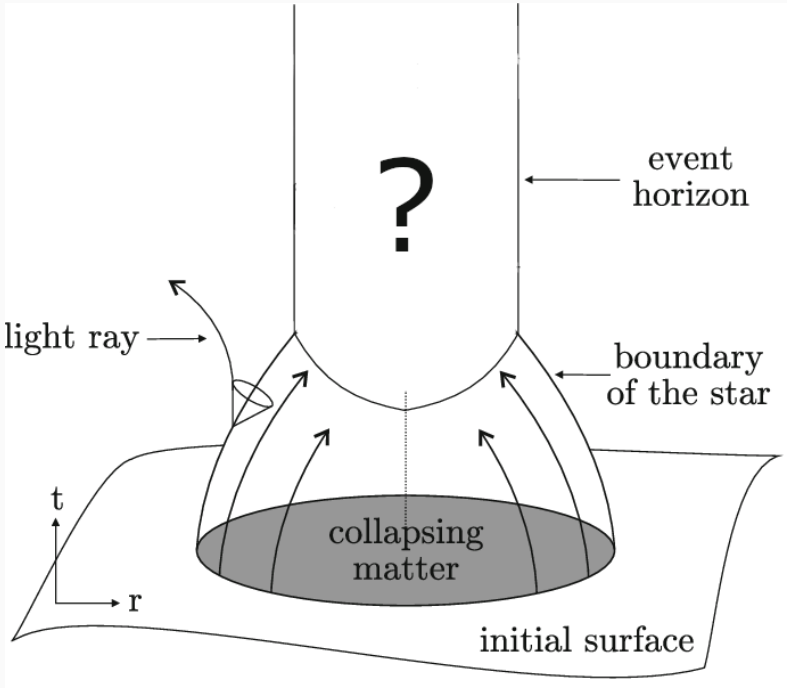
$$\mathrm{d}s^2_{\mathrm{ext}} = -F(X)\mathrm{d}t^2 + F(X)^{-1}\mathrm{d}X^2 + X^2\mathrm{d}\Omega^2 \quad (1)$$

$$F(X) = 1 - \frac{2MX^2}{X^3 + 2l^2M}.$$



What is the FRW geometry modelling the interior of the dust ball?

$$\mathrm{d}s^2_{\mathrm{int}} = -\mathrm{d}T^2 + a(T)^2\ \mathrm{d}r^2 + r^2 a(T)^2\ \mathrm{d}\Omega^2. \quad (2)$$



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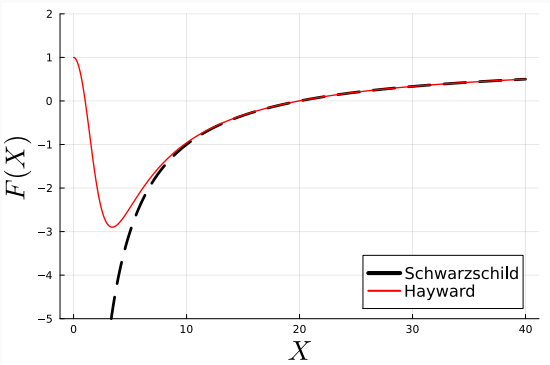

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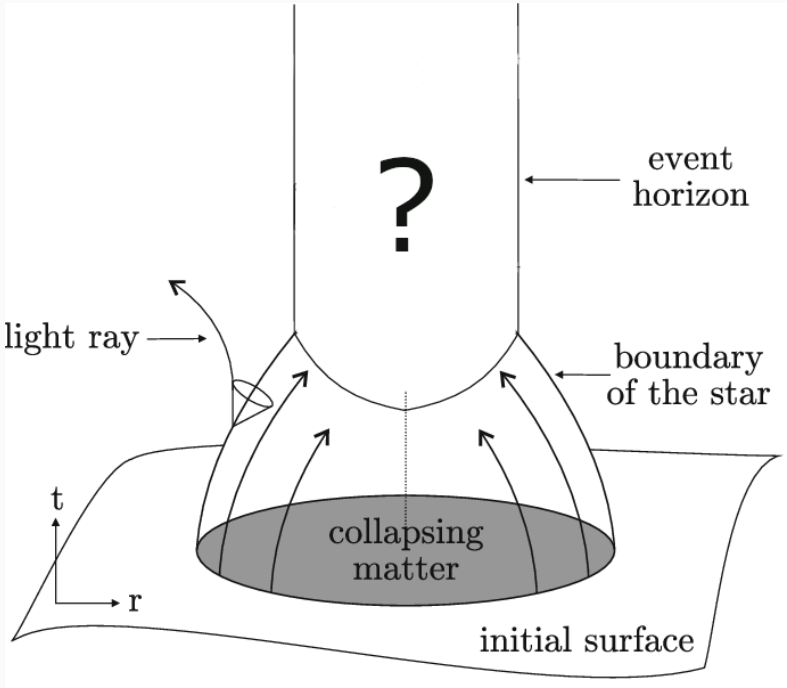
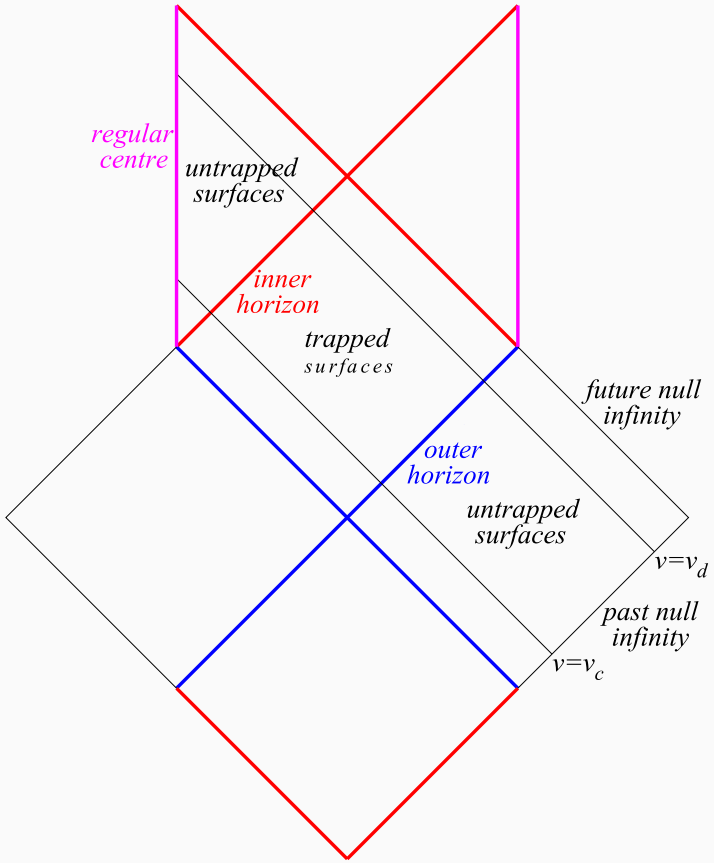


Two descriptions delivering Hayward black hole as a vacuum solution (no new fields or dof):
i) $D \geq 5$ Quasi-topological Gravity → E-H action supplemented with infinite tower of higher-curvature corrections. Eq. of motion of second order in sph. symm. [Bueno, et al. 2024]
ii) Giesel-Liu-Rullit-Singh-Weigl framework for polymerized LTB spacetimes [2024]. Hayward BH → specific Hamiltonian polymerization. Fine-tuning.

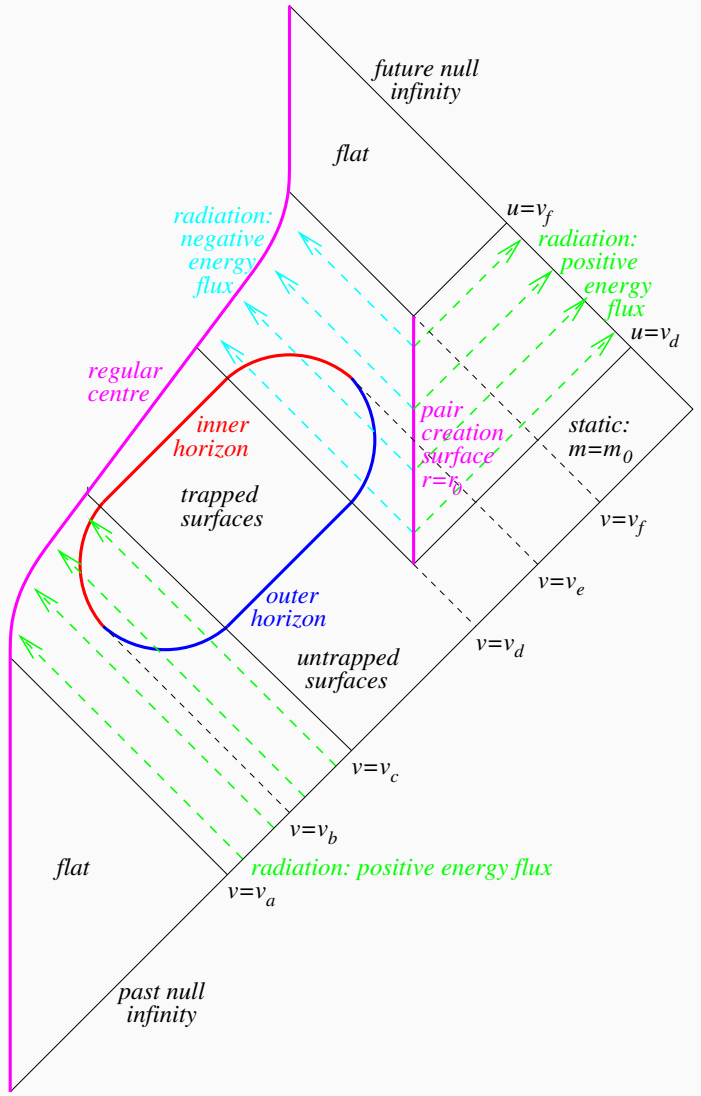
No BH information paradox. No event horizon $\rightarrow$ a dream scenario for any effective QG framework.



Static Hayward black hole [2005]

This talk: what are the details of Hayward black hole formation (without backreaction)?

Global hyperbolicity as physical requirement [Geroch, Hawking, Ellis, Penrose and others]



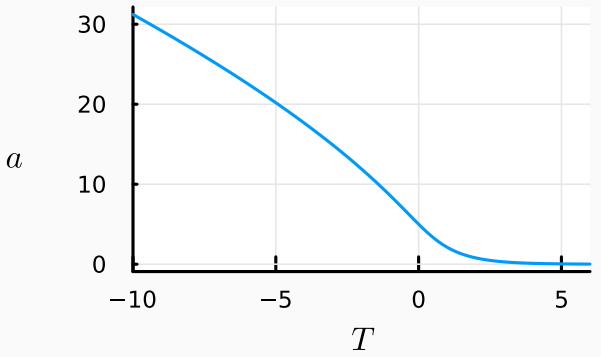
Formation and evaporation of Hayward black hole [Hayward, 2005]. Consistentency with Ashtekar-Bojowald paradigm [2005].

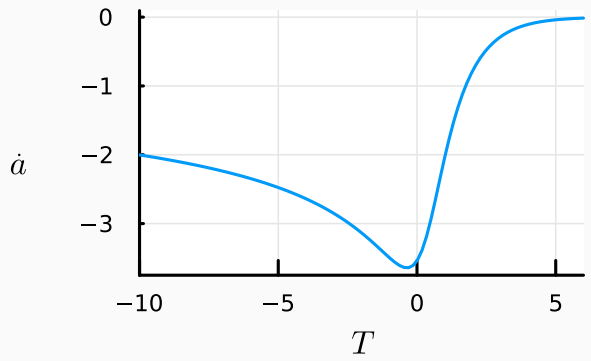
A universe out of Hayward black hole

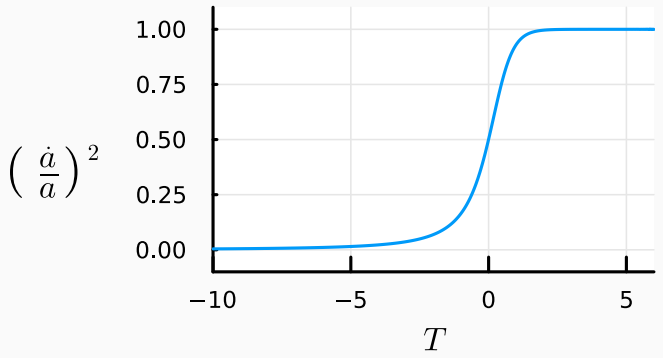
Assumptions:
i) Israel-Darmois junction conditions hold
ii) conservation of dust EM tensor
They fully determine the dynamics.

- Modified Friedmann equation

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi\rho}{3 + 8\pi l^2 \rho}$$







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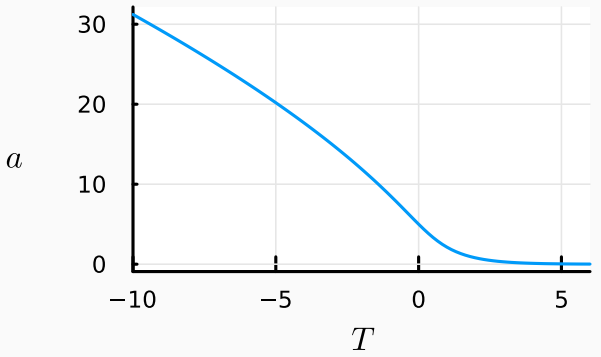
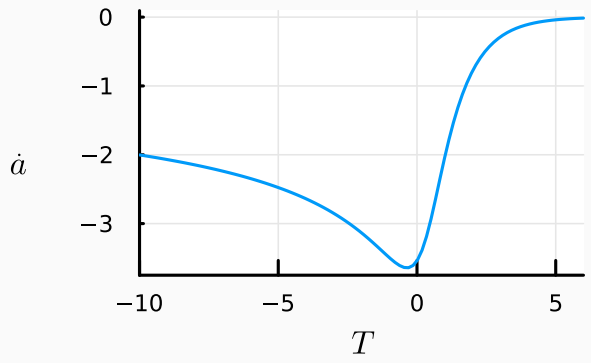
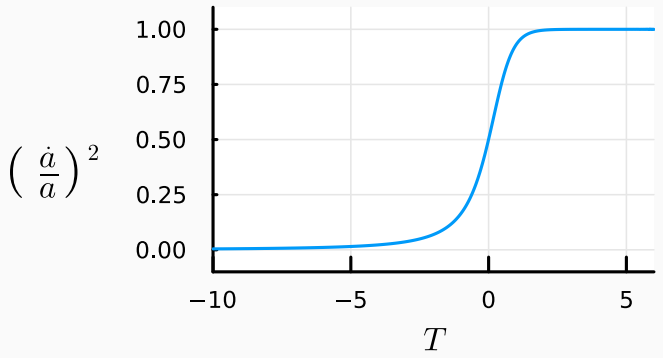
Expanding

$$\frac{8\pi\rho}{3+8\pi l^2\rho} = \frac{8\pi\rho}{3} - \frac{64}{9}\left(\pi^2 l^2\right)\rho^2 + \frac{512}{27}\pi^3 l^4 \rho^3 \ldots$$

Infinite tower of higher-order correction weighted by powers of Planck length







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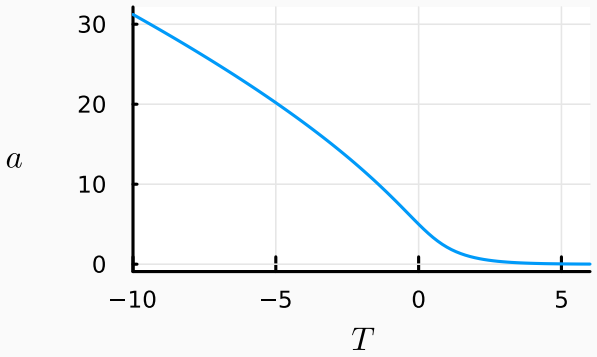

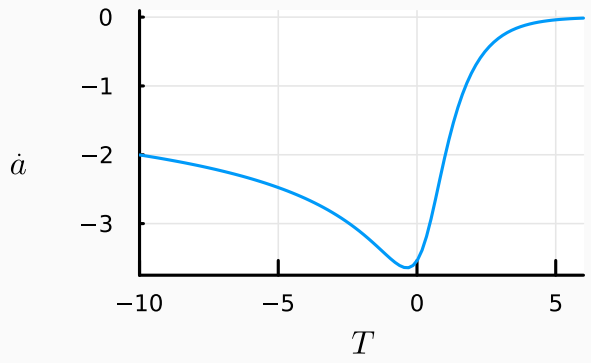

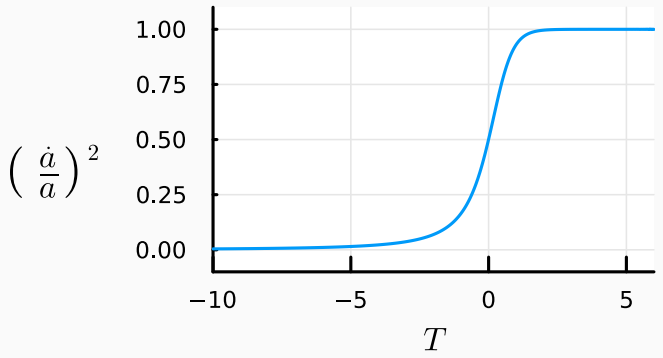

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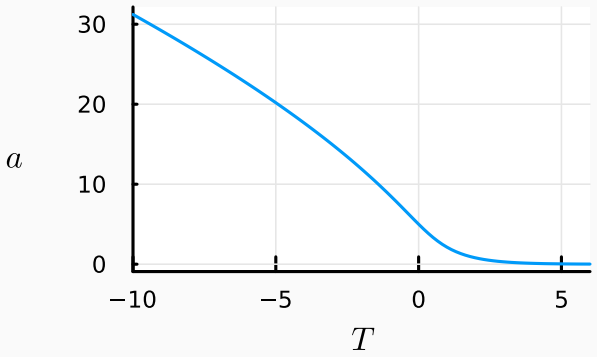

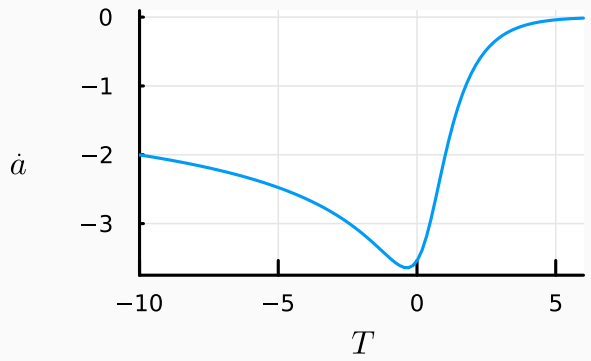

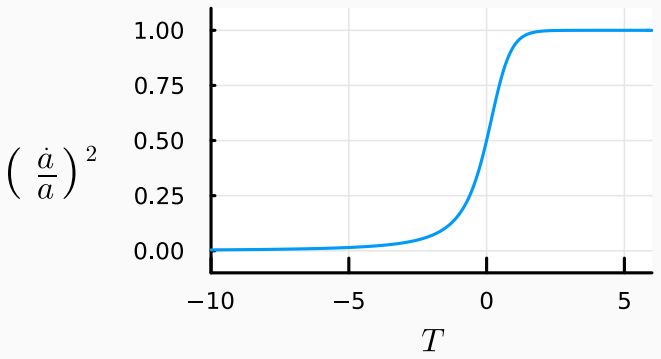

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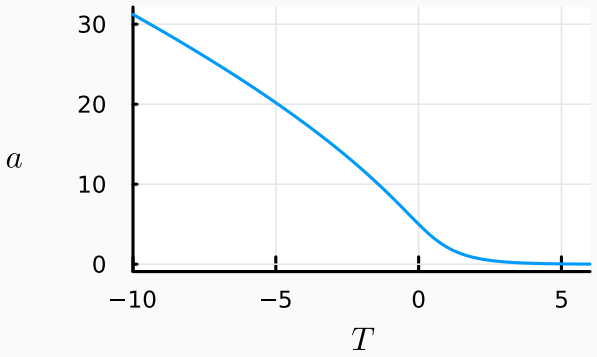
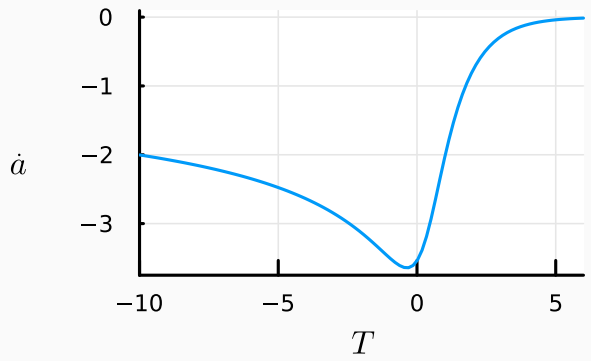
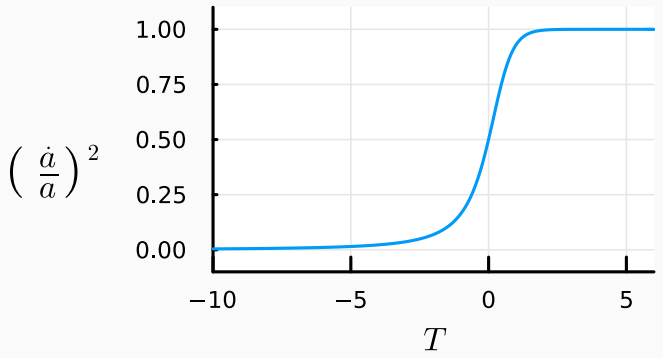
- The energy density $\rho = M/\left(\frac{4}{3}\pi r_b^3 a^3\right)$ diverges in the final collapsing point $T \to \infty$.







Conformal diagram for modified OS collapse

- Perpetual collapse. Long Squeeze instead of Big Crunch.
- Two null horizons: inner X^- and outer X^+.
- Unique radial null geodesic reaching final collapsing point (inf affine time)
- Geodesically complete spacetime.
- Hawking radiation included $\rightarrow$ infinite density $\rho \rightarrow \infty$ not reached. Black hole could evaporate in finite time.

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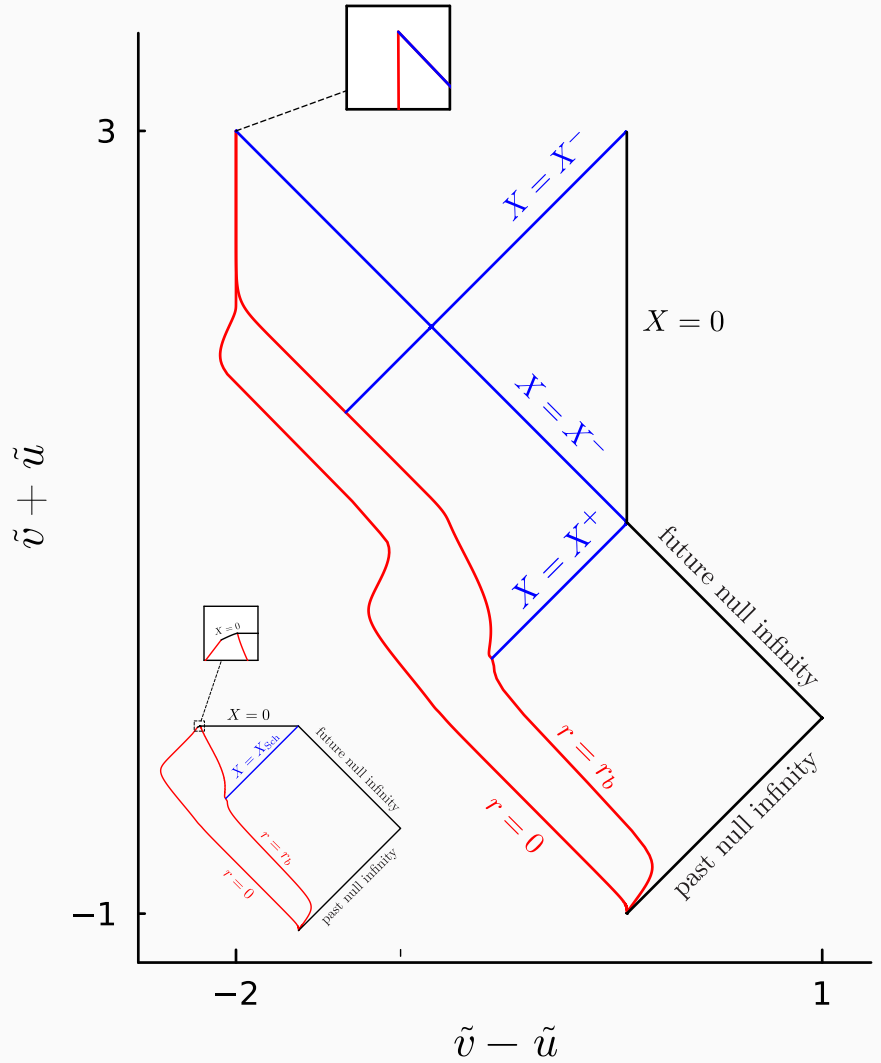

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- Cauchy horizon instabilities $\rightarrow$ problem of several quantum gravitational collapse models:
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  - asymptotic-safety-inspired models [Bonanno, et al., 2024]
  - quasi-topological gravity (string-theory-inspired) [Bueno et al., 2024]

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