Geometry of the black-to-white hole transition

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Based on work with
M. Han and C. Rovelli

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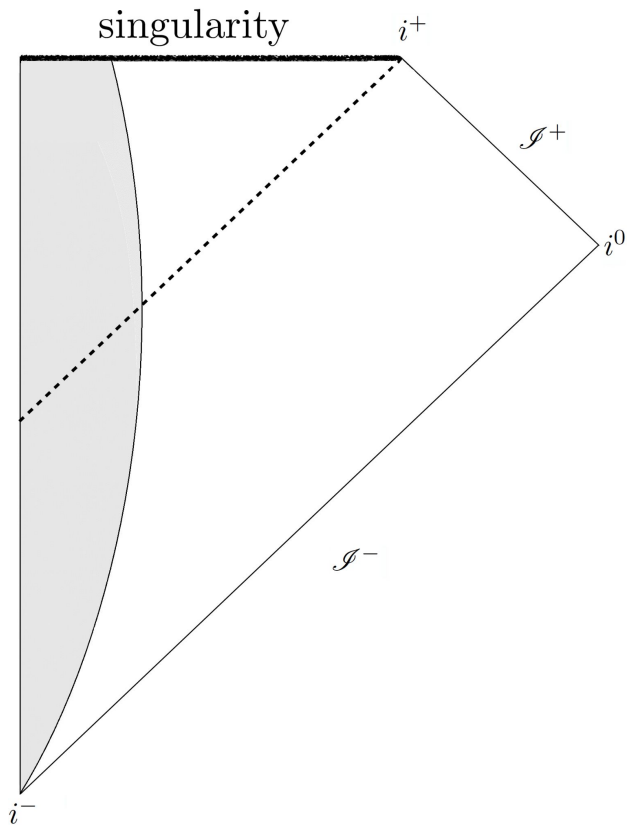
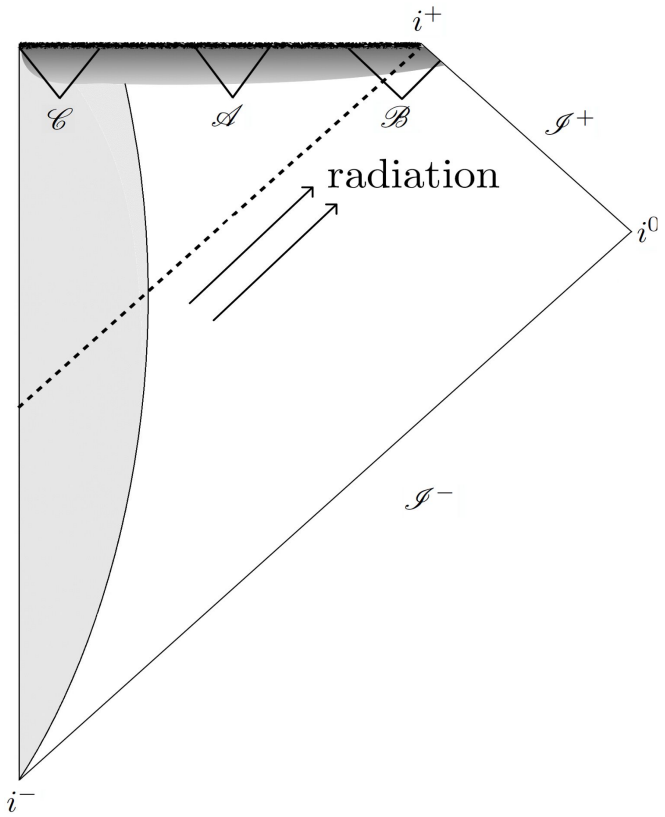
Oppenheimer–Snyder collapse



Oppenheimer–Snyder collapse



Quantum gravitational effects cannot be neglected in:

- Region A: large curvature near classical singularity
- Region B: physics of the horizon at the end of the evaporation
- Region C: quantum gravity regime of the collapsing matter

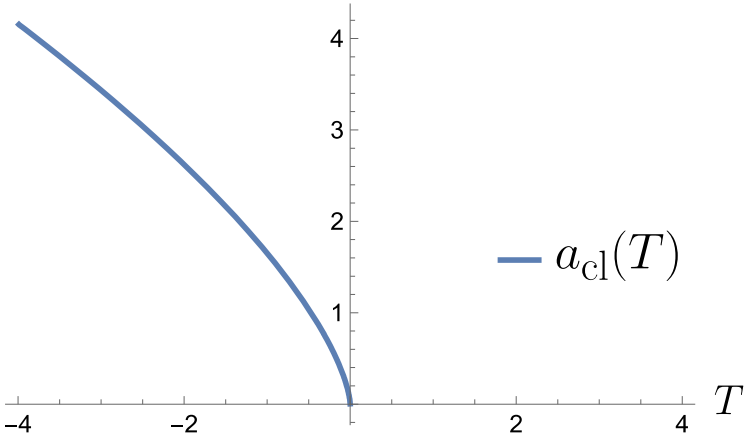
Interior of the star (region C)

Planck units $(c = G = \hbar = 1)$

Classical case

$$\mathrm{d}s^2 = -\,\mathrm{d}T^2 + a^2(T)\left(\mathrm{d}R^2 + R^2\,\mathrm{d}\Omega^2\right)$$

$$\frac{\dot{a}^2}{a^2} = \frac{8\pi}{3}\rho \quad \Rightarrow \quad a(T) = \left(\frac{9mT^2}{2R_{\mathrm{star}}^3}\right)^{1/3}$$



(Loop-)Quantum case

Interior of the star (region C)

Planck units ($c = G = \hbar = 1$)

Classical case

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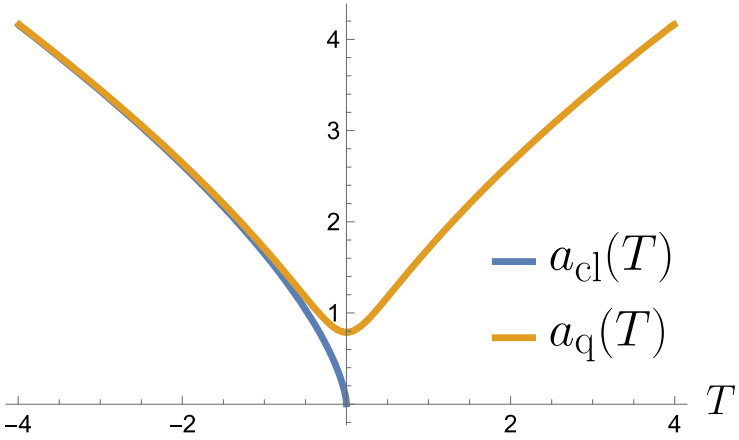


(Loop-)Quantum case

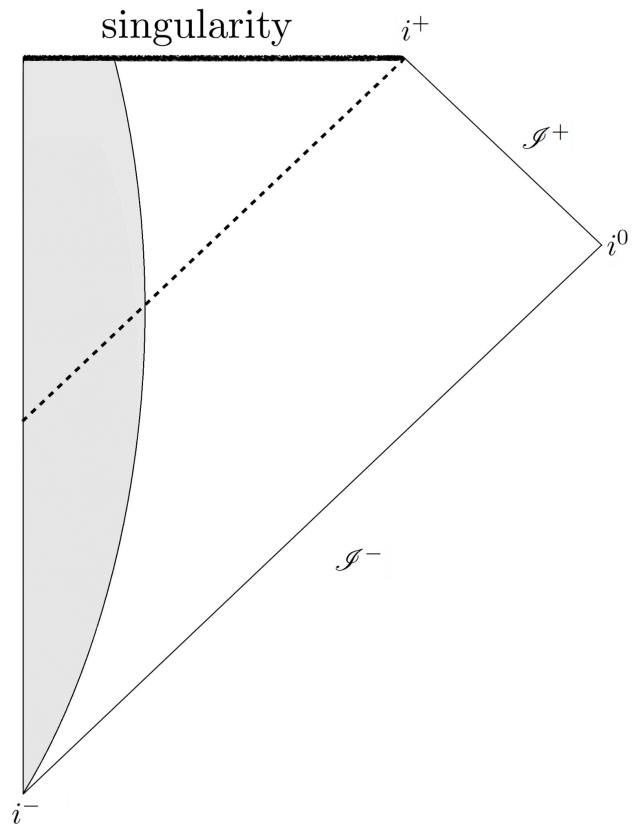
$$\frac{\dot{a}^2}{a^2} = \frac{8\pi}{3}\rho\left(1 - \frac{\rho}{\rho_c}\right)$$

$$A = \frac{3}{2\pi\rho_c}$$

$$a(T) = \left(\frac{9mT^2 + Am}{2R_{\text{star}}^3}\right)^{1/3}$$

Ashtekar, Pawlowski, Singh (2006)
Kelly, Santacruz, Wilson-Ewing (2020)

Exterior of the star (region A)



Classical case

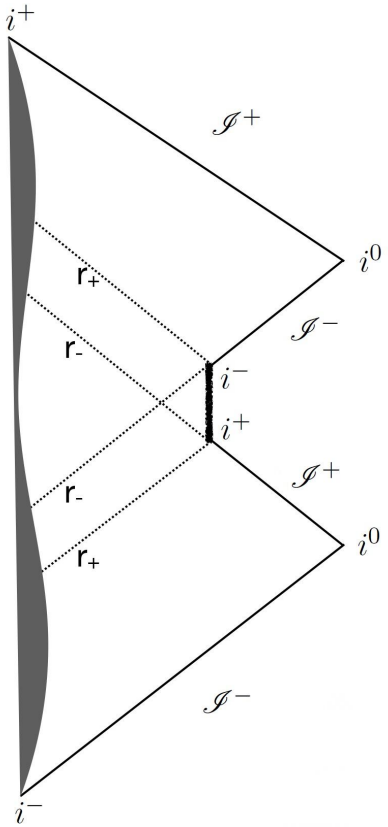
$$\mathrm{d}s^2 = -f(r)\,\mathrm{d}t^2 + f^{-1}(r)\,\mathrm{d}r^2 + r^2\,\mathrm{d}\Omega^2$$

$$f(r) = 1 - \frac{2m}{r}$$

$$r_\mathrm{h} = 2m$$

Exterior of the star (region A)

$$\left(A = \frac{3}{2\pi\rho_c} \ll m^2\right)$$



(Loop-)Quantum case

$$\mathrm{d}s^2 = -f(r)\,\mathrm{d}t^2 + f^{-1}(r)\,\mathrm{d}r^2 + r^2\,\mathrm{d}\Omega^2$$

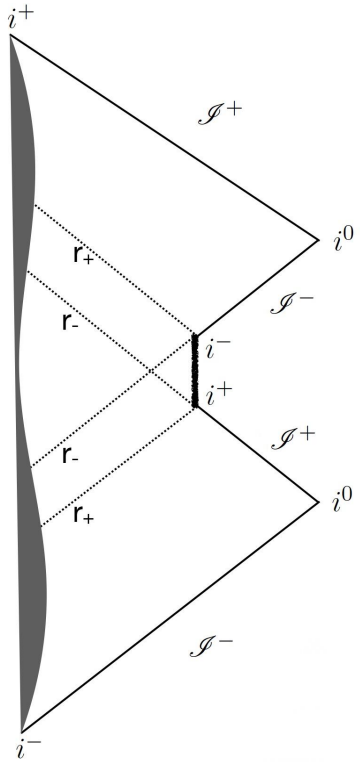
$$f(r) = 1 - \frac{2m}{r} + \frac{Am^2}{r^4}$$

$$r_+ = 2m + O(A/m)$$

$$r_- = \sqrt[3]{Am/2} + O\left(A^{2/3}/m^{1/3}\right)$$

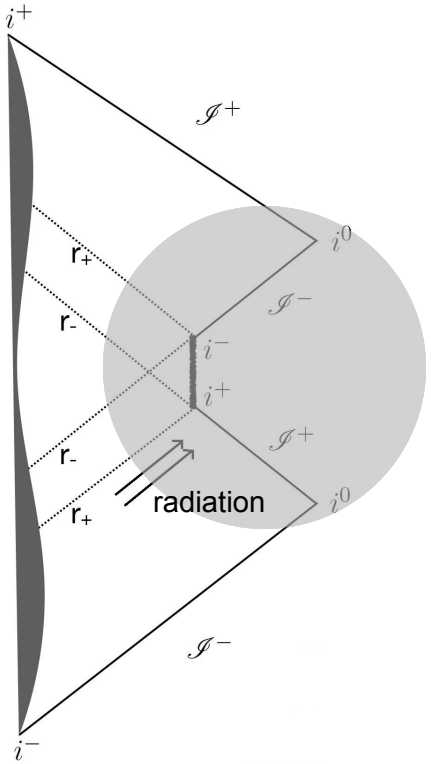
Kelly, Santacruz, Wilson-Ewing (2020)
Lewandowski, Ma, Yang, Zhang (2023)

Physics of the horizon (region B)



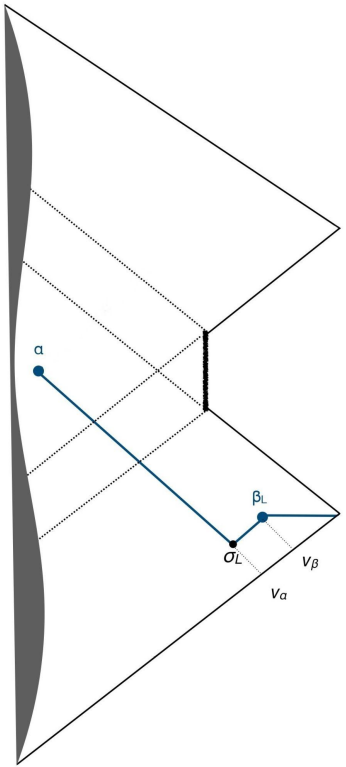
Physics of the horizon (region B)

Haggard and Rovelli (2015)



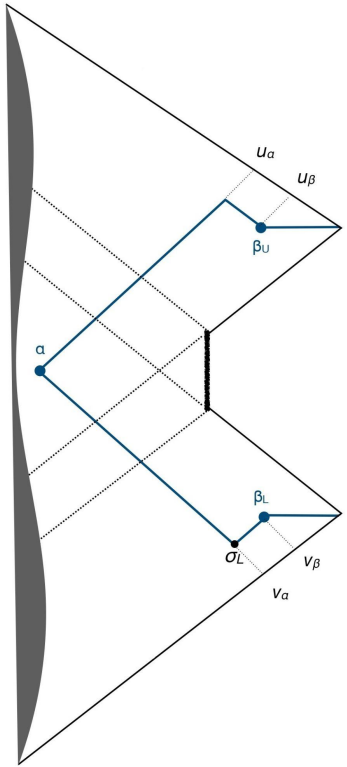
Physics of the horizon (region B)

Han, Rovelli, FS (2023)



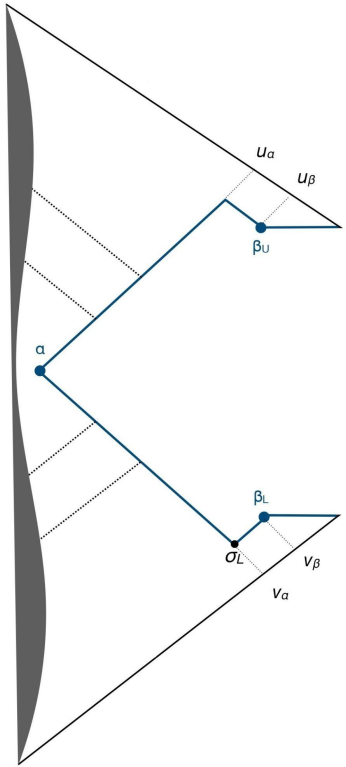
Physics of the horizon (region B)

Han, Rovelli, FS (2023)



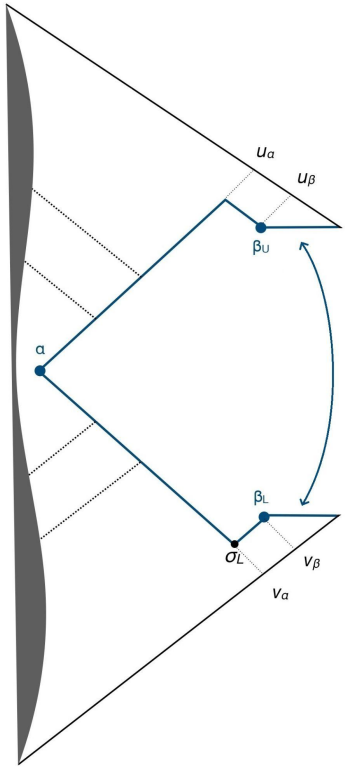
Physics of the horizon (region B)

Han, Rovelli, FS (2023)



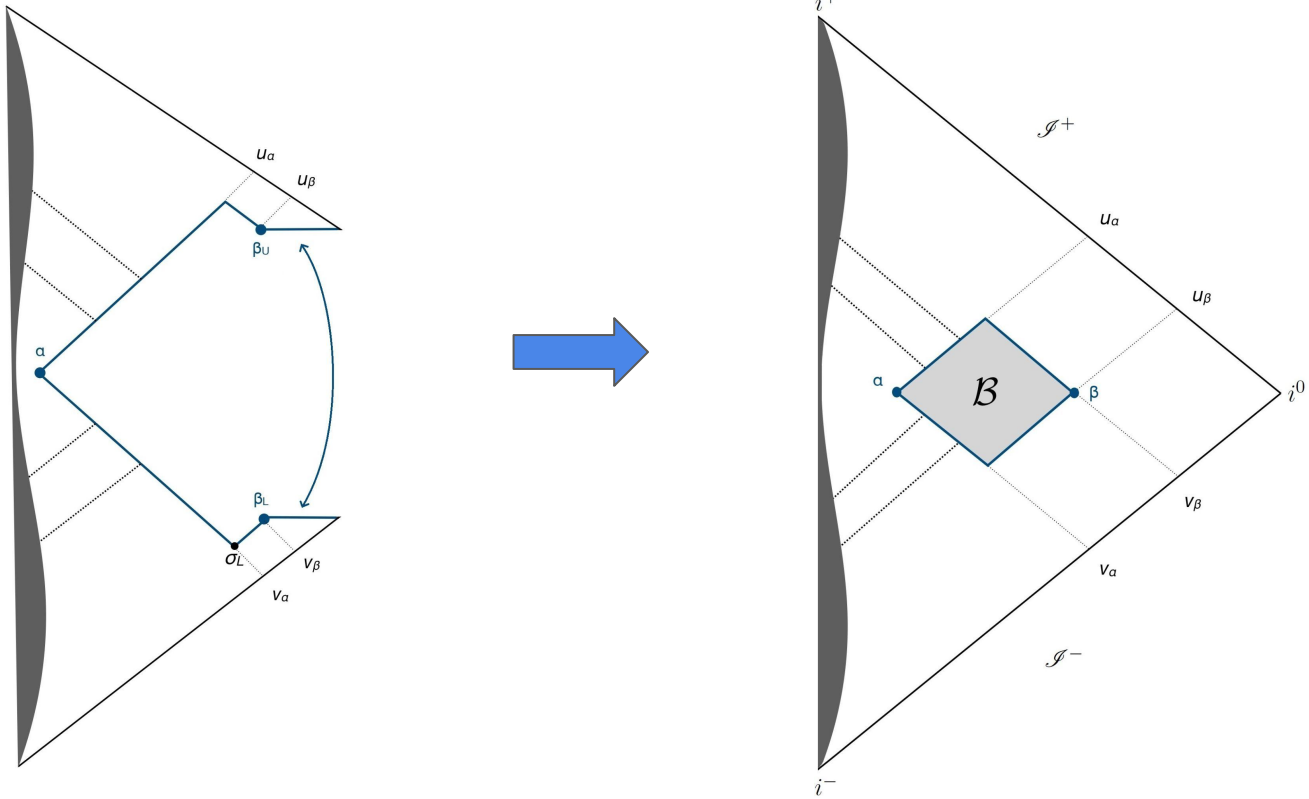
Physics of the horizon (region B)

Han, Rovelli, FS (2023)



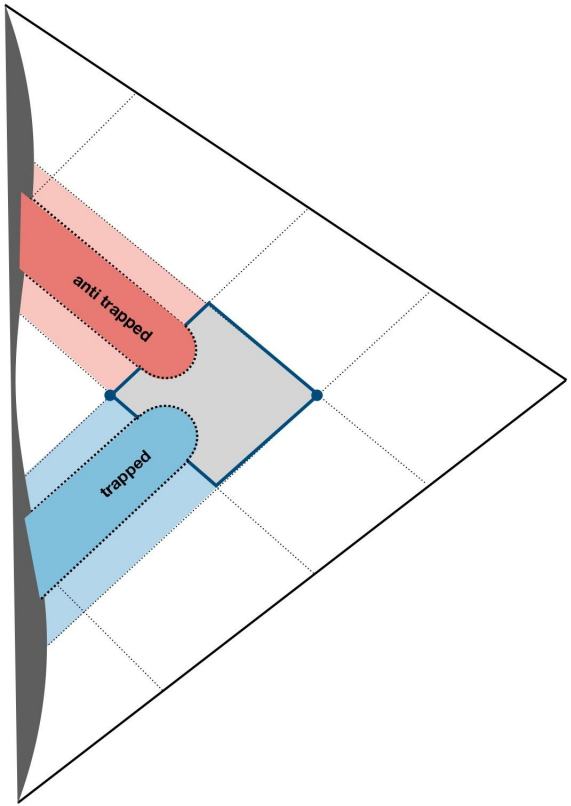
Physics of the horizon (region B)

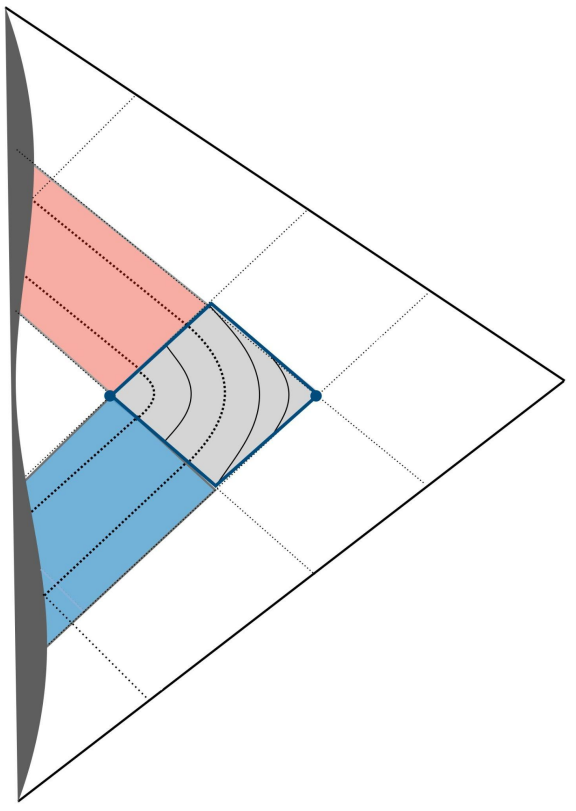
Han, Rovelli, FS (2023)



Physics of the horizons

Han, Rovelli, FS (2023)





Future work

- Further study the physics of the effective metric in region B
- Study the quantum physics of region B with covariant LQG
- Study the stability of the inner horizon under mass inflation
- Generalize the model to physical rotating black holes
- Take into account Hawking evaporation process