Revisiting quantum BHs from effective LQG

Geeth Ongole, Parampreet Singh and Anzhong Wang, Phys. Rev. D 109, 026015

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Loops

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Overview

- LOOP QUANTUM BLACK HOLES
- AOS MODEL
- FAMILY OF SOLUTIONS
- ASYMPTOTIC BEHAVIOR
- SUMMARY

LOOP QUANTUM BLACK HOLES

CLASSICAL

$$\mathscr{H}_{cl}\,(b, p_b; c, p_c) = -\frac{1}{2G\gamma}\left(2cp_c + \left(b + \frac{\gamma^2}{b}\right)p_b\right)$$

Hamiltonian of the Schwarzschild solution

$$ds^2 = -N^2 dT^2 + \frac{p_b^2}{|p_c| L_o^2} dx^2 + |p_c| d\Omega^2$$

Schwarzschild metric in Kantowski-Sachs form

$$b \rightarrow \frac{\sin\left(\delta_b b\right)}{\delta_b} \quad ; \quad c \rightarrow \frac{\sin\left(\delta_c c\right)}{\delta_c}$$

EFFECTIVE

$$\mathscr{H}_{eff}\,(b, p_b, \delta_b; c, p_c, \delta_c) = -\frac{1}{2G\gamma}\left[2\frac{\sin\left(\delta_c c\right)\,\left|p_c\right|}{\delta_c} + \left(\frac{\sin\left(\delta_b b\right)}{\delta_b} + \frac{\gamma^2 \delta_b}{\sin\left(\delta_b b\right)}\right)p_b\right]$$

Effective loop quantized Schwarzschild solution

δ_i: quantum parameters

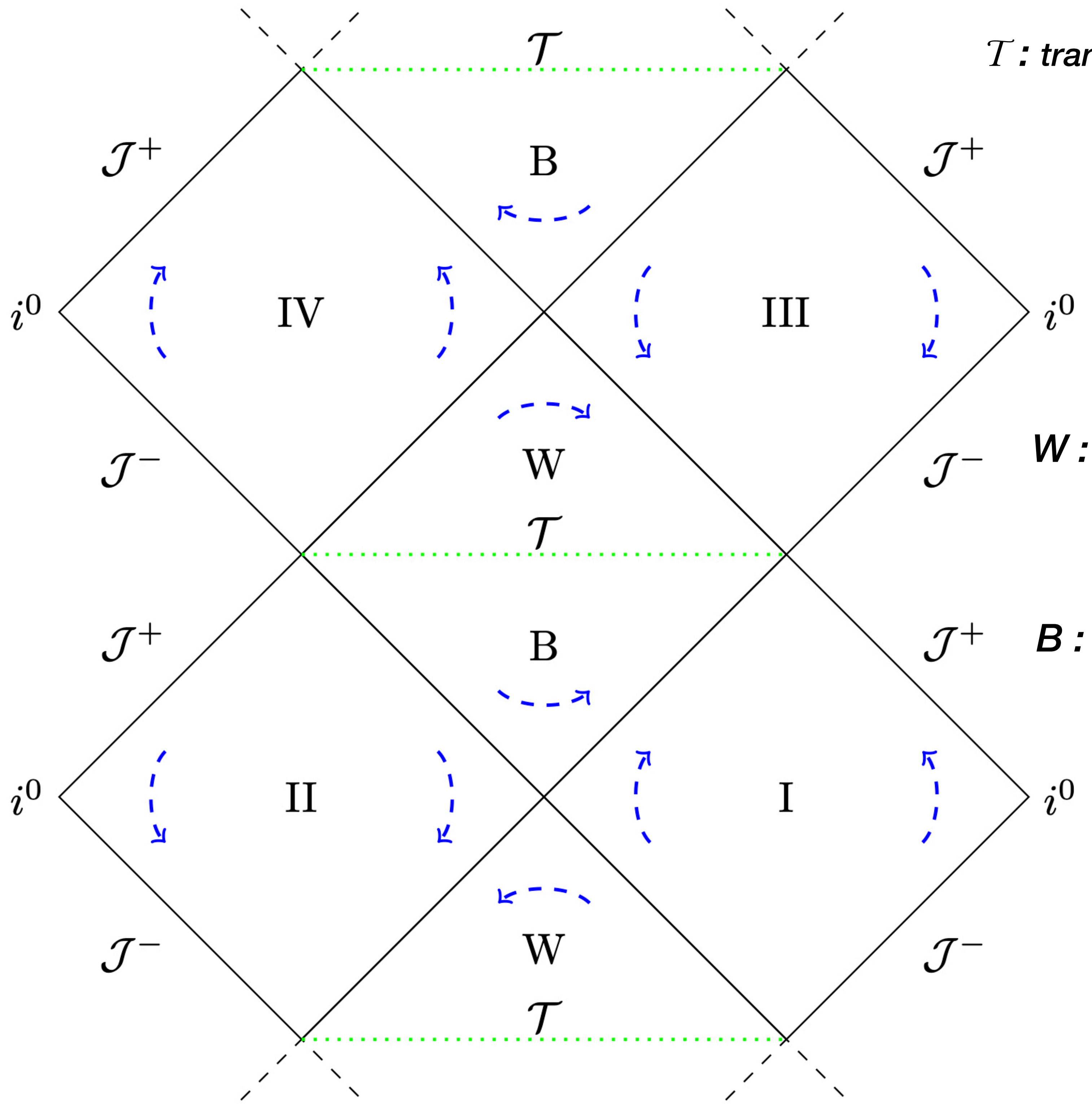
AOS MODEL

AOS: Ashtekar, Olmedo & Singh

$$\delta_b = \left(\frac{\sqrt{\Delta}}{\sqrt{2\pi\gamma^2 m}} \right)^{\frac{1}{3}}, \quad L_0\delta_c = \frac{1}{2}\left(\frac{\gamma\Delta^2}{4\pi^2 m} \right)^{\frac{1}{3}}$$

δ_i: Dirac observables

- BH singularity replaced by a transition surface.
- Symmetric spacetime near the transition surface.
- Universal upper bound of invariants at $\mathcal{T}$.
- No mass amplification of the WH.
- Negligible quantum corrections at classical scales.
- Asymptotically flat-like spacetime at infinity.



$\mathcal{T}$: transition surface

***W :** white hole like*

***B :** black hole*

Penrose diagram of the AOS model

Image:arXiv:1806.02406v3

FAMILY OF SOLUTIONS

$$\mathscr{H}_{eff}\,(b, p_b, \delta_b\,;\, c, p_c, \delta_c)$$

$$(B_o, \delta_b\,;\, c_o, p_c^o, \delta_c)$$

The solution space of the effective Hamiltonian has 5 free parameters

$$(\delta_b, \delta_c, c_o, m)$$

Reduces to 4 parameters after matching with classical solution & gauge fixing

$$(\alpha_b, m)$$

Reduces to 2 parameters to ensure negligible quantum corrections at classical scales

FAMILY OF SOLUTIONS

AOS

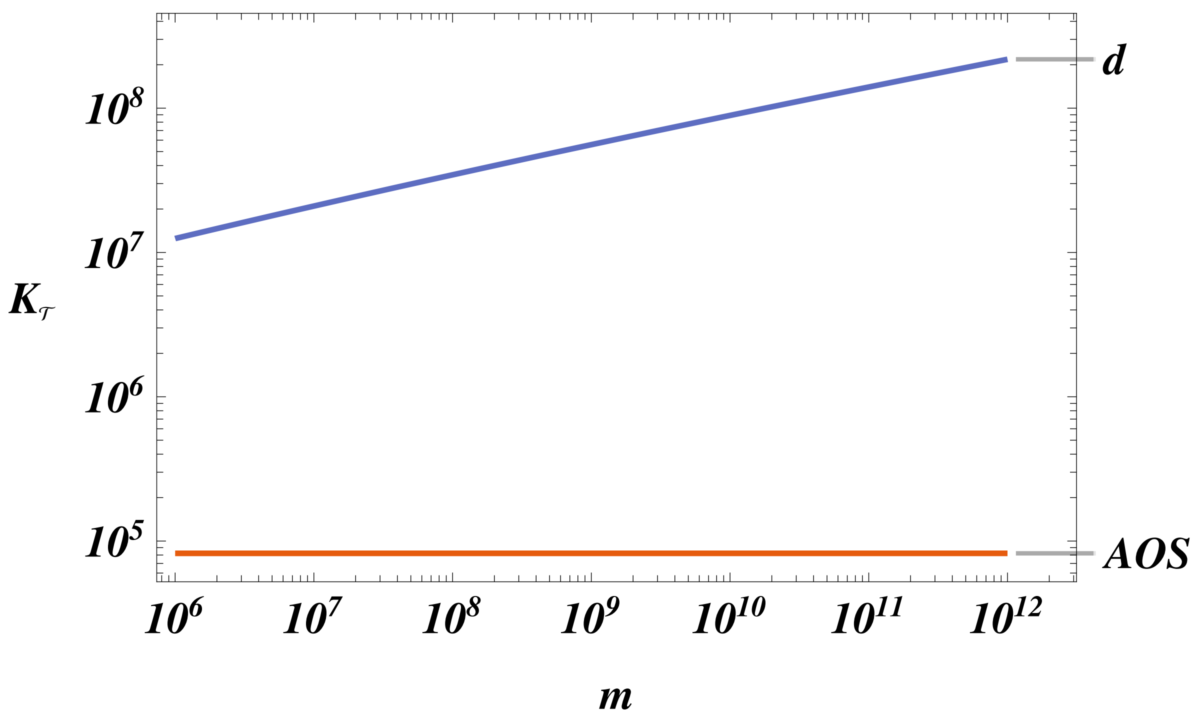
$$\delta_b^{AOS} = \alpha_b^{AOS}\left(\frac{\ell_p}{m}\right)^{1/3} \quad , \quad L_o\delta_c^{AOS} = \alpha_c^{AOS}\left(\frac{\ell_p}{m}\right)^{1/3}$$

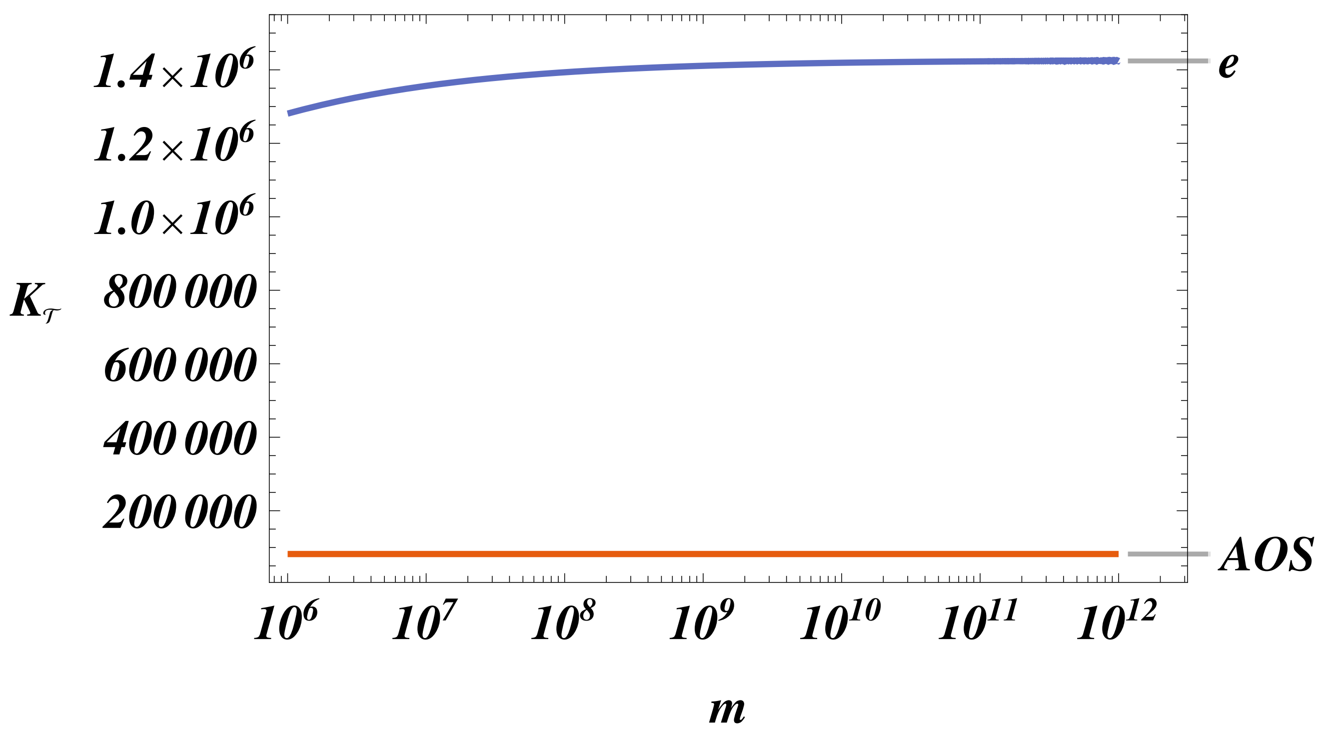
$$\alpha_b^{AOS} \simeq 2.52 \quad , \quad \alpha_c^{AOS} \simeq 0.27$$

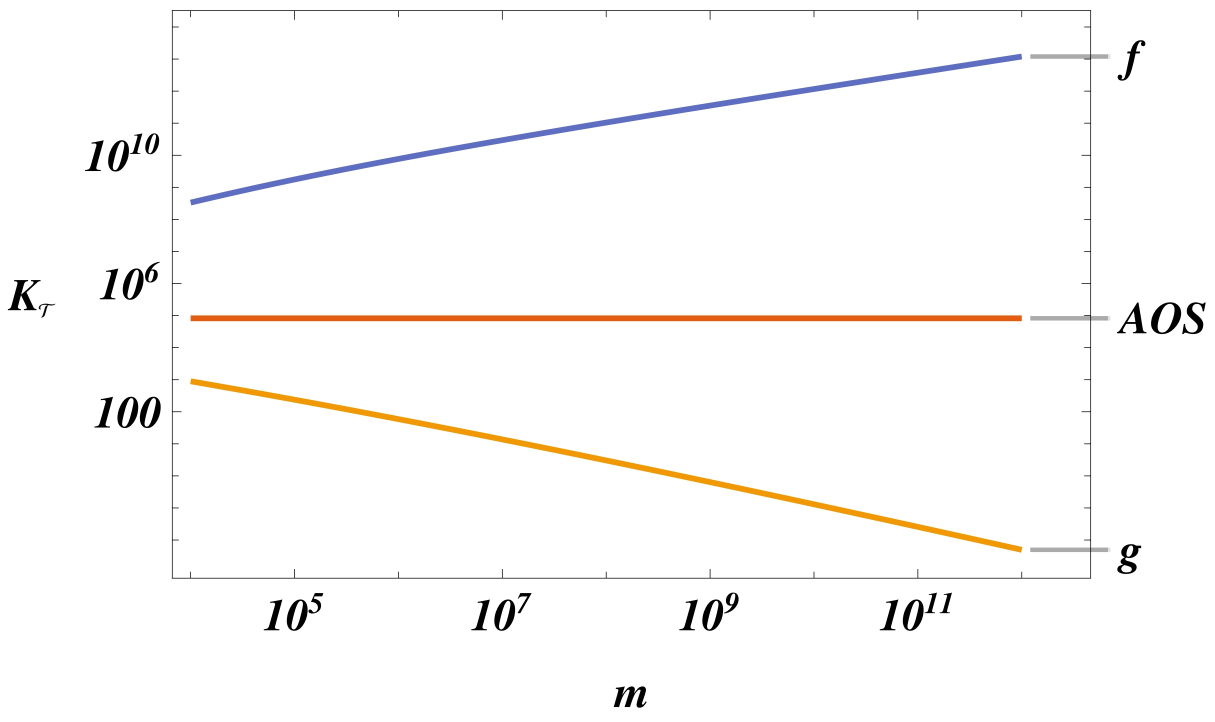
FAMILY

$$\delta_b = \alpha_b\left(\frac{\ell_p}{m}\right)^{1/3} \quad , \quad L_o\delta_c = \alpha_c\left(\frac{\ell_p}{m}\right)^{1/3}$$

FAMILY OF SOLUTIONS







Plots of Kretschmann scalar at transition surface vs mass for various choices in comparison to AOS

d: $(\delta_b, \delta_c) = \left(\delta_b^{(AOS)}, \frac{1}{2L_o}\left(\frac{\gamma\Delta^{3/2}}{4\pi^2 m}\right)^{1/2}\right)$

e: $(\delta_b, \delta_c) = \left(\left(\frac{\sqrt{\Delta}}{\sqrt{2\pi}\gamma^2 m}\right)^{1/2}, \delta_c^{(AOS)}\right)$

f: $(\delta_b, \delta_c) = \left(\left(\frac{\sqrt{\Delta}}{\sqrt{2\pi}\gamma^2 m}\right)^{1/2}, \frac{1}{2L_o}\left(\frac{\gamma\Delta^{3/2}}{4\pi^2 m}\right)^{1/2}\right)$

g: $(\delta_b, \delta_c) = \left(\left(\frac{\sqrt{\Delta}}{\sqrt{2\pi}\gamma^2 m}\right)^{1/4}, \frac{1}{2L_o}\left(\frac{\gamma\Delta^{5/2}}{4\pi^2 m}\right)^{1/4}\right)$

FAMILY OF SOLUTIONS

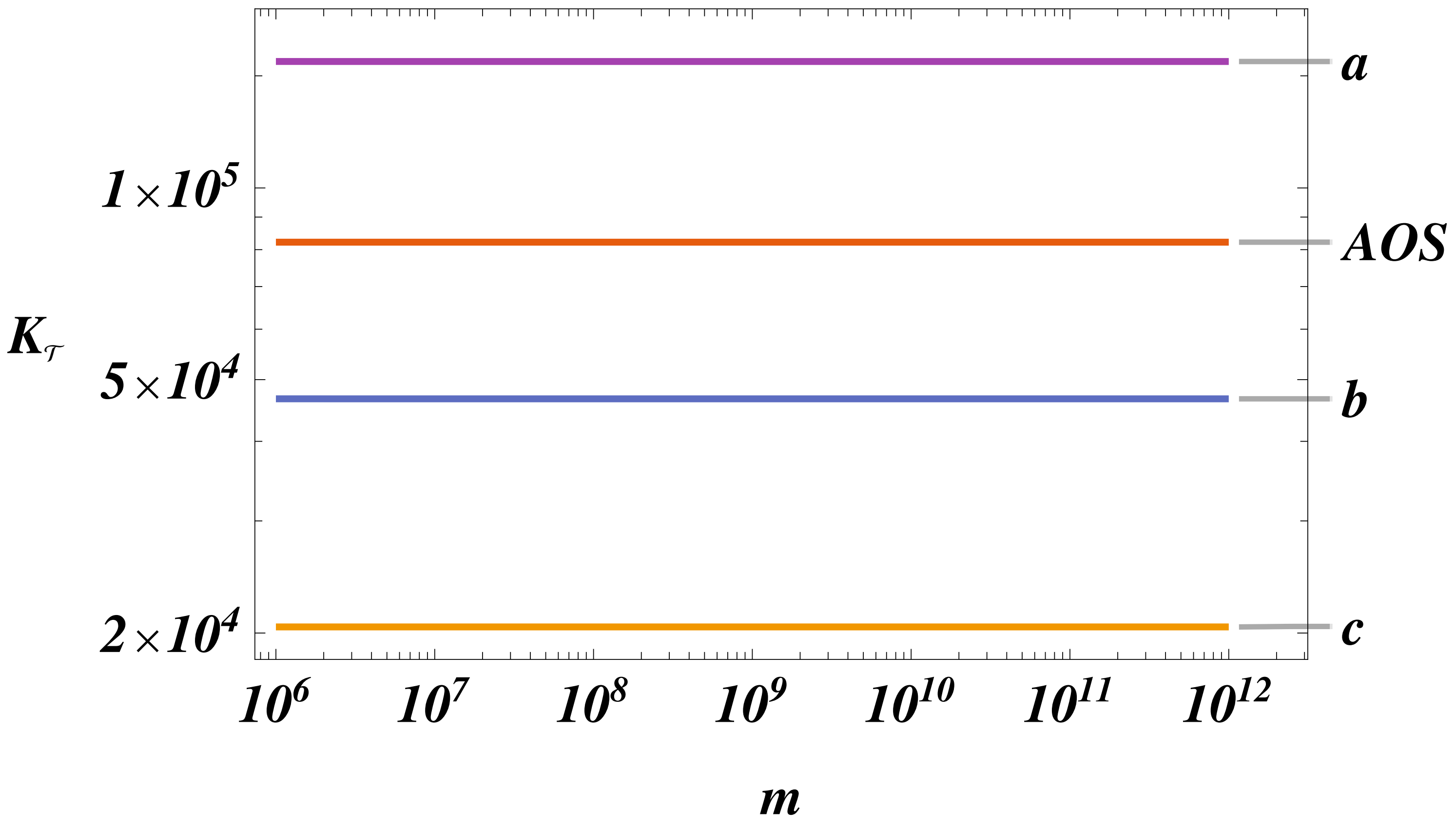
$$\delta_b = \alpha_b \left(\frac{\ell_p}{m}\right)^{1/3} \quad , \quad L_o\delta_c = \alpha_c \left(\frac{\ell_p}{m}\right)^{1/3}$$

&

Demanding radius of BH = WH we get

↓

$$\delta_b = \alpha_b \left(\frac{\ell_p}{m}\right)^{1/3} \quad , \quad L_o\delta_c = \alpha_b^4 \left(\frac{\gamma^3 \ell_p}{2}\right)\left(\frac{\ell_p}{m}\right)^{1/3}$$



Plot of Kretschmann scalar at transition surface vs mass

Few random choices

Line	α_b	α_c
a	1.97	3
b	2	0.5
c	1	1

ASYMPTOTIC BEHAVIOR

- Kretschmann Scalar in the asymptotic limit r→∞

$$K = \frac{a_0}{r^4} + \frac{a_1}{r^{4+b_o}} + \frac{a_2}{r^{4+2b_o}} + \frac{a_3}{r^{4+3b_o}} + \frac{a_4}{r^8} + \mathcal{O}\left(\frac{1}{r^{4(1+b_o)}}\right), \qquad (b_o \approx 1)$$

- However for a solar mass BH in the AOS and CS model, ***r***r^{-4} and r^{-5} terms dominate at scales greater than the size of our observable universe

$$r^{AOS}_{c,M_\odot} > L_{obs}$$

- Spacetime well described by its classical limit for macroscopic BHs

$$K \simeq r^{-6}$$

SUMMARY

- BH singularity replaced by a transition surface
- Antitrapped region (WH) to the future of the transition surface
- Kretschmann scalar of macroscopic BHs decays as r^{-6} within our observable universe
- Family of solutions to the quantum parameters***?***

Thank you!

Do you have any questions?