

A Unitary Black Hole Evaporation Model

The black hole-moving mirror
correspondence with no info loss

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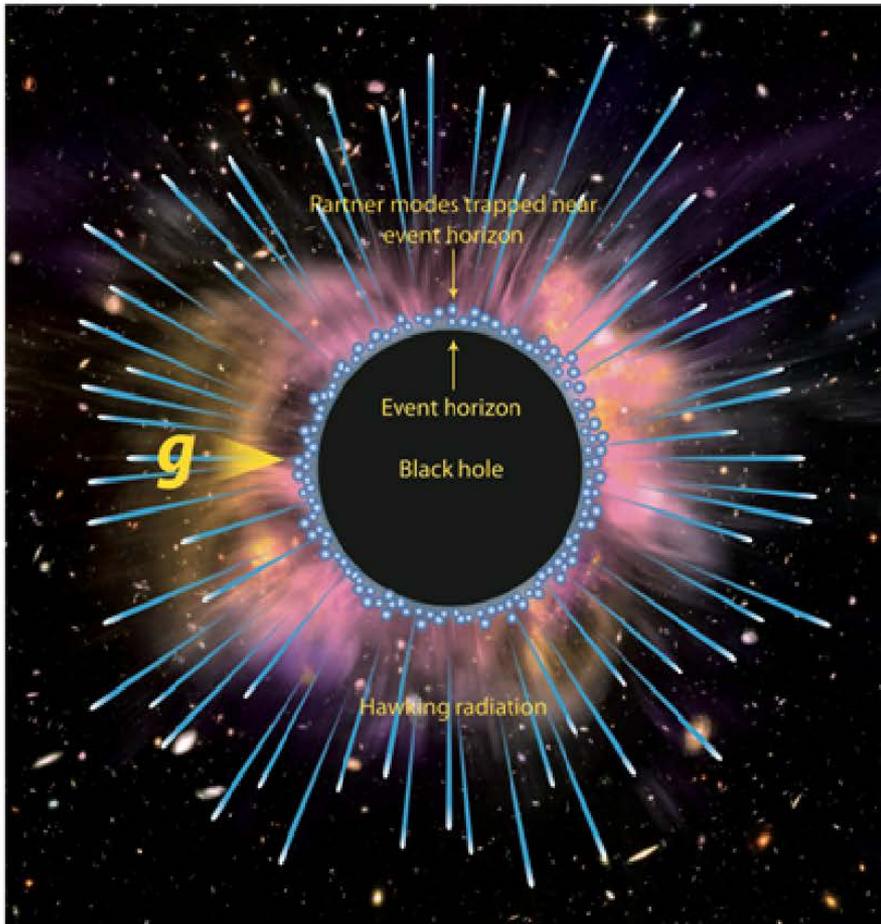
Greece, July 2018

US DOE: DE-SC-0007867, D-AC02-05CH11231

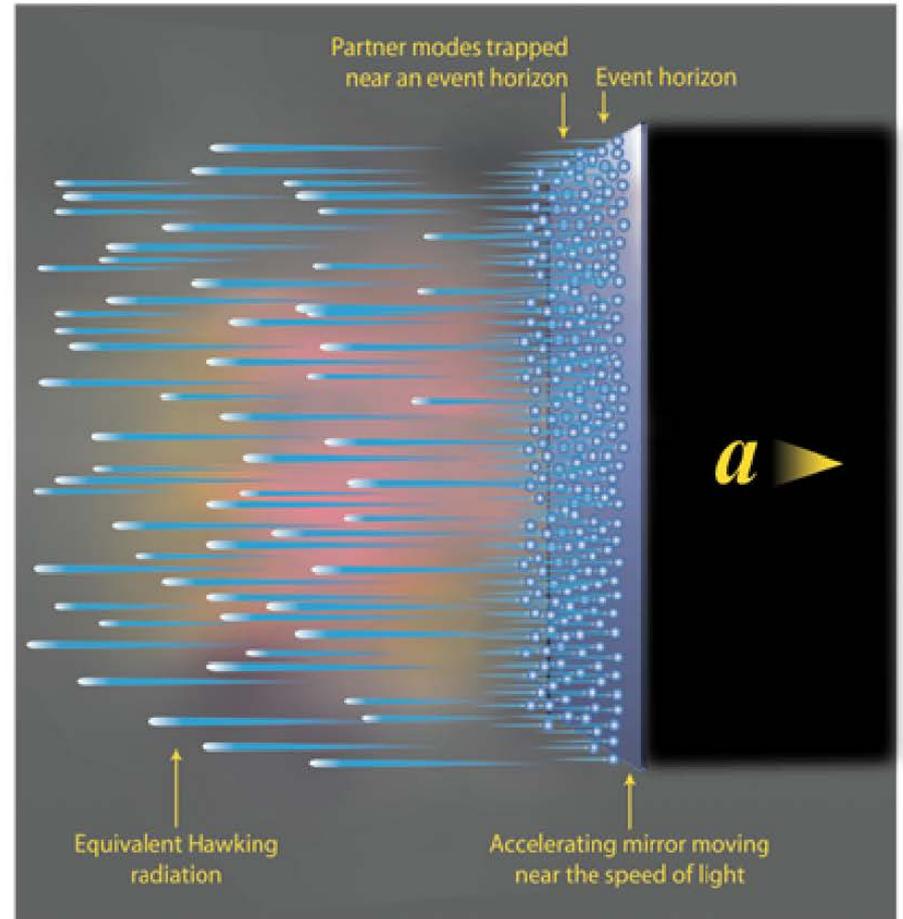
JSF 15-07-0000, ORAU and Social Policy

Talk based on: [Good, et al PRD] [1605.0663 \[gr-cq\]](#)





Black hole Hawking evaporation



Accelerating mirror as an analog black hole

Image Credit: Pisin Chen and Gerald Mourou.

Origin of Coordinates

Wilczek, Frank,
“Quantum Purity at a Small Price”, IASSNS-HEP, 1993

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Uniform Acc. vs Dynamic Acc.

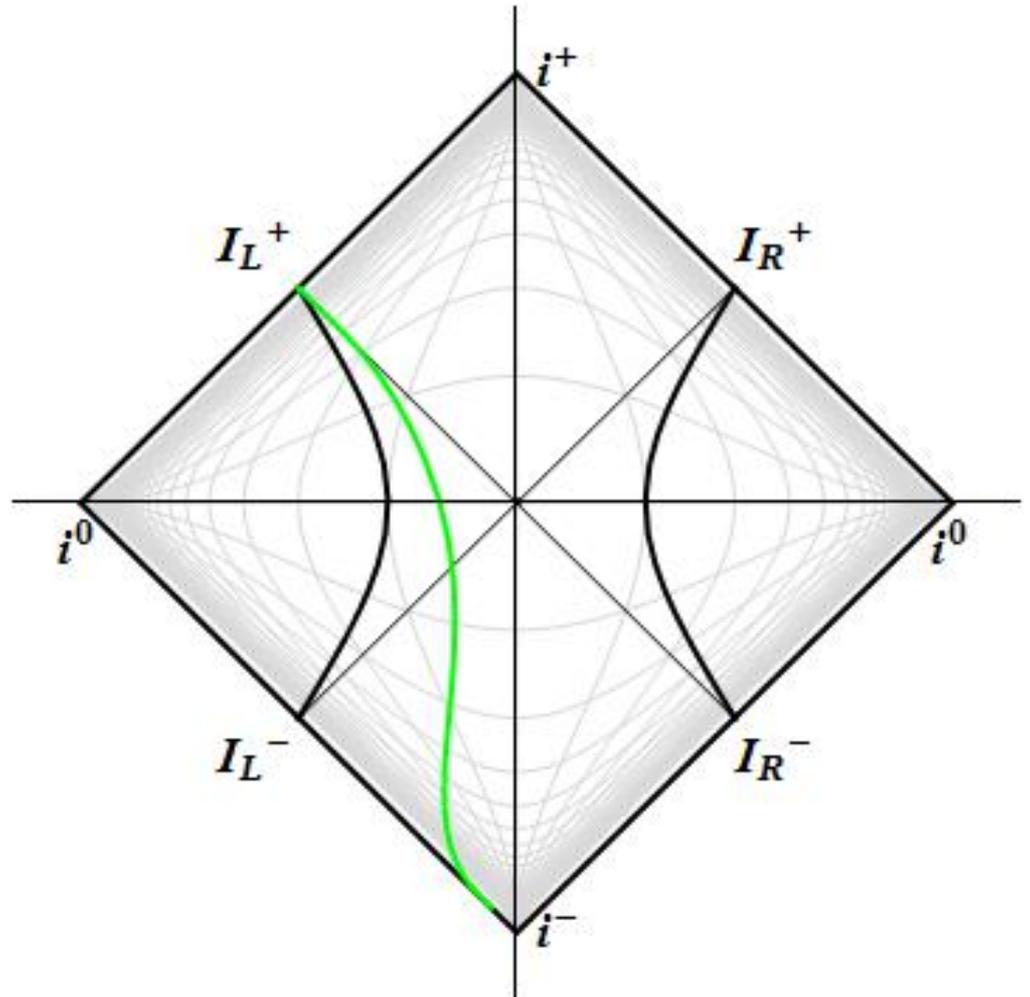
$$\alpha = \tau_0^{-1}$$

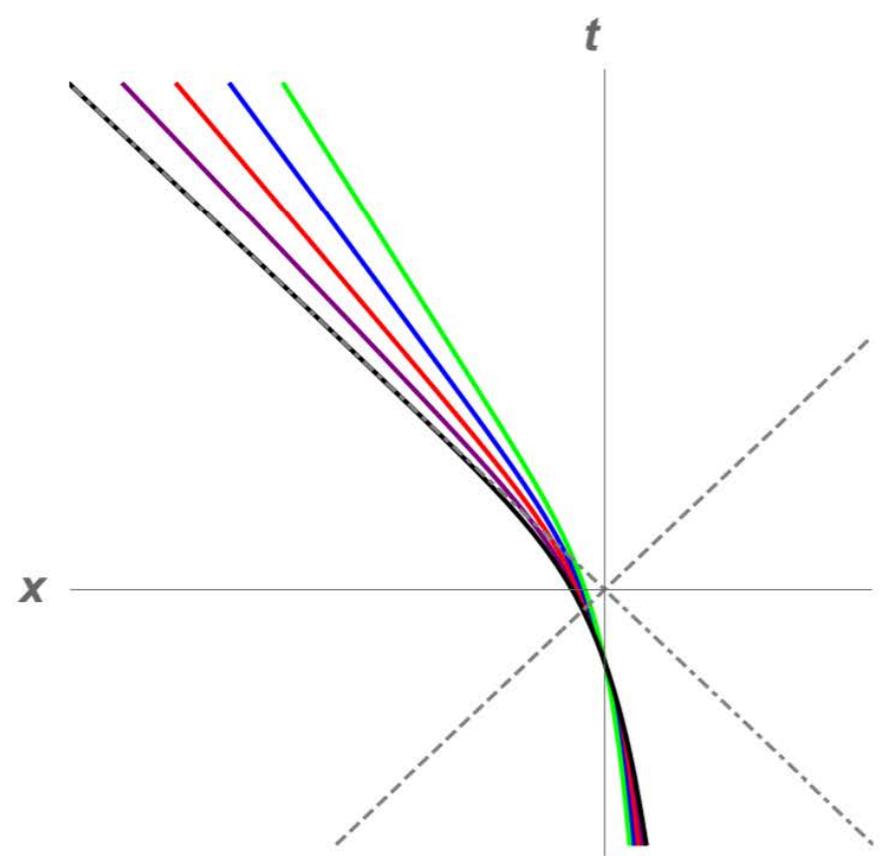
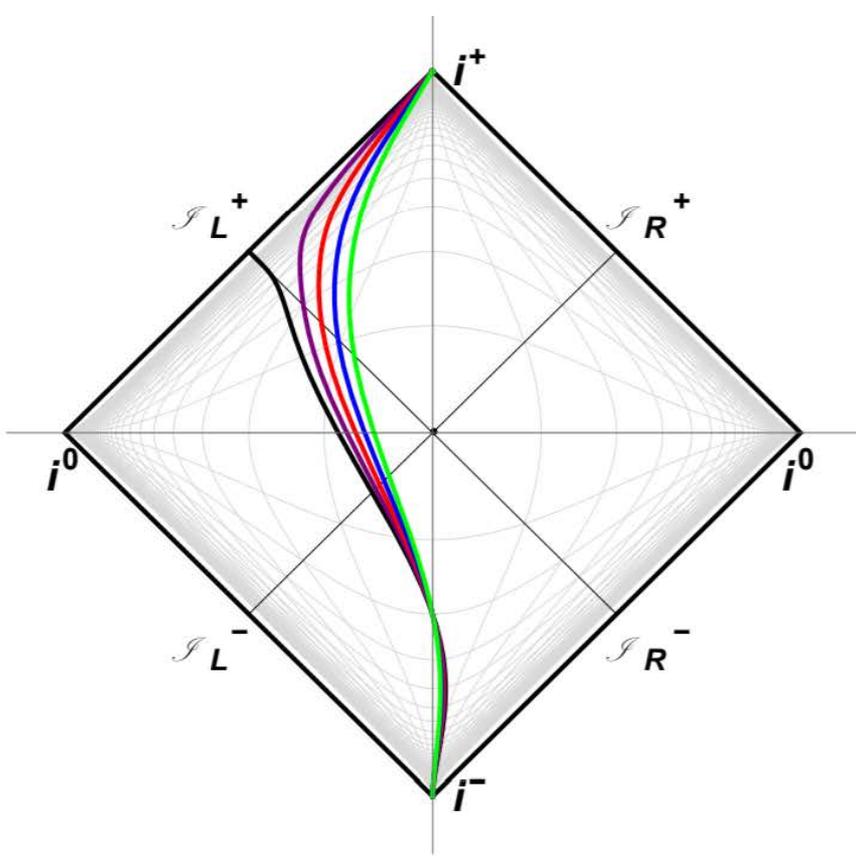
$$\alpha(\tau) = \tau^{-1}$$

Uniform Acc. vs Dynamic Acc.

$$\alpha = \tau_0^{-1}$$

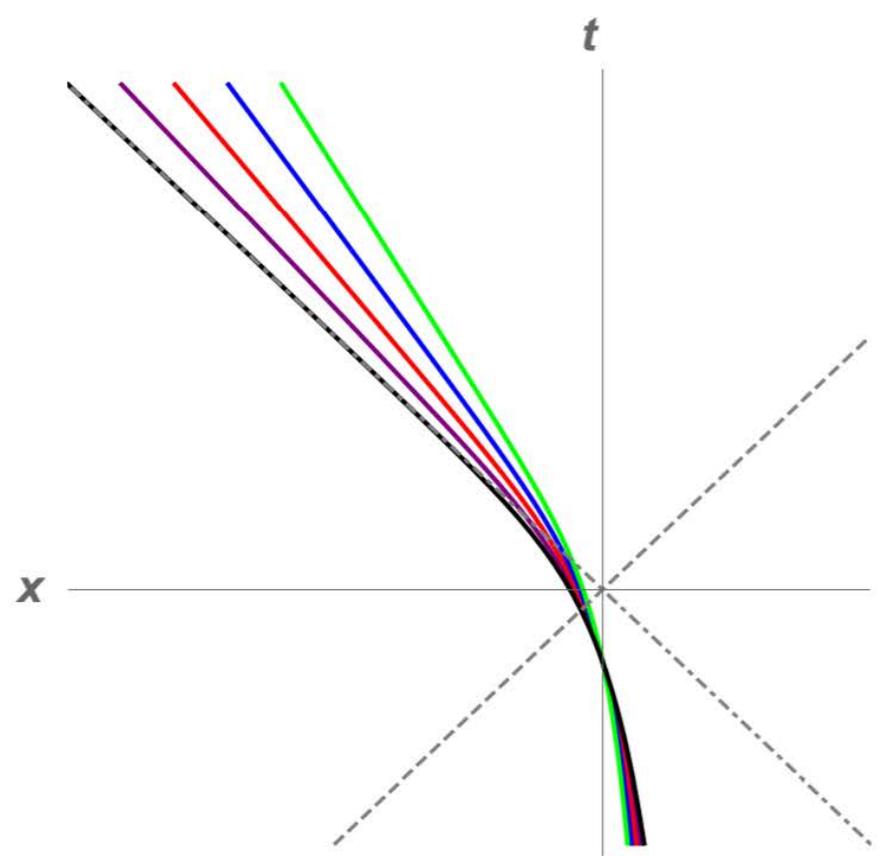
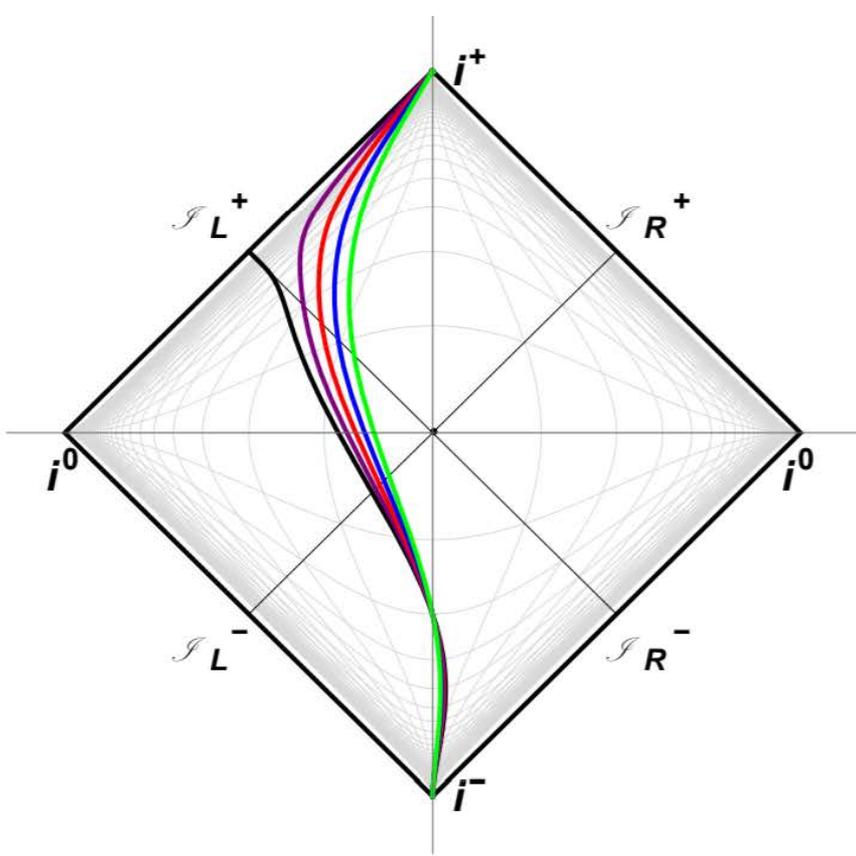
$$\alpha(\tau) = \tau^{-1}$$





$$t(x) = v_H - x - 4Me^{x/2M}$$

Good, M.R.R., Anderson, P.R., and Evans, C.R.
“Mirror Reflections of a Black Hole”, PRD, 2016.

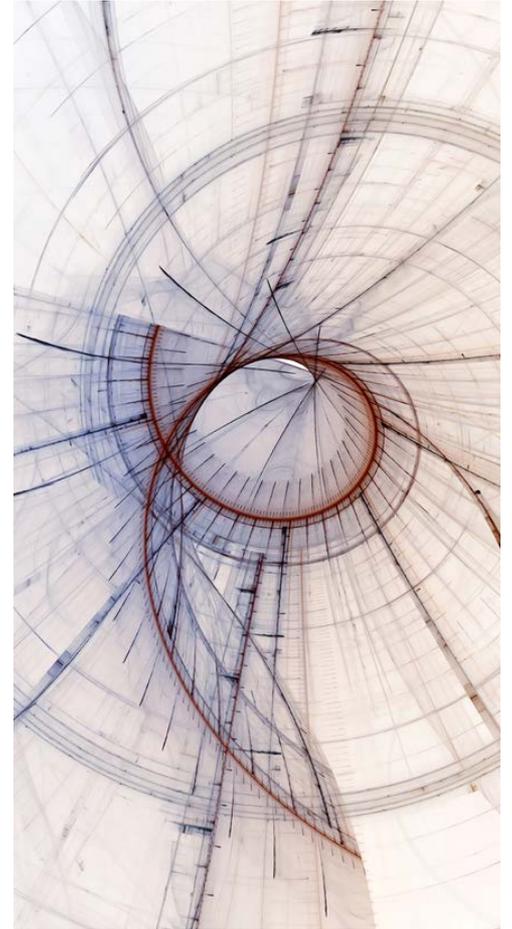


$$t(x) = v_H - x - 4Me^{x/2M}$$

$$t(x, \xi) = v_H - \frac{x}{\xi} - 4Me^{\frac{x}{2M\xi}}$$

Matching Condition

$$u_{\text{out}} = u_{\text{in}} - 4M \ln \frac{|v_H - u_{\text{in}}|}{4M}$$



Matching Condition

$$u_{\text{out}} = u_{\text{in}} - 4M \ln \frac{|v_H - u_{\text{in}}|}{4M}$$

$$u_{\text{out}} = u_{\text{in}} - 4M\xi \ln \left[\frac{1 - \xi}{2} \mathcal{W} \left(\frac{2e^{\frac{v_H - u_{\text{in}}}{2M(1-\xi)}}}{1 - \xi} \right) \right]$$



Giant Tortoise Coordinate

$$r^* \equiv r + 2M \log \left(\frac{r}{2M} - 1 \right)$$



Good, Michael, Yen Chin Ong, Aizhan Myrzakul, Khalykbek Yelshibekov,
“**Giant Tortoise Coordinate**”. arXiv:1801.08020 [gr-qc]

Giant Tortoise Coordinate

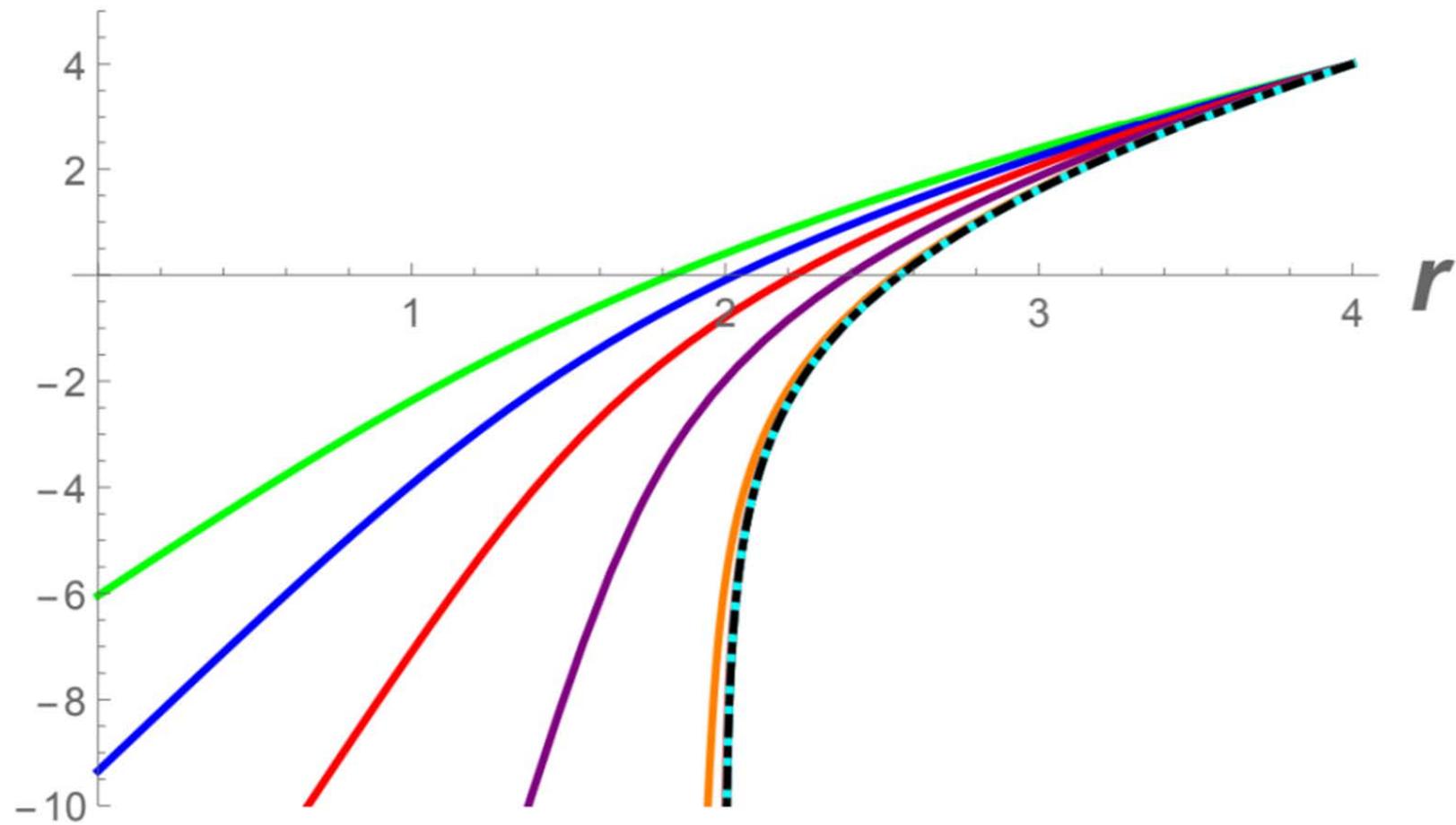
$$r^* \equiv r + 2M \log \left(\frac{r}{2M} - 1 \right)$$

$$r^*(\xi) \equiv r + 2M\xi \ln \left[\frac{1 - \xi}{2} \mathcal{W} \left(\frac{2e^{\frac{r-2M}{M(1-\xi)}}}{1 - \xi} \right) \right]$$



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“**Giant Tortoise Coordinate**”. arXiv:1801.08020 [gr-qc]

$r^*(\xi)$



Thermal Equilibrium

$$T = \frac{\kappa}{2\pi}$$



$$\xi \equiv 1 - \epsilon$$

Thermal Equilibrium

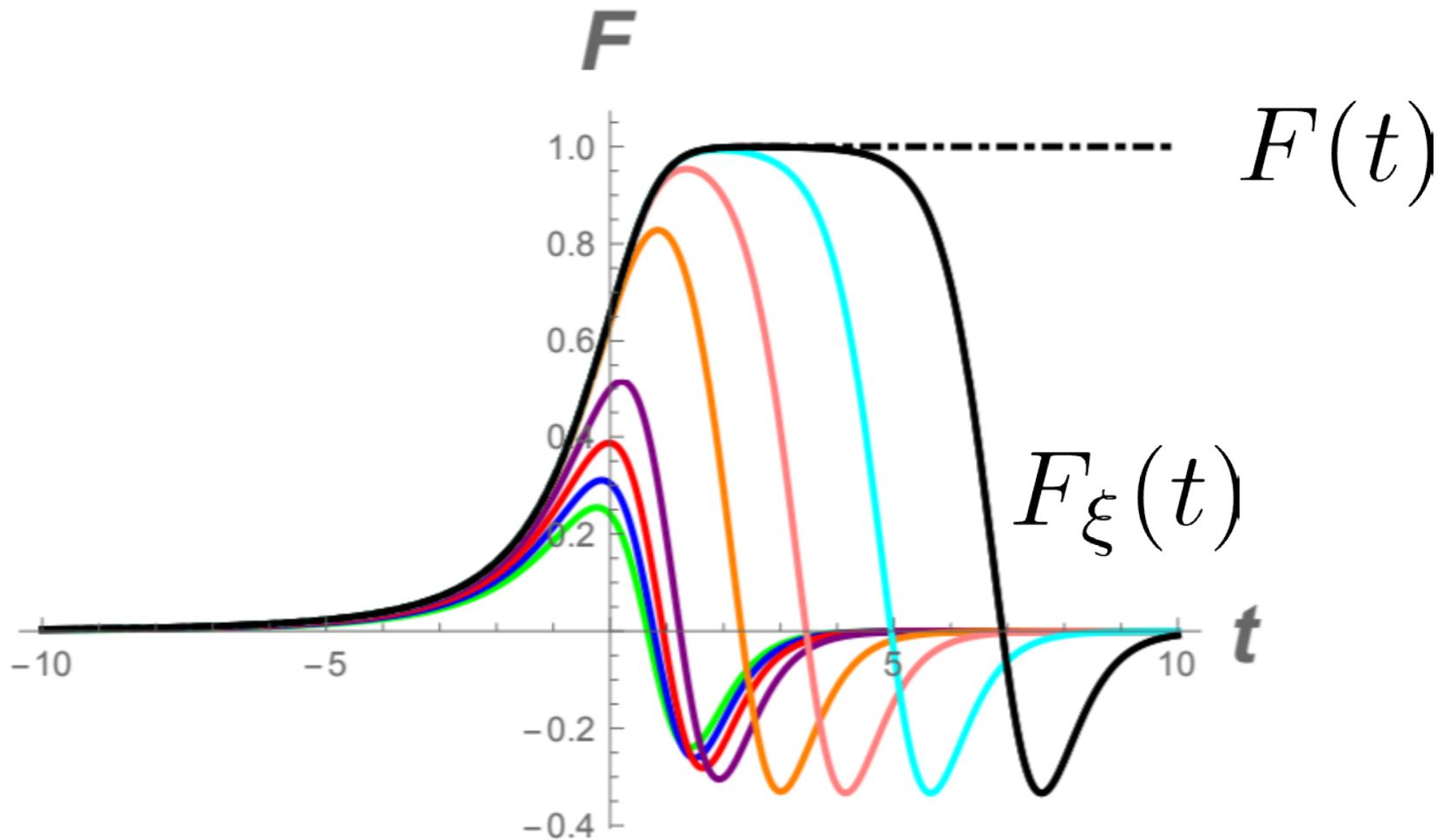
$$T = \frac{\kappa}{2\pi}$$



$$T_{\xi} = \frac{\kappa}{2\pi} \left[1 - 3 \left(\frac{3}{4} \right)^{1/3} \epsilon^{2/3} + \mathcal{O}(\epsilon) \right]$$

$$\xi \equiv 1 - \epsilon$$

Energy Flux



Evaporative Restriction

$$E = \infty$$

Evaporative Restriction

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$$E_{\xi} = \frac{\kappa}{24\pi} \gamma^2$$

Particle Count

$$\beta_{\omega\omega'} = -\frac{\sqrt{\omega\omega'}}{2\pi\kappa\omega_p} \left(\frac{i\kappa}{\omega_p}\right)^{i\frac{\omega}{\kappa}} \Gamma\left(i\frac{\omega}{\kappa}\right)$$

Particle Count

$$\beta_{\omega\omega'} = -\frac{\sqrt{\omega\omega'}}{2\pi\kappa\omega_p} \left(\frac{i\kappa}{\omega_p}\right)^{i\frac{\omega}{\kappa}} \Gamma\left(i\frac{\omega}{\kappa}\right)$$

$$\beta_{\xi\omega\omega'} = -\frac{\xi\sqrt{\omega\omega'}}{2\pi\kappa\omega_p} \left(\frac{i\kappa}{\omega_p}\right)^A \Gamma(A)$$

$$A \equiv \frac{i}{2\kappa} [(1 + \xi)\omega + (1 - \xi)\omega'] \quad \omega_p \equiv \omega + \omega'$$

Quanta Summing Consistency

$$\int_0^{\infty} \omega \langle N_{\omega} \rangle d\omega = \int_{-\infty}^{\infty} F(u) du.$$

$$E = \int_0^{\infty} \omega |\beta_{\xi\omega\omega'}|^2 d\omega' d\omega = \int_{-\infty}^{\infty} F(u) du$$

$$E = \frac{\kappa}{24\pi} \gamma^2$$

End State of the Black Hole

- Remnant
- Mass Gain



Soft Particles

$$N = \infty$$

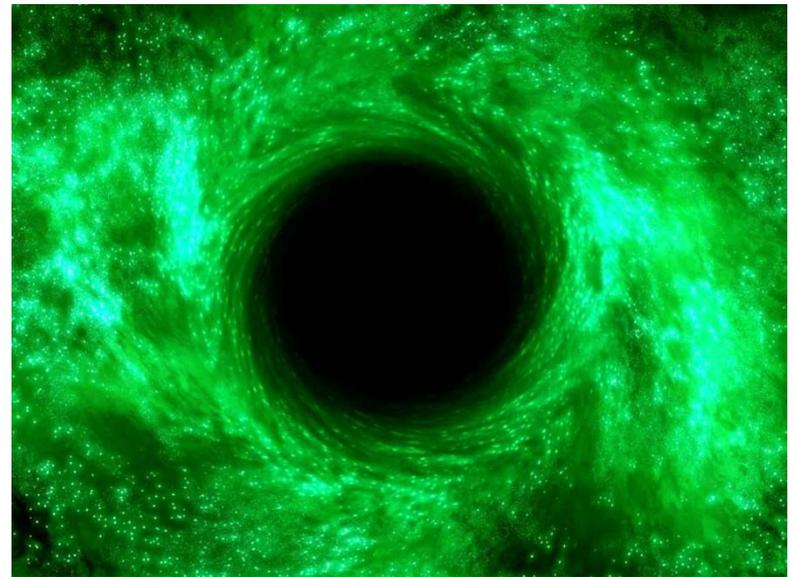
Soft Particles

$$N = \infty$$

$$N_{\xi} = \infty$$

Conclusions: Features of the Model

- Temperature
- Energy
- Causal
- Information



Monday, July 9

6. Edward Sarkisyan-Grinbaum
Multihadron production: universality, correlations and search for new physics. — 30 min.
7. Agustin Sabio Vera
Multiparticle production in the Multi-Regge limit. — 30 min.

Coffee Break. 16:00 – 16:30

8. Vladimir Vechernin
Strongly intensive observables in the model with string fusion. — 25 min.

Workshop on Frontiers in Gravitation, Astrophysics, and Cosmology (Room 2, 11:00)

1. Damian Ejlli
Vacuum polarization and superluminal photons in the era of gravitational waves. — 30 min.
2. Michael Good
A Unitary Black Hole Evaporation Model. — 30 min.

$$S(t) = \frac{1}{6} \tanh^{-1} \left(\frac{1}{W(2e^{-2\kappa t}) + 1} \right)$$

$$S_{\xi}(t) = \frac{1}{6} \tanh^{-1} \left(\frac{\xi}{W(2e^{-2\kappa t}) + 1} \right)$$

Finite Limiting Entropy or Rapidity

$$\lim_{t \rightarrow \infty} S(t) = \infty$$

$$\lim_{t \rightarrow \infty} S_{\xi}(t) = \frac{1}{6} \tanh^{-1}(\xi) = \frac{\eta}{6}$$

Entropy Flux

