Robustness of particle creation in a formation of a compact object

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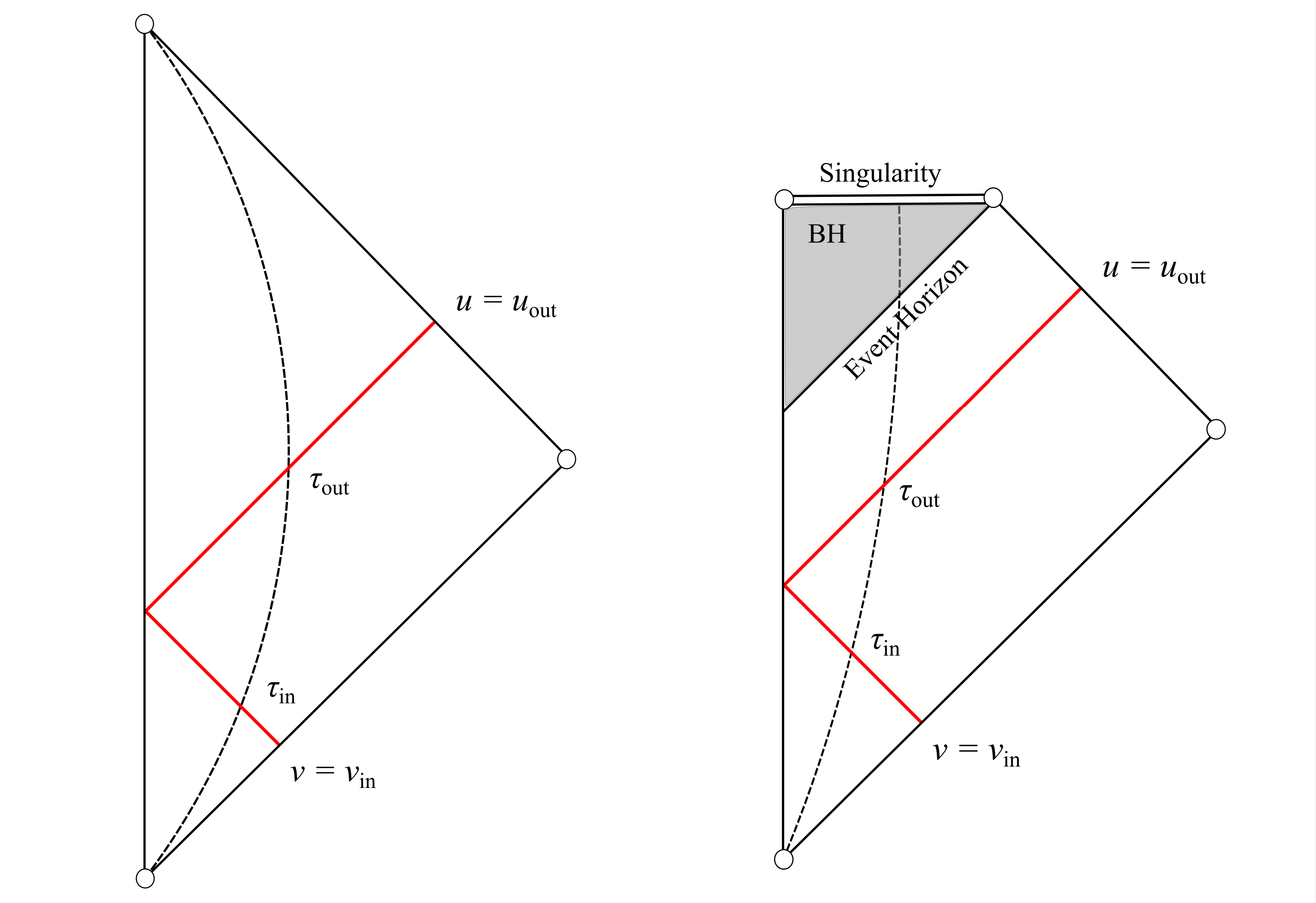
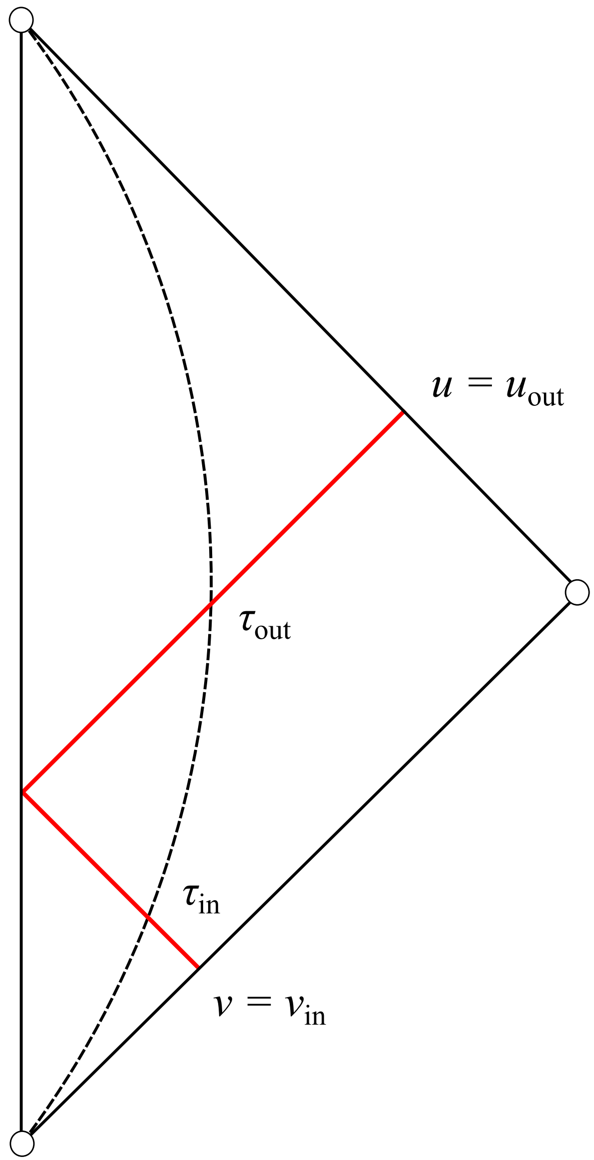
arXiv: in preperation

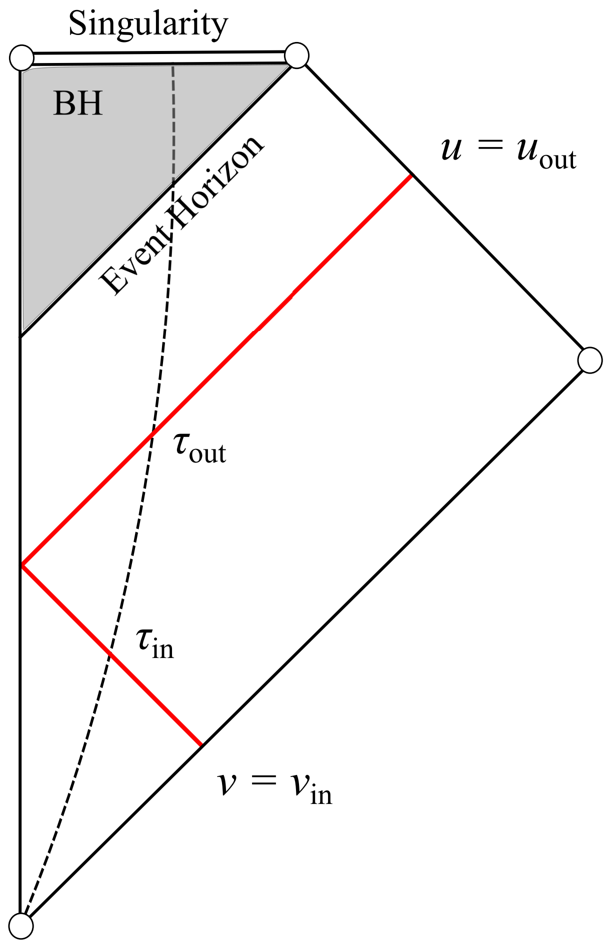
Introduction



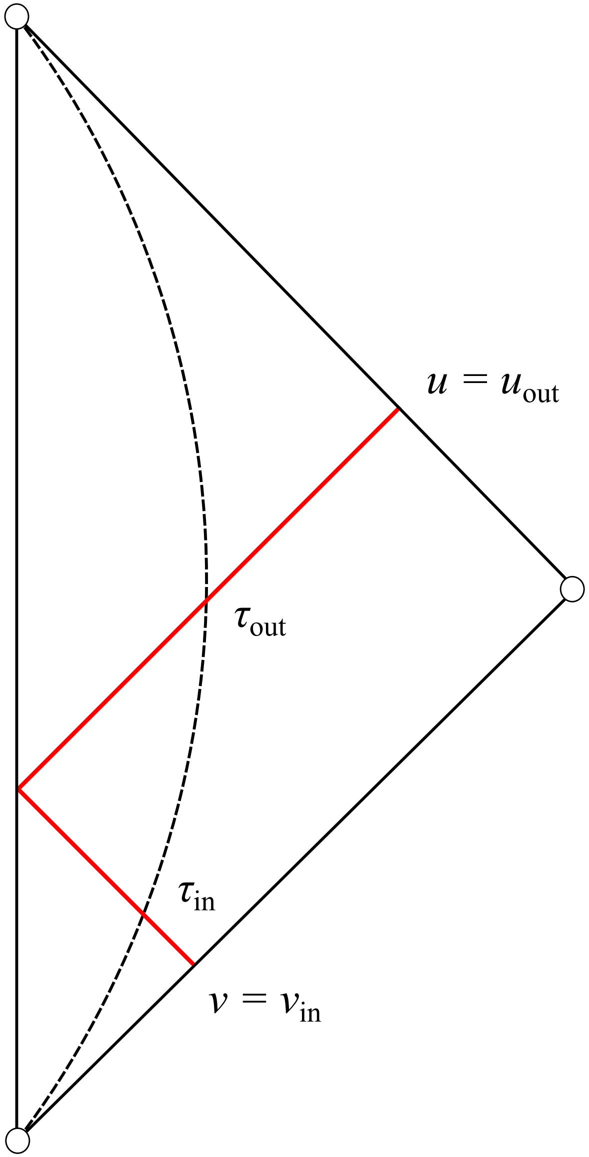
Introduction



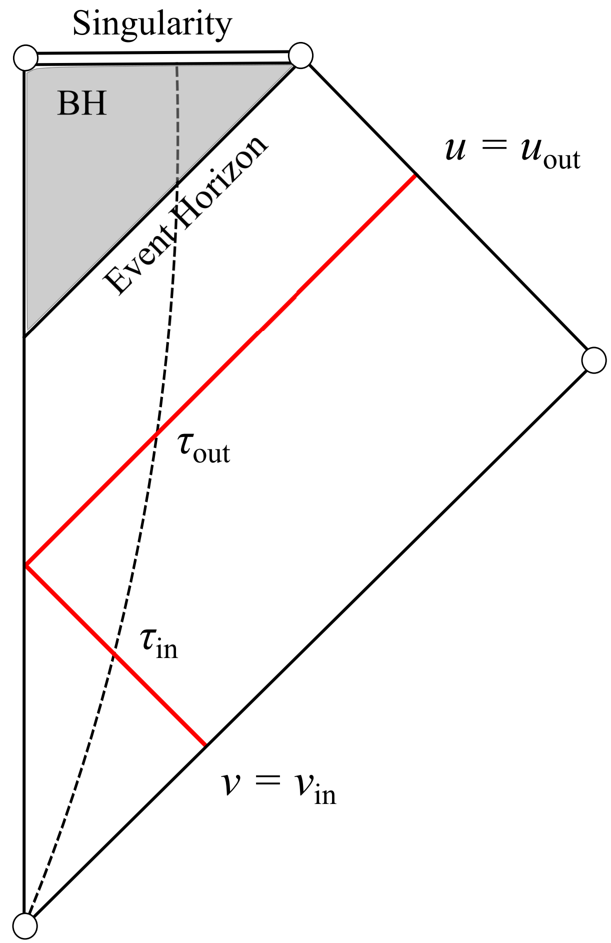
All we can do is to show that an object is not BH but BH mimic.



Introduction



We need to prepare a tool to show it.
→ <u>semiclassical approach</u>

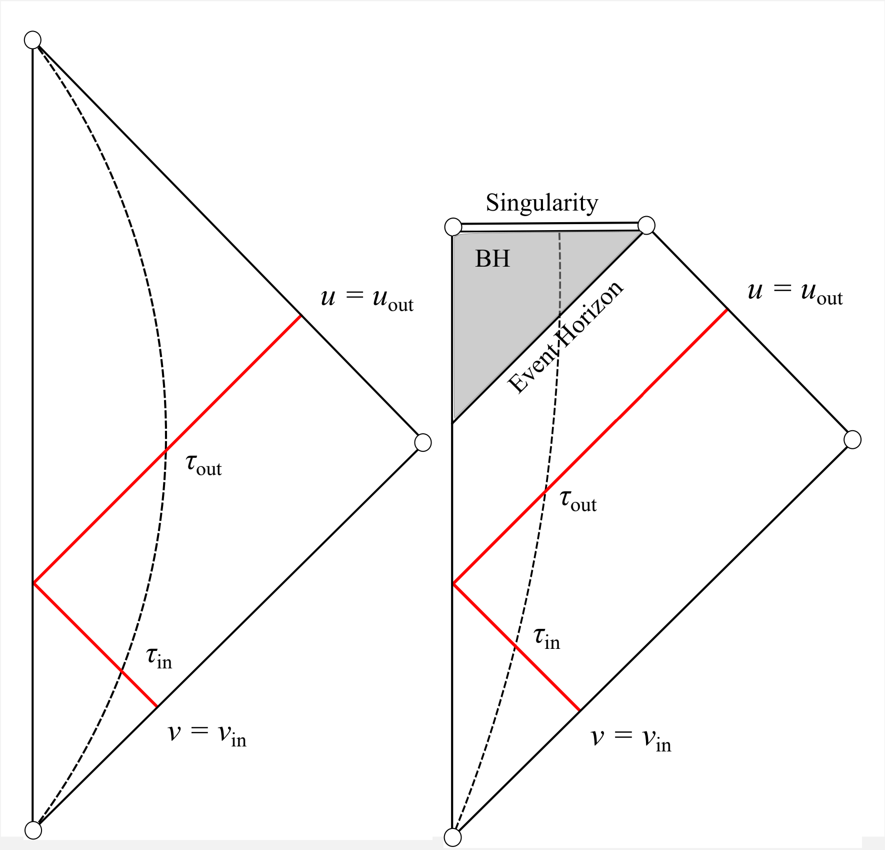


Introduction

- In 1970's, Hawking found particle creation with Planck distribution in BH spacetime. To obtain this particle creation, existence of the event horizon was assumed. (Hawking ,(1974), (1975))

- In 2011, it is shown this radiation arises without any horizon.
  (Barcelo, Liberati, Sonego, & Visser (2011))

- It is known that there is a peak specific to a BH mimic, not BH.
  (Paranjape & Padmanabhan (2009),
  Harada, Cardoso, & Miyata (2019), Kokubu & Harada (2019)
  Barcelo, Boyanov, Carballo-Rubio, & Garay (2019))



Introduction

A shell model between a closed FLRW and Schwarzschild metric

↓

The similar result to the hollow shell case is obtained.

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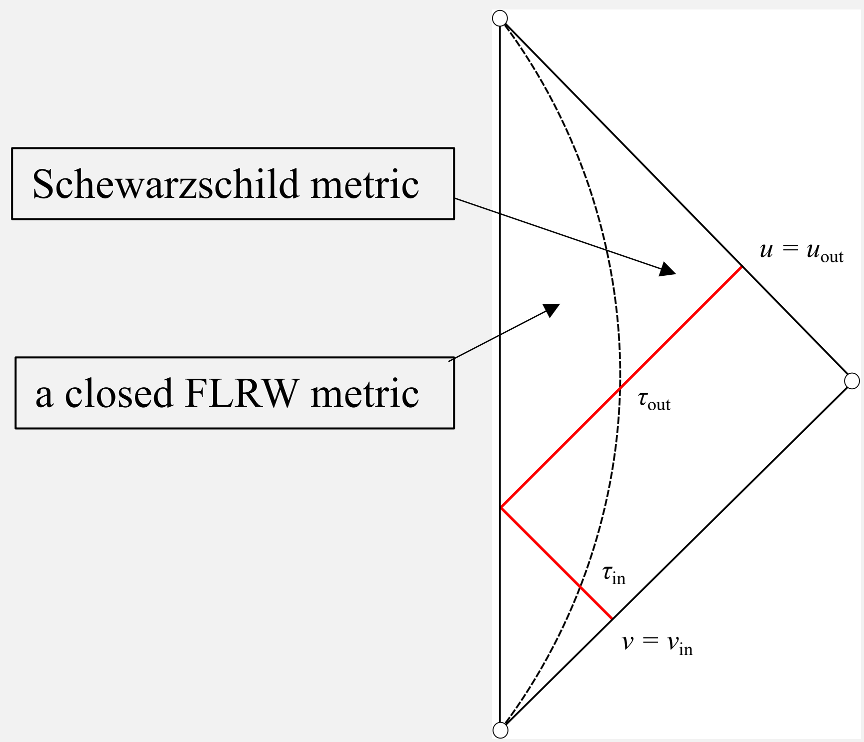
Q. How common is this result?

- Previous works are done in a hollow shell model.
- At least, matter is needed inside the shell as a star.



Particle creation without any horizon

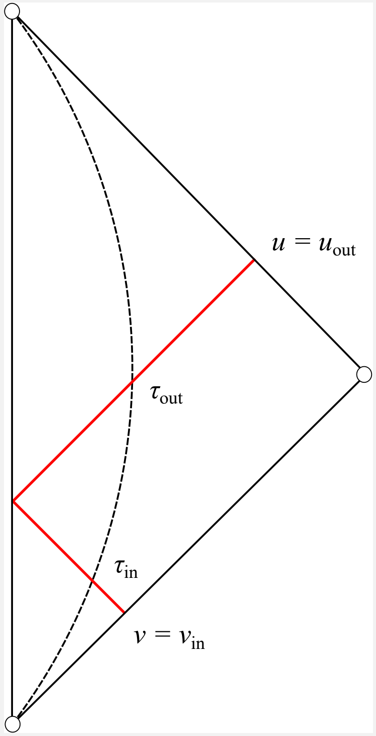
A generalization of the surface gravity is defined as

$$\kappa(u_{\text{out}}) := -\frac{d}{du_{\text{out}}} \ln \frac{dv_{\text{in}}}{du_{\text{out}}} = -(\ln G')'(u_{\text{out}}),$$

$$v_{in} = G(u_{out})$$

When the adiabatic condition $|\kappa'(u_*)| \ll \kappa^2(u_*)$ is satisfied, the following relations are obtained

$$kT(u_*) = \frac{\kappa(u_*)}{2\pi}, \quad P_{lm} = \frac{1}{48\pi}(\kappa^2 + 2\delta\kappa'),$$



In this sense, particle creation arises without any horizon.

(Barcelo, Liberati, Sonego, & Visser (2011), Ford & Parker (1977))

Particle creation without any horizon

For a shell model, $G'(u)$ can be evaluated as

$$G'(u) = \frac{dv_{\rm in}}{du_{\rm out}} = \frac{dv_{\rm in}}{d\tau_{\rm in}} \frac{d\tau_{\rm in}}{dV_{\rm in}} \frac{dV_{\rm in}}{dU_{\rm out}} \frac{dU_{\rm out}}{d\tau_{\rm out}} \frac{d\tau_{\rm out}}{du_{\rm out}} = \frac{A_{\rm out}}{B_{\rm in}},$$

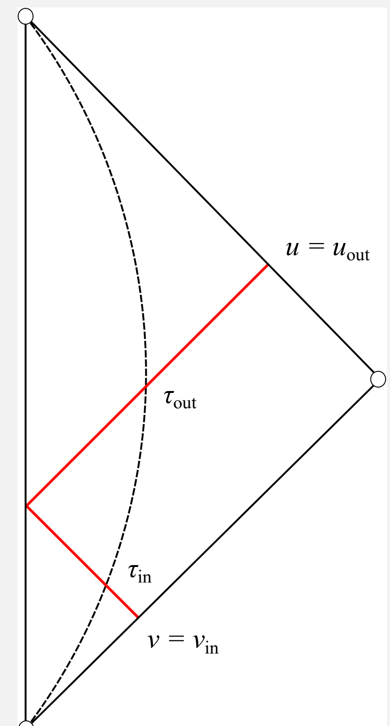
$$v_{in} = G(u_{out})$$

then we obtain

$$\kappa(u) = C_{\rm out} - \frac{A_{\rm out}}{B_{\rm in}} D_{\rm in},$$

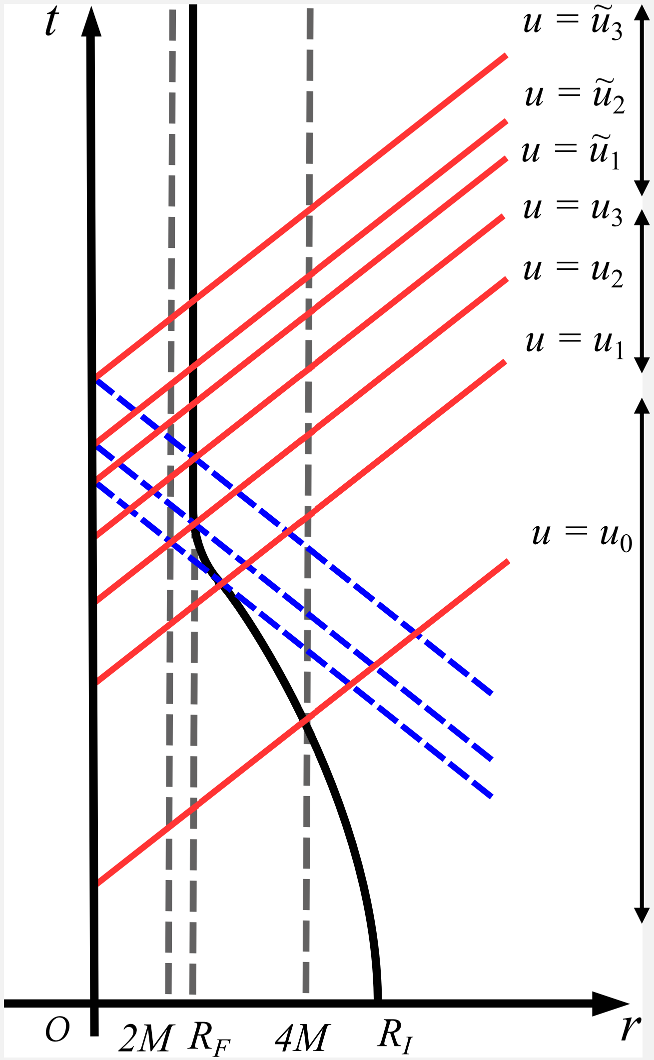
where $A := \frac{\dot{U}}{\dot{u}},\ B := \frac{\dot{V}}{\dot{v}},\ C := -\frac{1}{\dot{u}} \frac{d\ln A}{d\tau},\ D = -\frac{1}{\dot{v}} \frac{d\ln B}{d\tau}.$

To evaluate particle creation, the relation between v_{in} and u_{out} is important.



Particle creation for a timelike shell model

Scenario to form a compact object



Static phase for $u_3 < u$, $\left(R_F = \frac{2M}{1-\epsilon^2}\right)$

Braking phase for $u_1 < u < u_3$

Collapsing phase for $u < u_1$

After $v_{in} = G(u_{out})$ is obtained,

we can evaluate particle creation.

Particle creation for a timelike shell model

- Collapsing phase around $u = u_1$

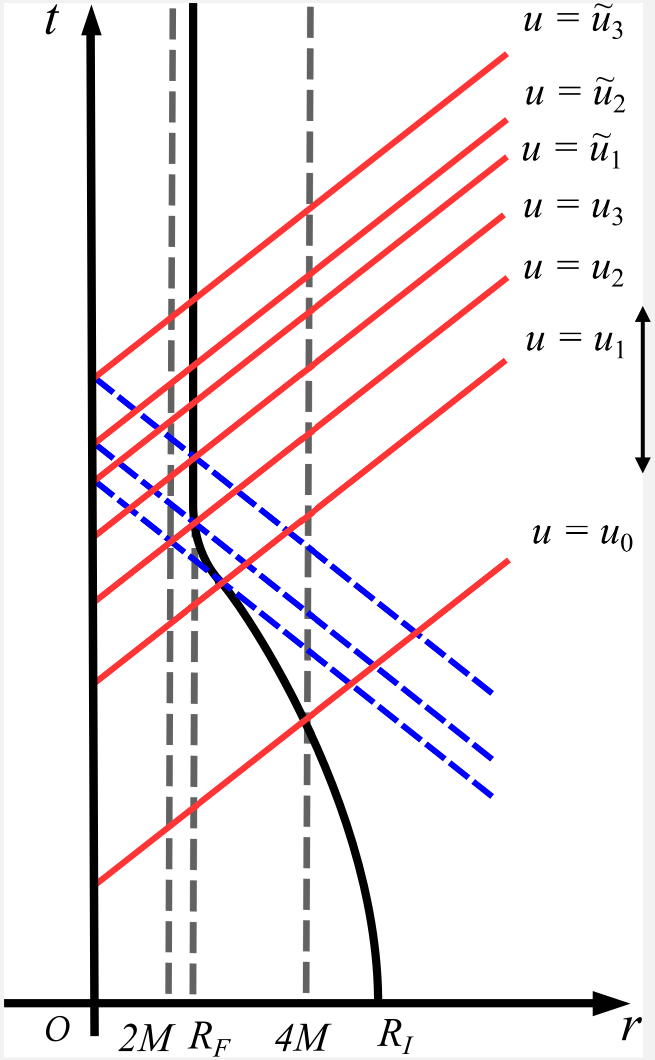
$$\kappa \simeq \frac{M}{R^2} - \frac{F}{2|\dot{R}|}\left(\frac{\ddot{U}}{\dot{U}} + \frac{\ddot{R}}{|\dot{R}|}\right) \quad \text{around } u_1.$$

Since $R \simeq 2M$, $\kappa \simeq \dfrac{1}{4M}$ is obtained.

the same value with the original Hawking radiation.

This result is come from $R \simeq 2M$, or $F \simeq 0$.

Transient Hawking radiation does not depend on the inside matter.

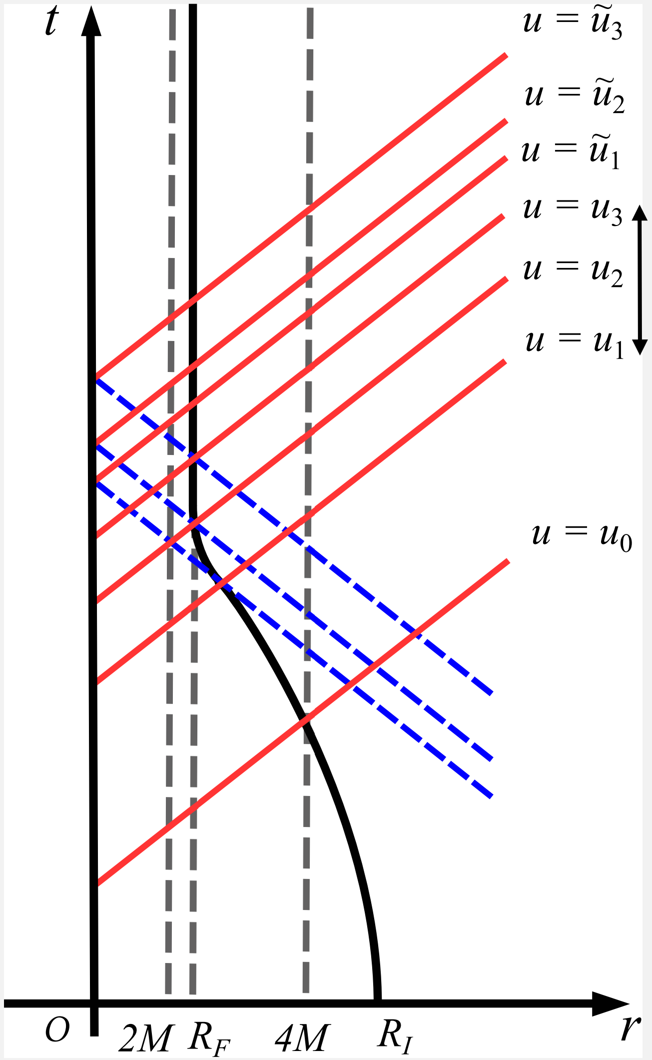


Particle creation for a timelike shell model

- Braking phase

To evaluate particle creation for $u_1 < u < u_3$ and $\tilde{u}_1 < u < \tilde{u}_3$ in detail, we need a concrete model to stop collapsing.

$$R_B - R_F = 2M\epsilon^{2\beta}$$



Model A: Exponentially slowed-down model

$$R - R_F \propto e^{-\sigma\tau}, \quad (u_1 < u < u_3)$$

$$\sigma = \frac{\dot{R}_B}{R_B - R_F} \simeq \frac{1}{2M\epsilon^{2\beta}}$$

Model B: Constant-deceleration model

$$\ddot{R} = \tilde{a} \simeq \frac{1}{4M\epsilon^{2\beta}}, \quad (u_1 < u < u_3)$$

Particle creation for a timelike shell model

Post Hawking burst for $u_1 < u < u_3$,

$$\kappa = C_{\text{out}} + O(\epsilon M^{-1})$$
$$\simeq \left[\frac{|\dot{R}|}{\sqrt{F+\dot{R}^2}}\frac{M}{R^2}\right]_{\text{out}} - \frac{1}{\dot{u}_{\text{out}}}\left[\frac{\ddot{U}}{\dot{U}} + \frac{\ddot{R}}{\sqrt{F+\dot{R}^2}}\right]_{\text{out}}$$

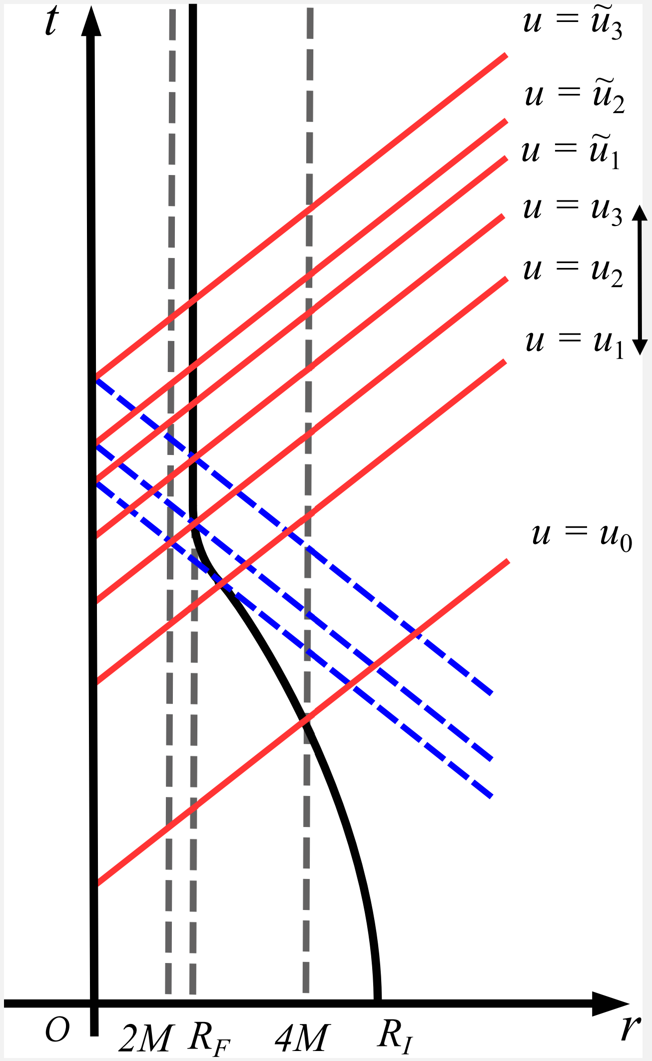
When $\left|\frac{\ddot{U}_{out}}{\dot{U}_{out}}\right| < \left|\frac{\ddot{u}_{out}}{\dot{u}_{out}}\right|$, $\kappa \simeq O(\ddot{R}_{out})$ is obtained because $\ddot{R}_{out}$ takes much large value for $u_1 < u < u_3$.

This radiation does not depend on the inside matter under the condition $\left|\frac{\ddot{U}_{out}}{\dot{U}_{out}}\right| < \left|\frac{\ddot{u}_{out}}{\dot{u}_{out}}\right|$.

Model A: $\kappa \simeq \dfrac{1}{4M\epsilon^{2\beta-1}}$

Model B: $\kappa \simeq \dfrac{1}{8M\epsilon^{2\beta}}$

$R_B - R_F = 2M\epsilon^{2\beta}$



Particle creation for a timelike shell model

Late-time burst for $\tilde{u}_1 < u < \tilde{u}_3$,

$$\kappa = -\epsilon \frac{\dot{U}_{\rm out}}{\dot{V}_{\rm in}} \left[\frac{\ddot{R}}{\sqrt{F+\dot{R}^2}} - \frac{\ddot{V}}{\dot{V}} - \frac{M\dot{v}\dot{R}}{R^2\sqrt{F+\dot{R}^2}} \right]_{\rm in}$$

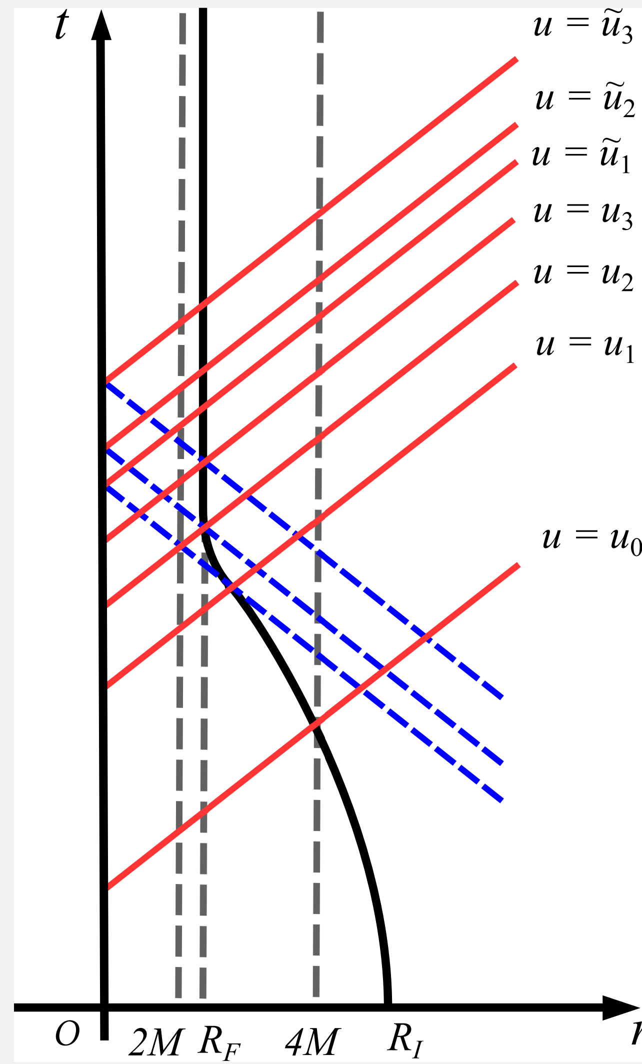
When $\left|\frac{\ddot{V}_{in}}{\dot{V}_{in}}\right| < \left|\frac{\ddot{v}_{in}}{\dot{v}_{in}}\right|$, $\kappa \simeq O(\ddot{R}_{in})$ is obtained because $\ddot{R}_{in}$ takes much large value for $\tilde{u}_1 < u < \tilde{u}_3$.

This radiation does not depend on the inside matter under the condition $\left|\frac{\ddot{V}_{in}}{\dot{V}_{in}}\right| < \left|\frac{\ddot{v}_{in}}{\dot{v}_{in}}\right|$.

$$\text{Model A:} \quad \kappa \simeq \frac{1}{2M\epsilon^{2\beta-1}}$$

$$\text{Model B:} \quad \kappa \simeq \frac{1}{4M\epsilon^{2\beta}}$$

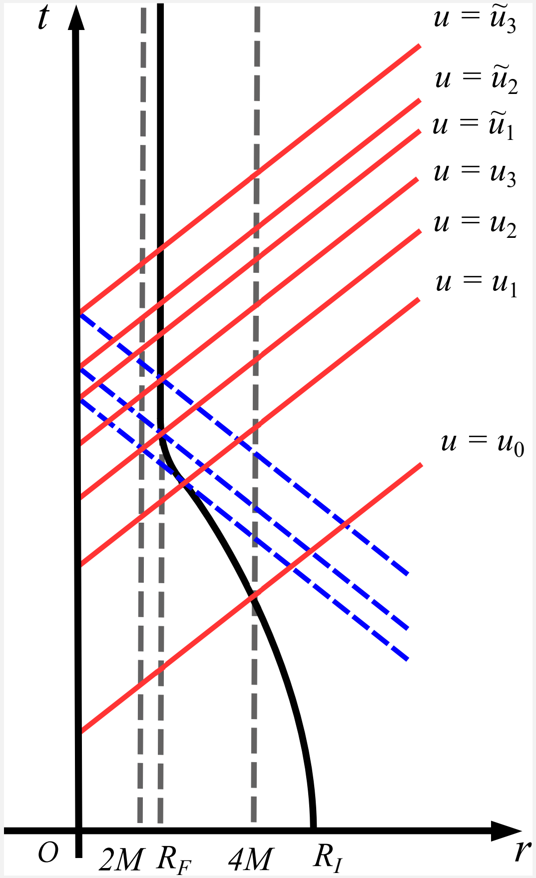
$R_B - R_F = 2M\epsilon^{2\beta}$



Time intervals

$$R_B - R_F = 2M\epsilon^{2\beta}$$

$$u \simeq \begin{cases} \dfrac{\tau}{\sqrt{F(R_I)}} + \text{const.} & (u < u_0) \\ -4M \ln\left[\dfrac{R}{2M} - 1\right] - 2R + \text{const.} & (u_0 < u < u_2) \\ \displaystyle\int \dfrac{d\tau}{\sqrt{F(R)}} + \text{const.} & (u_2 < u < u_3) \\ \dfrac{\tau}{\epsilon} + \text{const.} & (u_3 < u) \end{cases} .$$



$$u_1 - u_0 \simeq \begin{cases} 4M\beta \ln \epsilon^{-2} & (0 < \beta < 1) \\ 4M \ln \epsilon^{-2} & (1 \leq \beta) \end{cases}$$

$$\tilde{u}_2 - u_2 \simeq \frac{\tilde{\tau}_2 - \tau_2}{\epsilon}, \quad \tilde{u}_3 - u_3 \simeq \frac{\tilde{\tau}_3 - \tau_3}{\epsilon}. \quad \tilde{u}_i - \tilde{u}_j \simeq \frac{\tilde{\tau}_i - \tilde{\tau}_j}{\epsilon}.$$

- Time intervals are also mainly determined by the dynamics of the shell: ϵ and β.
- τ_i, and $\tilde{\tau}_j$ are a function of U and V → the coefficients of these time intervals have the information of the inside detail.

Conclusion

- Transient Hawking radiation, post Hawking burst, and late-time burst have a robust property in the sense that particle creation does not depend on the inside detail.

- Time intervals also does not depend on the inside matter.

- Even if a BH mimic is consisted of any matter, particle creation is the same under the condition: $\left|\frac{\ddot{U}_{out}}{\dot{U}_{out}}\right| < \left|\frac{\ddot{u}_{out}}{\dot{u}_{out}}\right|$ and $\left|\frac{\ddot{V}_{in}}{\dot{V}_{in}}\right| < \left|\frac{\ddot{v}_{in}}{\dot{v}_{in}}\right|$.

Future works

- A more complicated shell model
  to deeply understand the condition $\left|\frac{\ddot{U}_{out}}{\dot{U}_{out}}\right| < \left|\frac{\ddot{u}_{out}}{\dot{u}_{out}}\right|$ and $\left|\frac{\ddot{V}_{in}}{\dot{V}_{in}}\right| < \left|\frac{\ddot{v}_{in}}{\dot{v}_{in}}\right|$.

- Including back reaction