UV Dispersive Effects on Hawking Radiation

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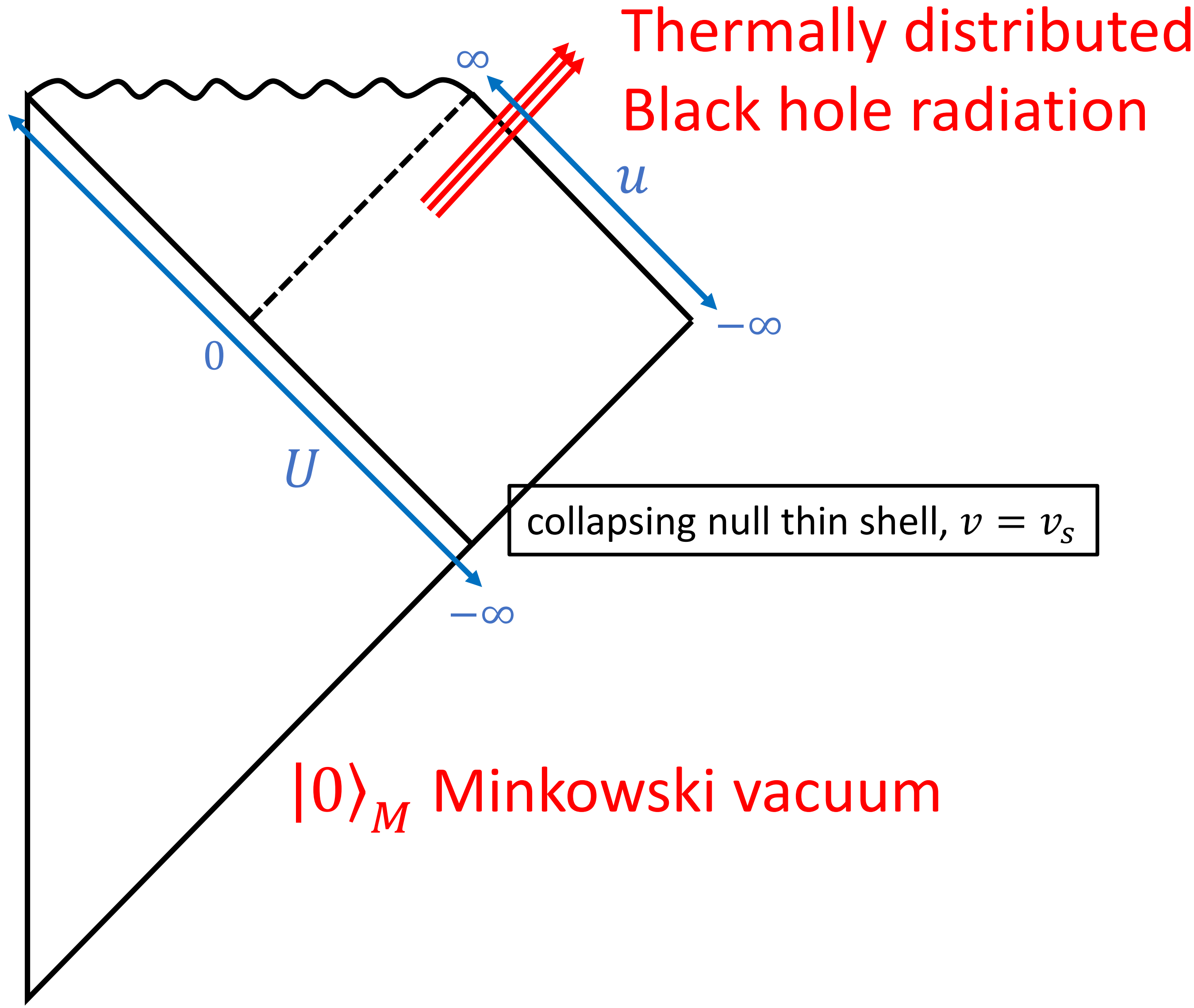
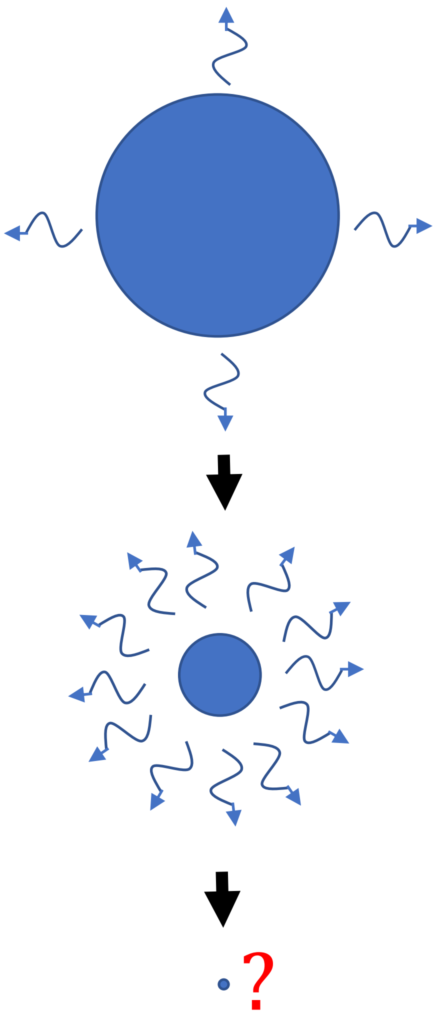
KEK Theory Workshop 2023

Hawking Radiation



Information loss paradox

a=2GM: Schwarzschild radius



Thermal distribution $N_\omega(u \gg a) \approx \frac{1}{e^{\omega/T}-1}$
with temperature $\mathrm{T} = 1/4\pi a.$
(Black holes No Hair Theorem)

↓

Black hole evaporation
but without information being carried out

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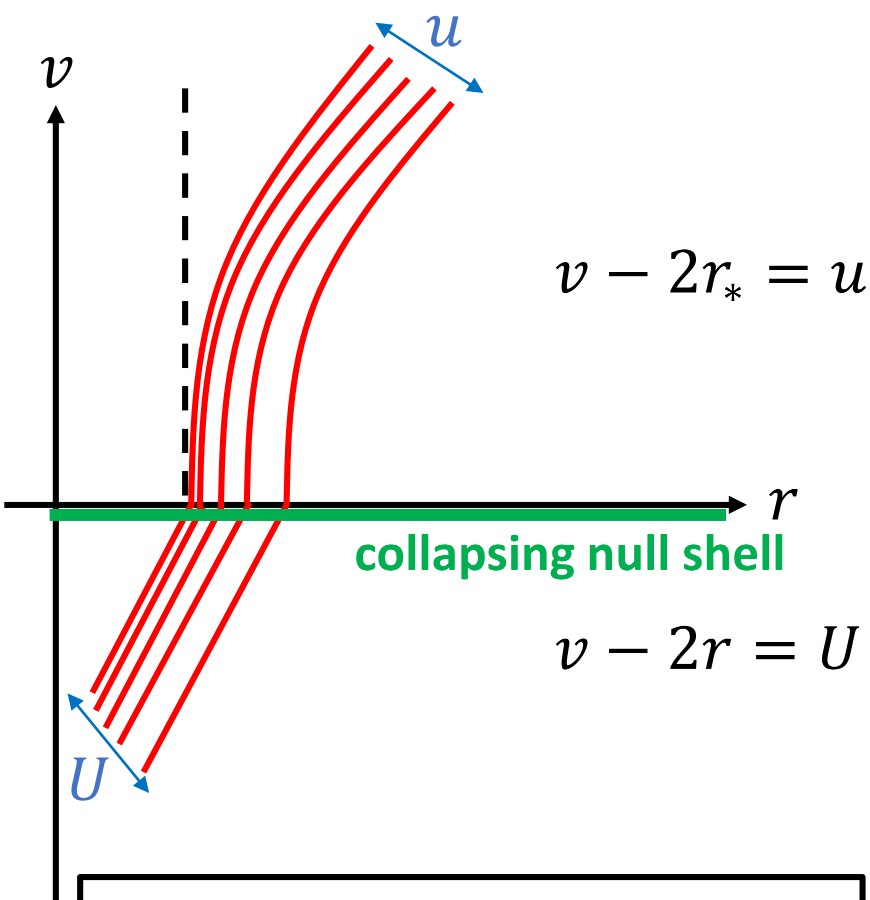
Information of the collapsing matter lost

Black hole life time$\sim O(a^3/L_P^2)$

Trans-Planckian Problem(1/2)



$$ds^2 = -\left(1 - \Theta(v - v_{\mathrm{s}})\frac{a}{r}\right) dv^2 + 2dvdr$$

After scrambling time $u \sim O(a \ln(a/L_P))$, Hawking particle reaches the shell with trans-Planckian energy.

↓

Since UV physics comes into play, Hawking Radiation may not be a valid prediction.

Trans-Planckian Problem(2/2)

However, people found that Hawking Radiation(temperature) is quite insensitive to UV physics.(e.g. renormalizable interaction, modified dispersion relation, GUP…)

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Hawking Radiation is not a probe of UV physics.
Information loss paradox persists.

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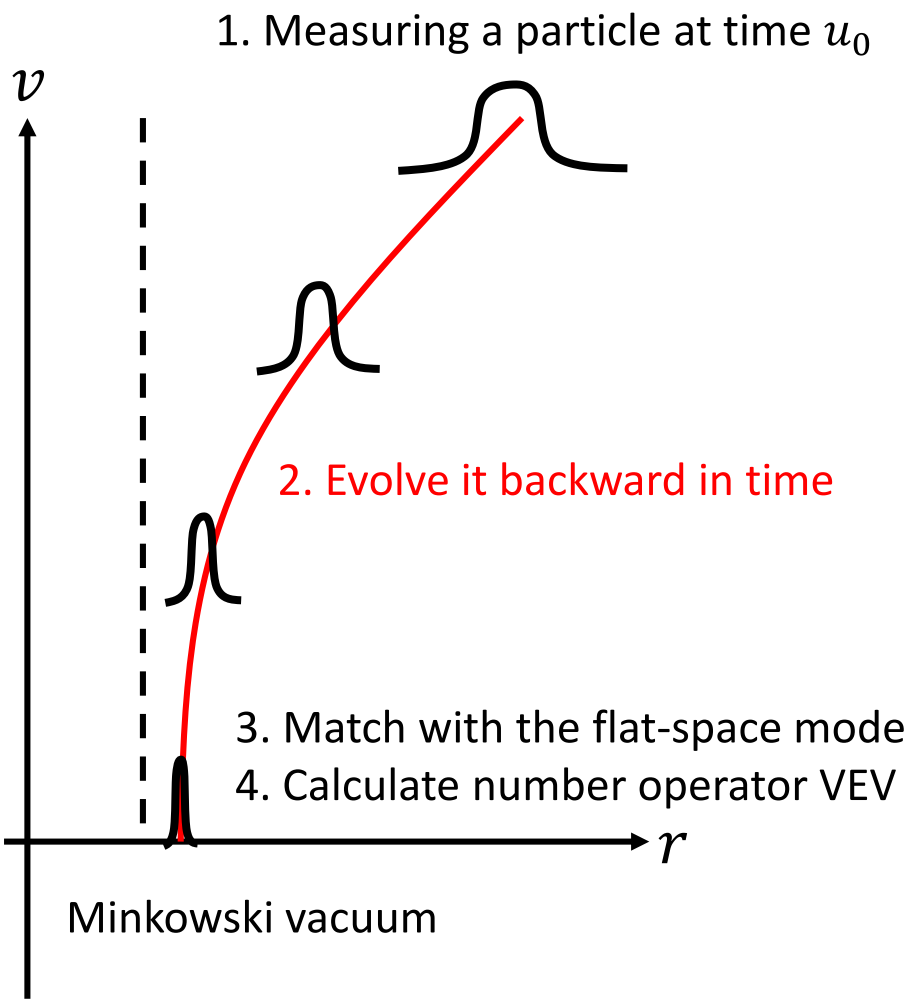
Recently, Prof. Ho ,Kawai-san and Yokokura-san discovered that considering non-renormalizable interactions, Hawking radiation encounters order one corrections after the scrambling time.

Linear Dispersion(1/2)



When tracing Hawking particles backwards, they follow geometric optics approximation and pile up in front of the horizon.

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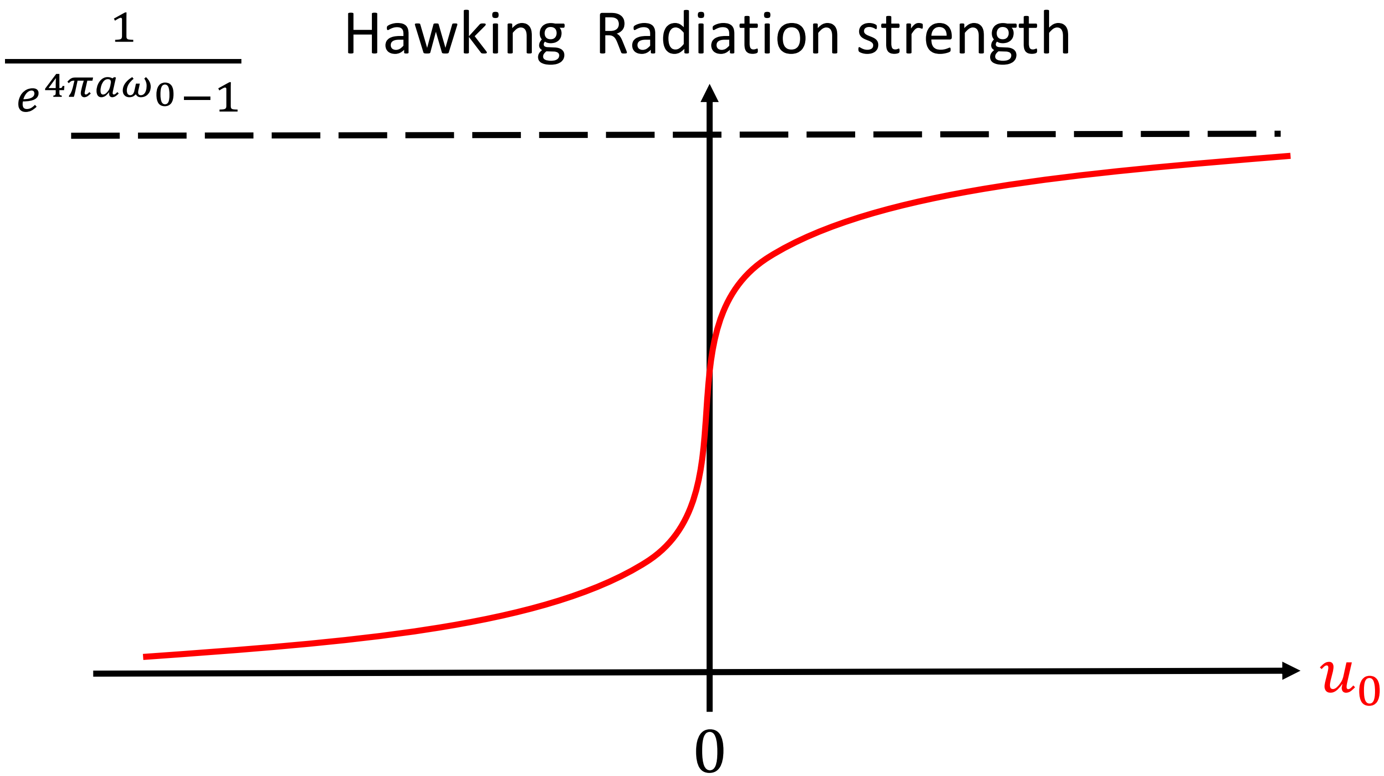
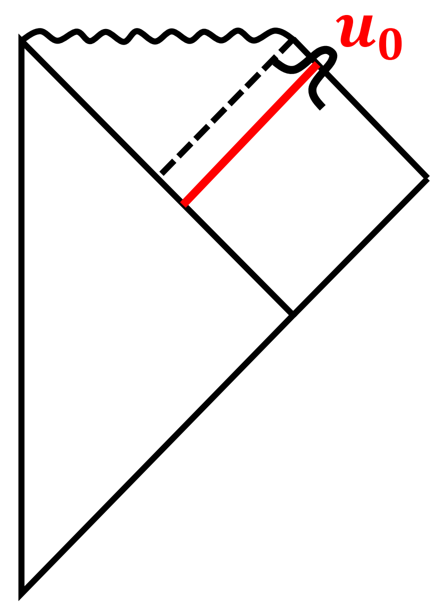
The distortion of the wavepacket leads to the positive and negative frequency mixing.

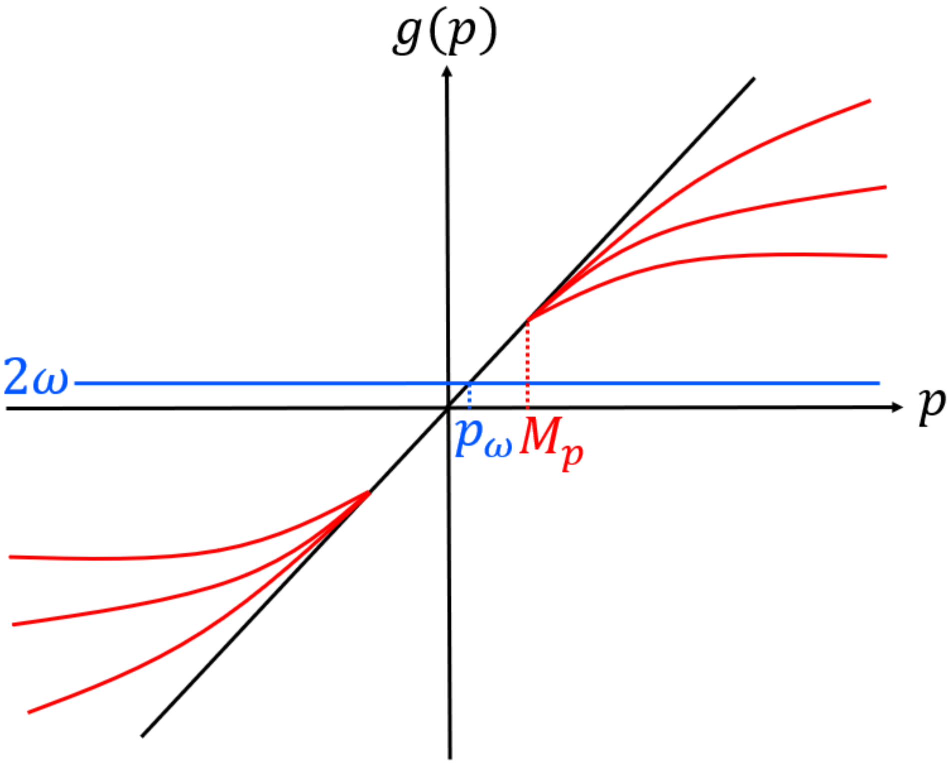
Linear Dispersion(1/2)





Monotonic Dispersion(1/2)

$\omega = p/2$ → $\omega = g(p)/2$



One possible UV feature is the breakdown of Lorentz symmetry at high energy such that the dispersion is no longer linear.

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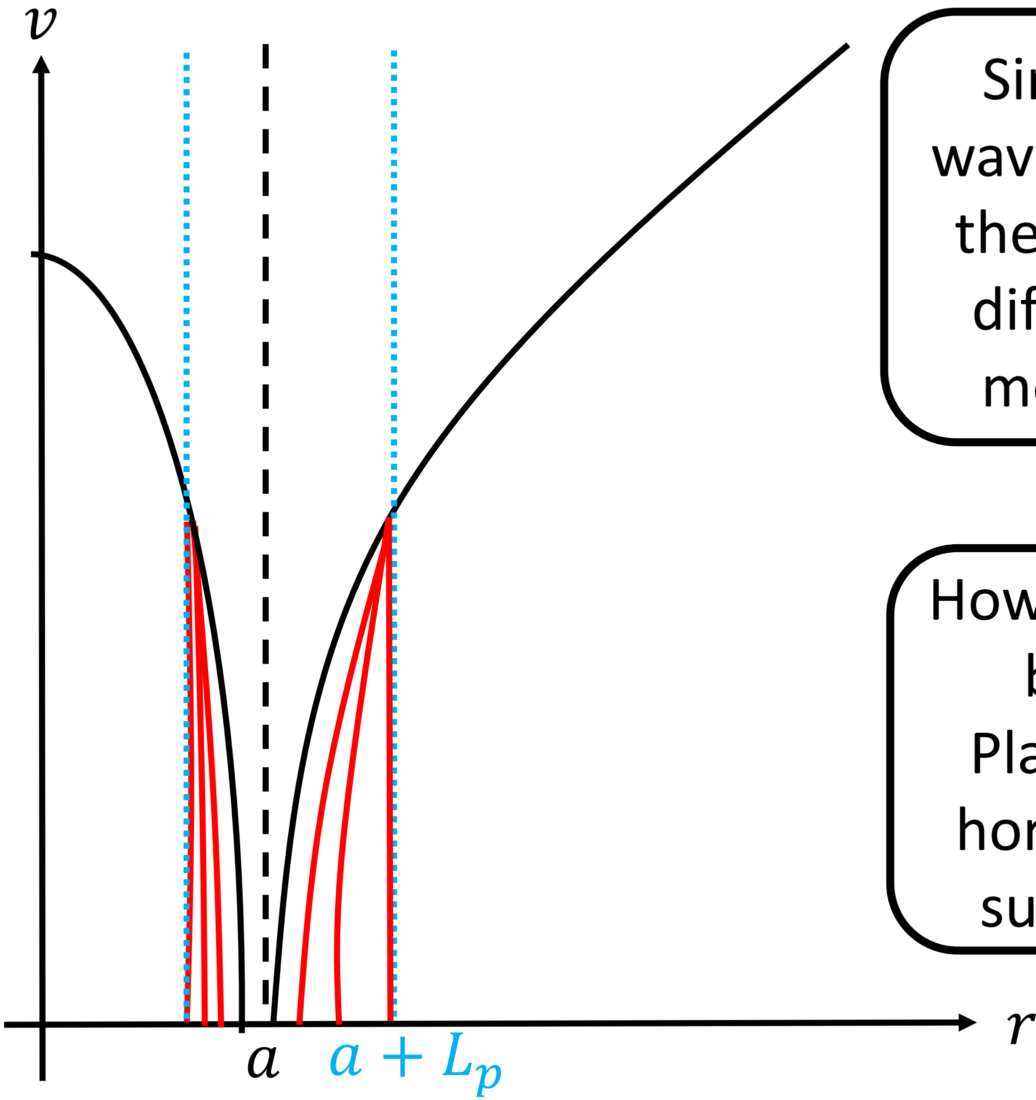
Hawking particles after the scrambling time approach the horizon with slower rate or event stop in front of it.

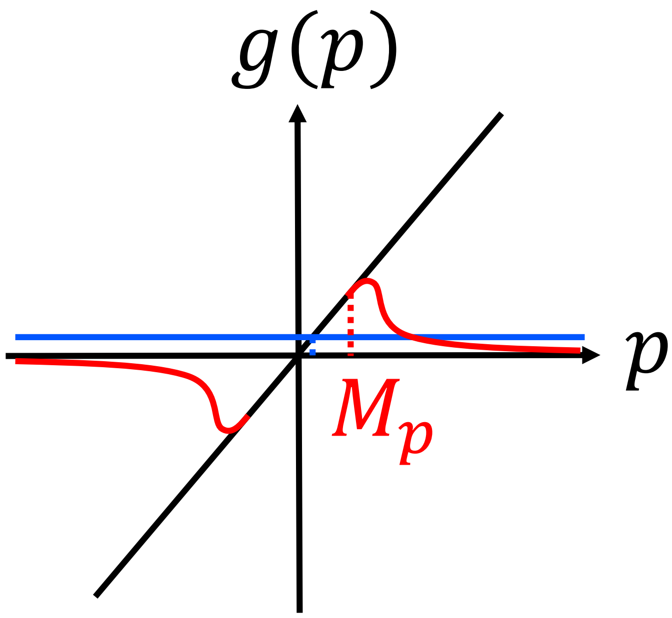
Monotonic Dispersion(1/2)

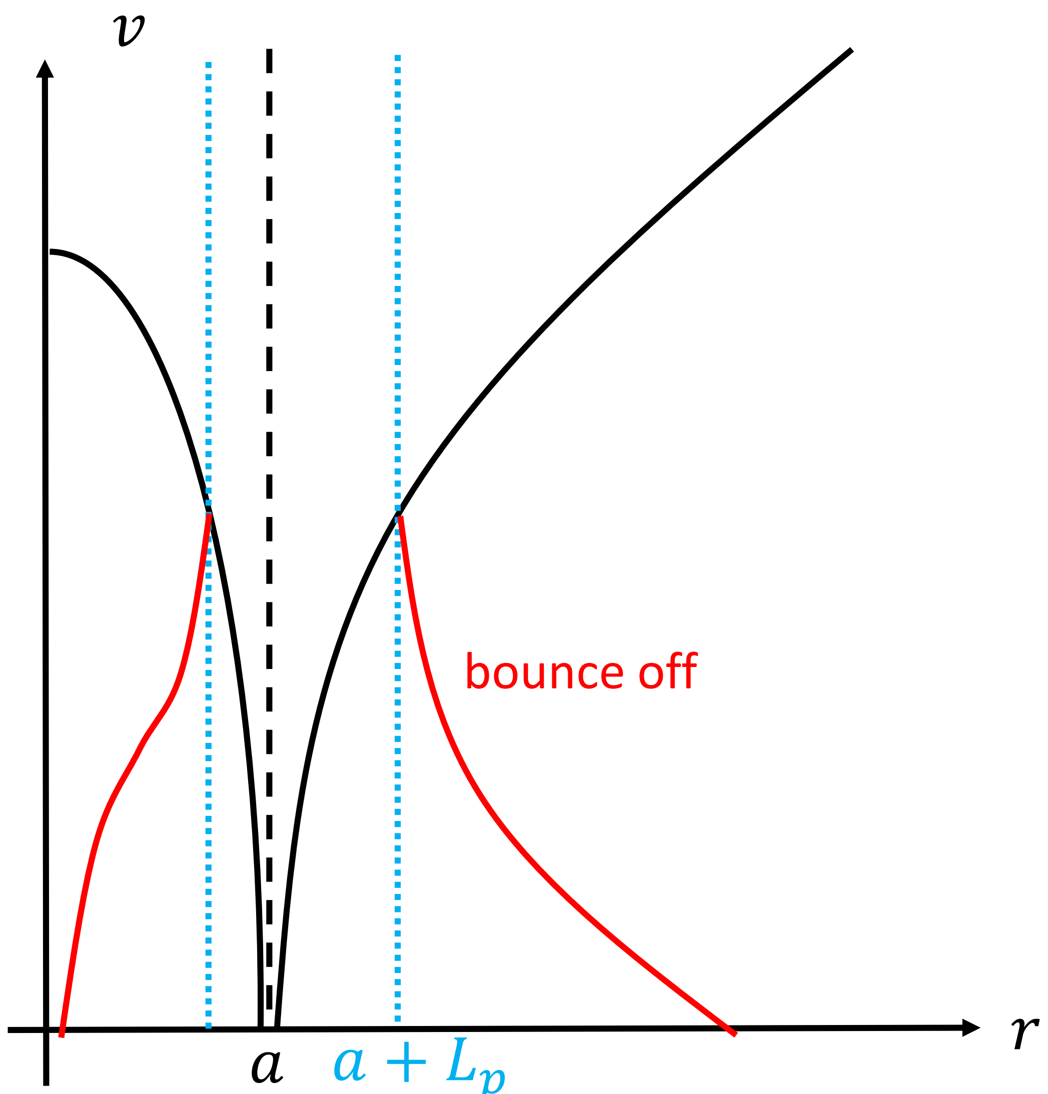


Since this distortion of the wavpeacket is already there in the near horizon region. The different trajectory doesn't modify Hawking radiation.

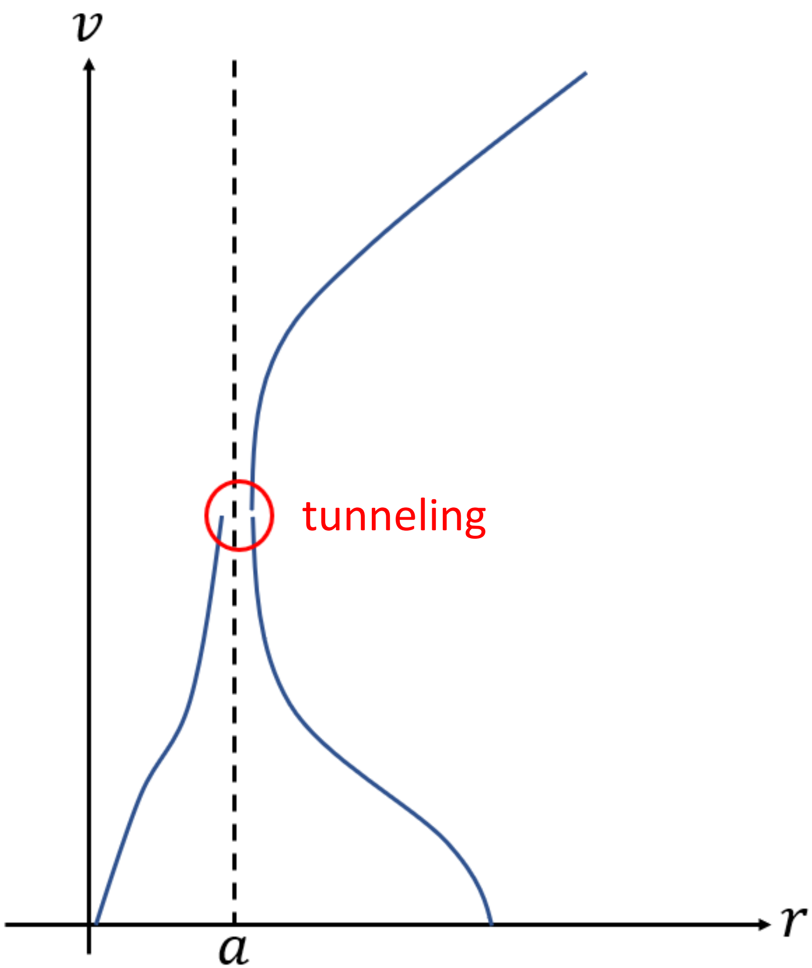
However, The geometric optics breaks down within the Planckian distance from the horizon. The wavepacket has support inside the horizon.

Non-monotonic Dispersion(1/4)





Non-monotonic Dispersion(2/4)



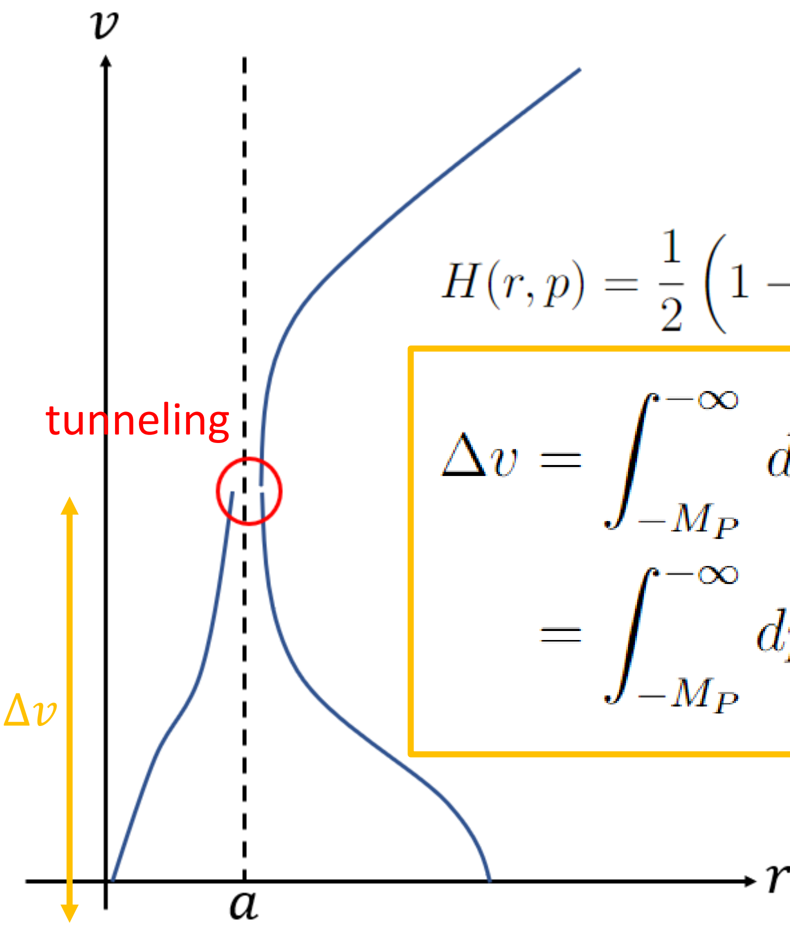
The non-monotonic dispersion leads Hawking particle bounce off from the horizon.

The non-locality and bounce-off together make Hawking particle tunneling across the horizon.

After the tunneling, Hawking particle approaches the blackhole singularity.

Non-monotonic Dispersion(3/4)

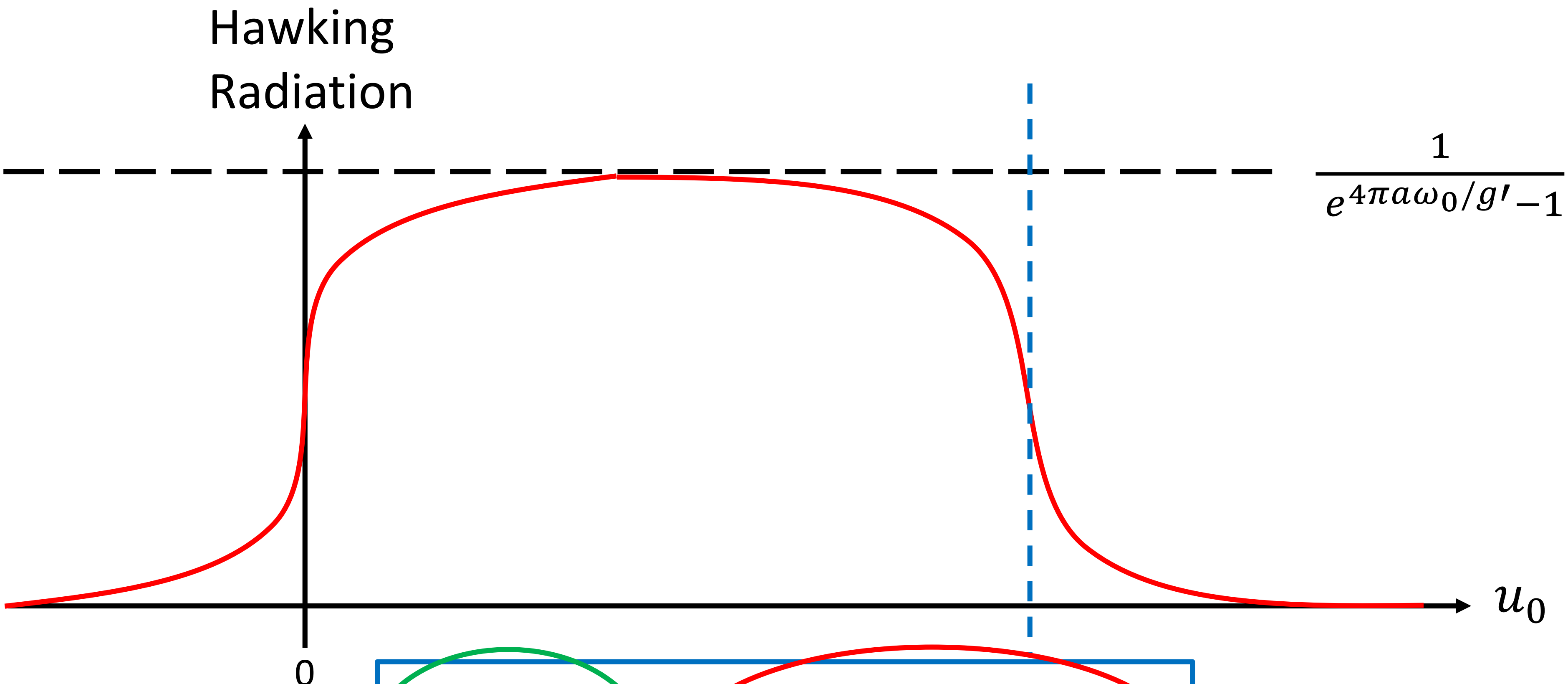
If $g(p)$ decays faster than $O(1/p)$,
Δv is finite and Hawking particle hits the singularity in finite time.
Hawking radiation is then turned off.



$$H(r,p) = \frac{1}{2}\left(1 - \frac{a}{r}\right) g(p) = \omega.$$

$$\Delta v = \int_{-M_P}^{-\infty} dp \, \frac{dv}{dp} = \int_{-M_P}^{-\infty} dp \, \frac{g(p)}{[2\omega - g(p)]^2}$$

Non-monotonic Dispersion(4/4)



scrambling time

$$2a\ln\left(\frac{M_p}{2\omega_0}\right)+2a\int_{-M_p}^{-\infty}dp\,\frac{g(p)}{[2\omega_0-g(p)]^2}$$

UV sensitivity!

Summary

- Hawking radiation is found to be turned off after the scrambling time if the dispersion decays faster than $O(1/\text{p})$.
- The turned-off time depends on the details of dispersion relation: how long it takes for Hawking particle to hit the singularity.
- Hawking radiation after that depends on the boundary condition at the singularity.
- Trans-Planckian problem is still there, the information loss paradox of low energy effective theory is dismissed.

Thank You