Horizontal Charge Excitation of Supertranslation and Superrotation

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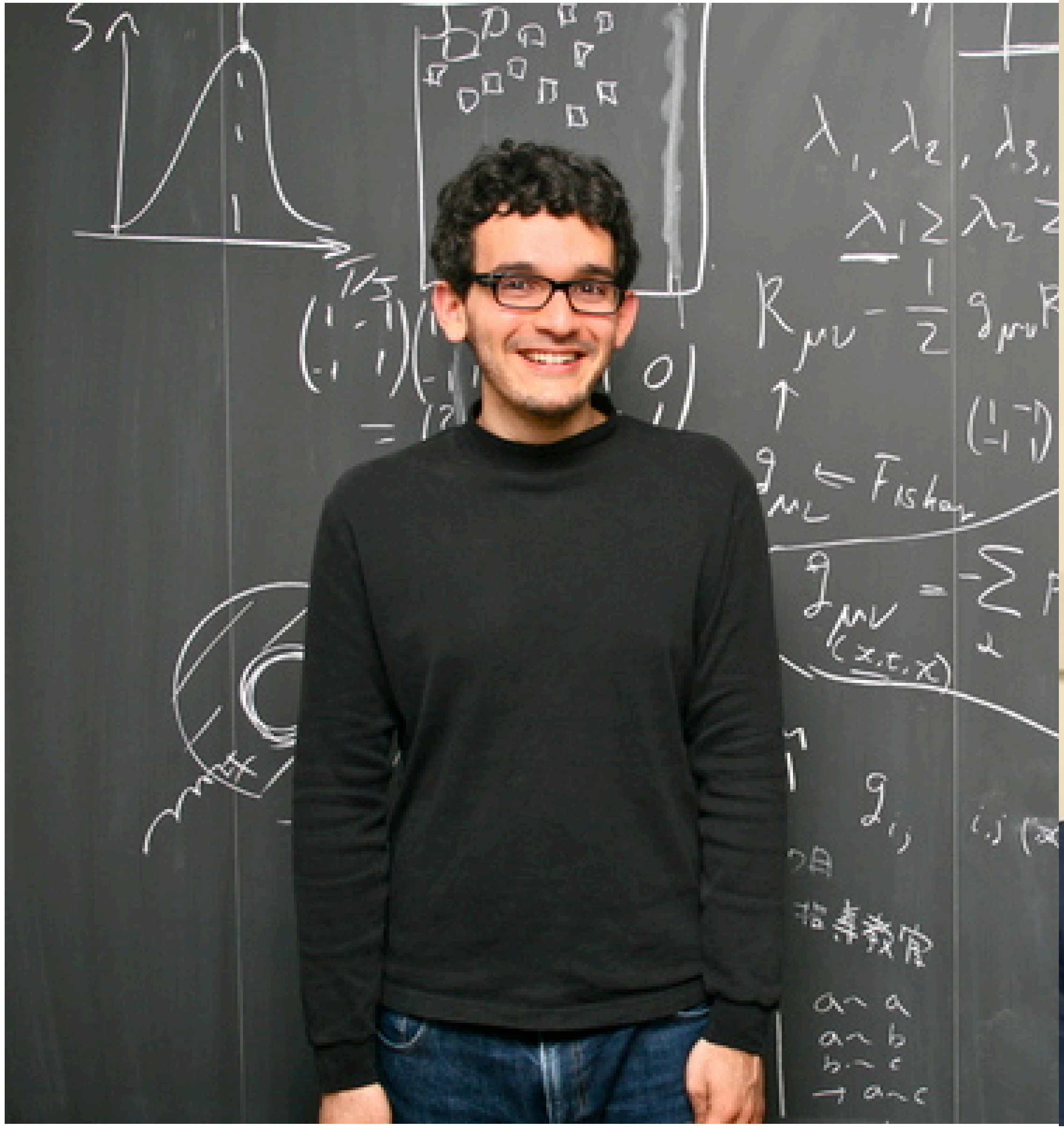
Based on

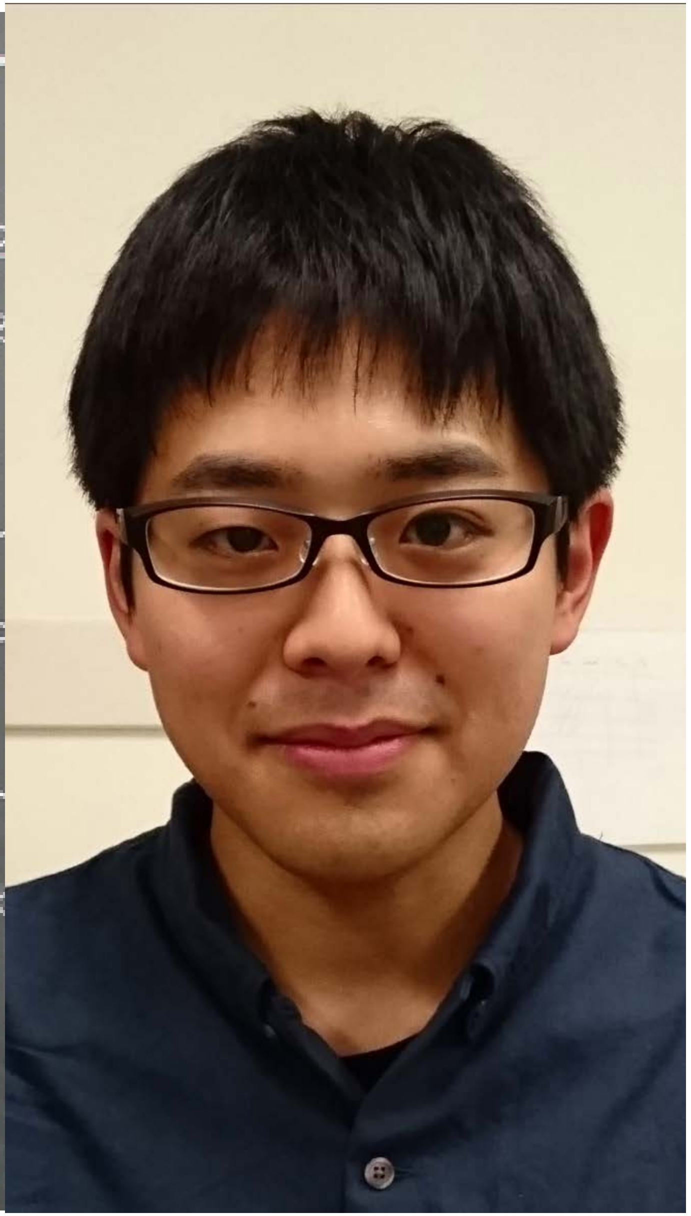
M. Hotta, J. Trevison and K. Yamaguchi arXiv:1606.02443.

M. Hotta, K. Sasaki and T. Sasaki, Class. Quantum Grav. 18, 1823 (2001).

M. Hotta, Phys. Rev. D 66, 124021 (2002).



Jose Trevison



Koji Yamaguchi

Introduction

Two Big Problems in Black Hole Physics

○ **Black Hole Information Loss Problem**

Is the process of black hole formation and evaporation unitary?

○ **Black Hole Entropy Problem**

What is the spacetime origin of statistical mechanical black hole entropy $A/(4G)$? Where do the quantum states live in the spacetime?

Hawking, Perry and Strominger (HPS) proposed a symmetry-based conjecture of simultaneous resolution of the information loss problem and the black hole entropy problem, using supertranslation and superrotation on a black hole horizon, and BMS gravitational degeneracy of vacuum states at the null future infinity.

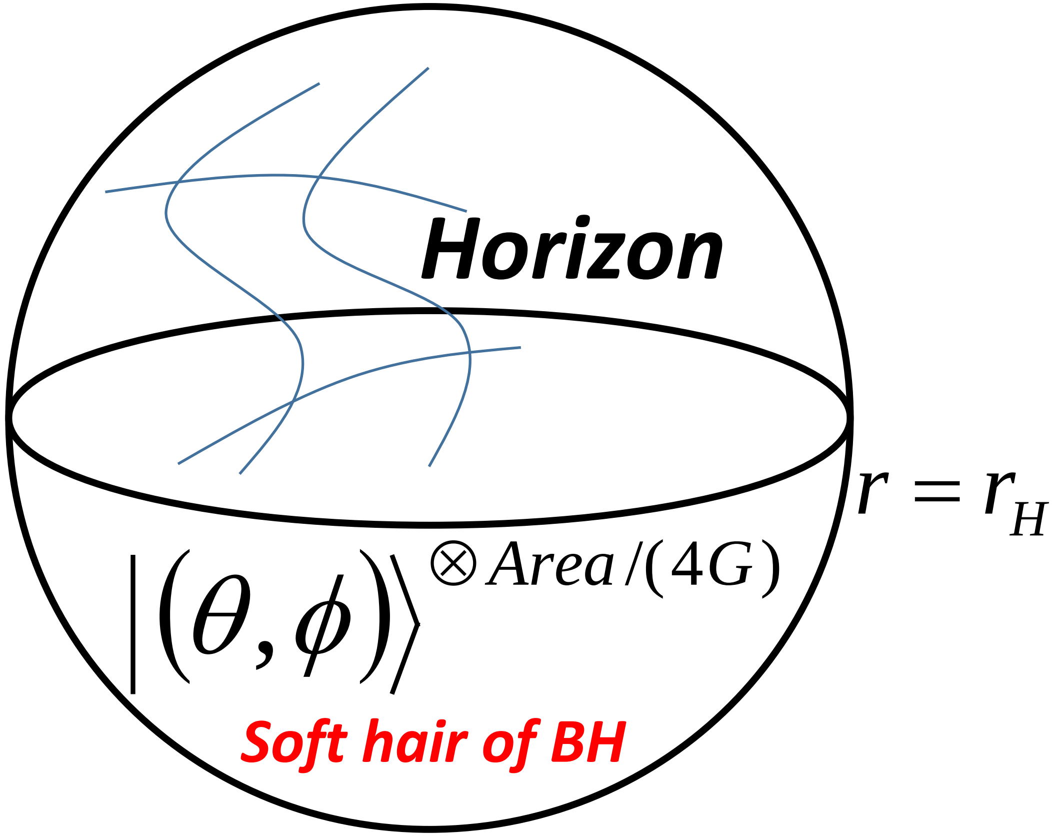
S. W. Hawking, "The Information Paradox for Black Holes", arXiv:1509.01147.
S. W. Hawking, M. J. Perry and A. Strominger, "Soft Hair on Black Holes", arXiv:1601.00921.

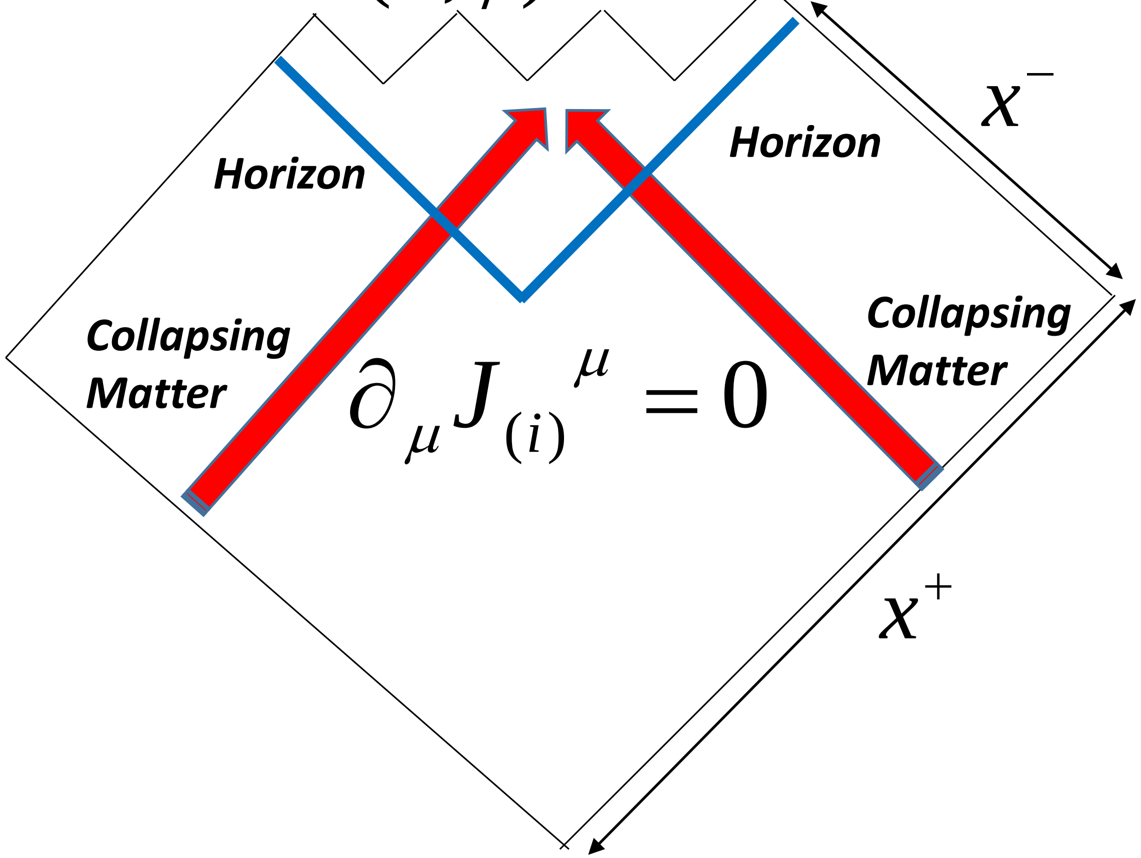
Near-Horizon Asymptotic Metric of HPS

$$ds^2 = 2dx^+ dr + \sum_{\theta,\phi} g_{AB} dx^A dx^B + O(r - r_H)$$

$$\delta x^+ = T(\theta,\phi) + \cdots$$ ← **Supertranslation**

$$\delta x^A = R^A(\theta,\phi) + \cdots$$ ← **Superrotation**





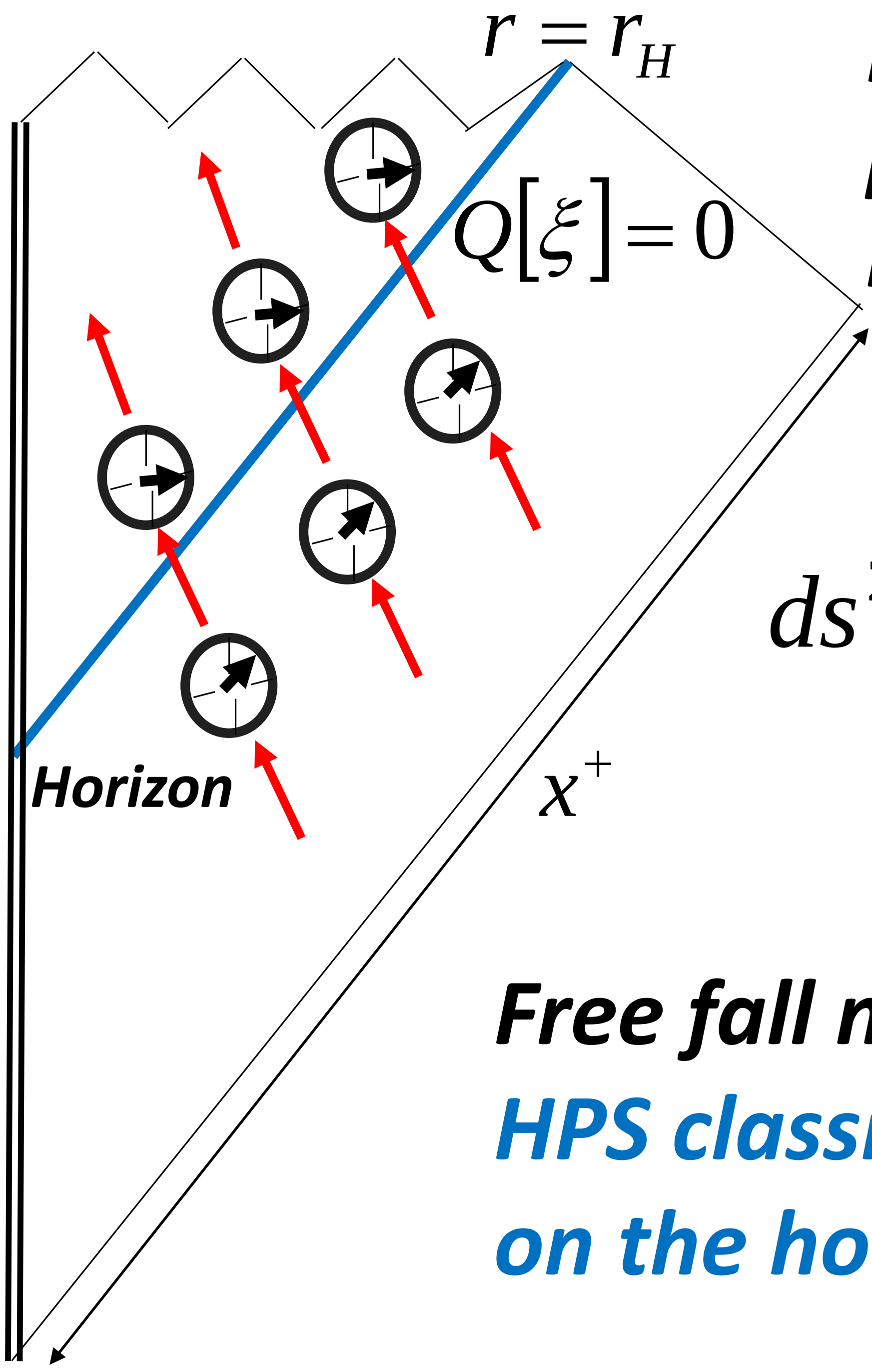
$$\ln W_{soft\ hair} \approx Area/(4G)$$

An infinite number of holographic charges on the horizon store whole quantum information of absorbed matter.

⇒ **Unitarity**

HPS said,
"Stationary black holes do not carry classical supertranslation hair." **(arXiv:1601.00921)**

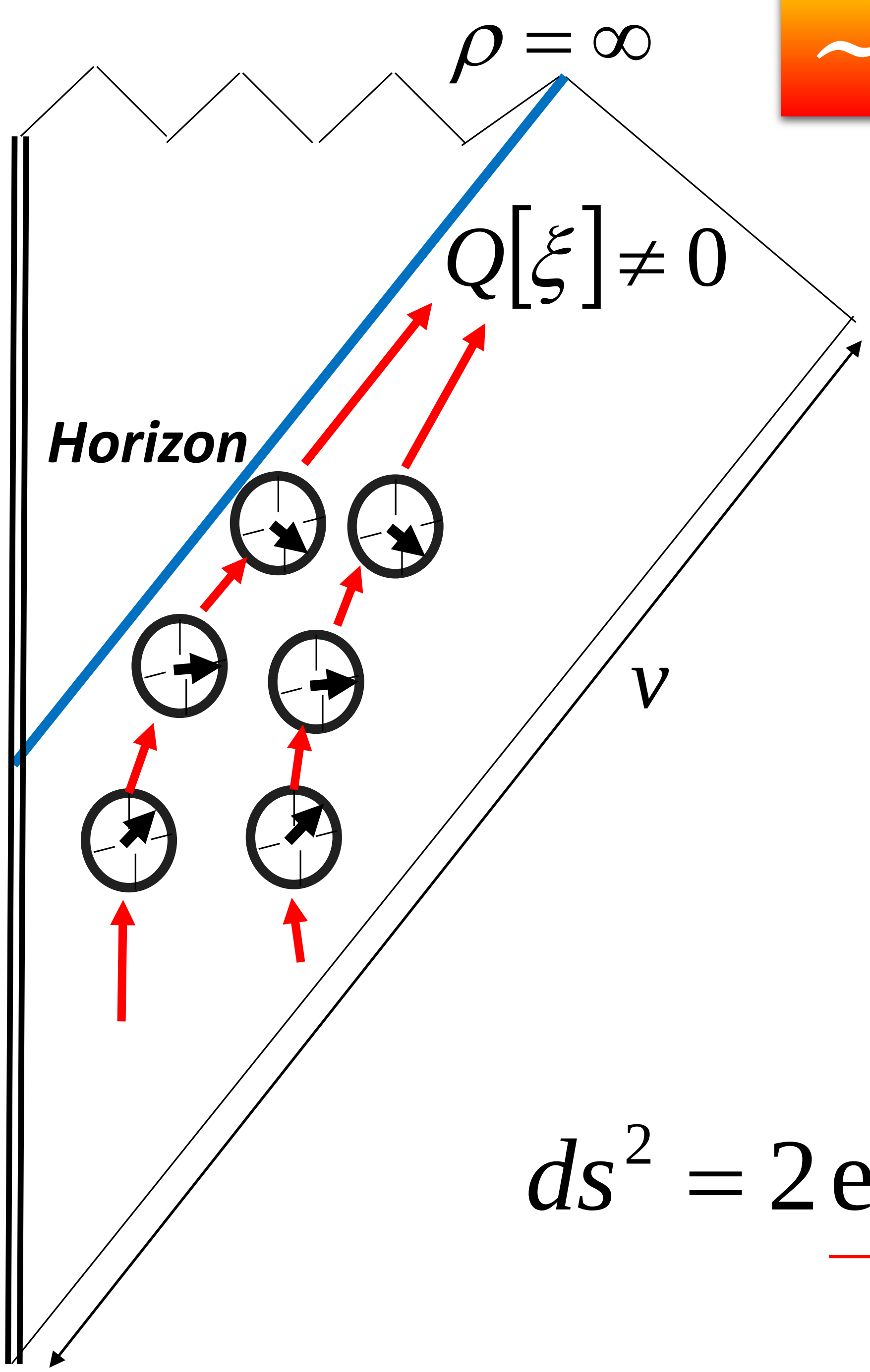
So they consider purely quantum supertranslation hair on the horizon with reluctance.



HPS coordinate system near horizon is physically implemented by free-falling block-numbered clocks distributed in the space.

$$ds^2 = 2dx^+dr + \sum_{\theta,\phi} g_{AB} dx^A dx^B + O(r - r_H)$$

Free fall motion of the clocks makes HPS classical supertranslation charge vanish on the horizon due to the equivalence principle.



~MASSAGE (I) of THIS TALK~

In a Rindler-type coordinate system implemented by accelerating block-numbered clocks distributed in the space, stationary black holes indeed carry non-vanishing classical charges of supertranslation and superrotation.

【M. Hotta, K. Sasaki and T. Sasaki, Class. Quantum Grav. 18, 1823 (2001)】

Similarity to Unruh effect.

$$ds^2 = 2\underline{\exp(-\rho/\kappa)}dv d\rho + \sum_{\theta,\phi} g_{AB} dx^A dx^B + \cdots$$

Rindler factor

$$\left(\kappa = \sqrt{16\pi G}\right)$$

~MASSAGE (II) of THIS TALK~

Taking a large blackhole mass limit, near-horizon geometry of a black hole is described by Minkowski space, and the horizon is mapped into one of Rindler horizons.

【*M. Hotta, J. Trevison and K. Yamaguchi arXiv:1606.02443* 】

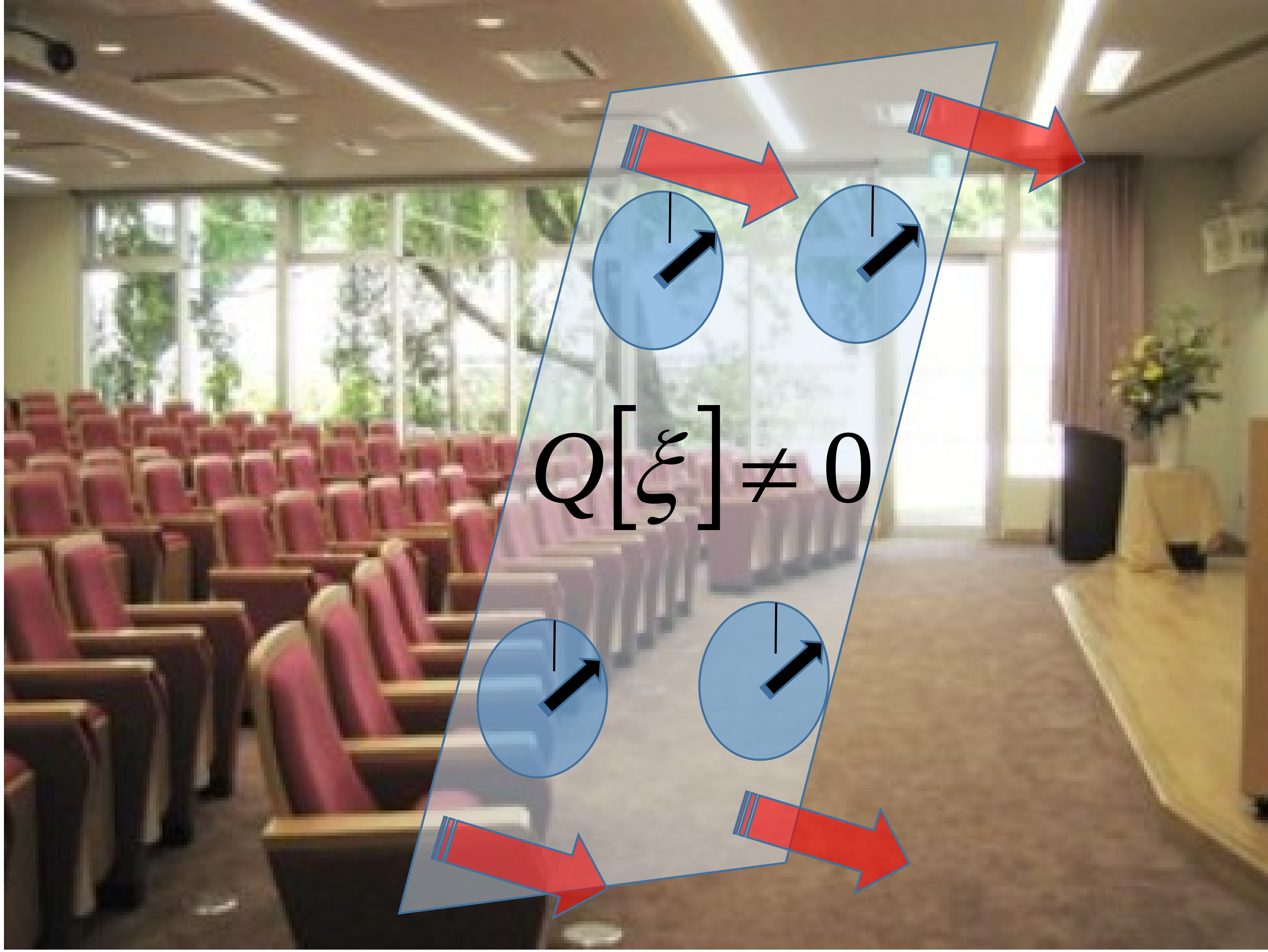
We construct a general theory of gravitational holographic charges on Rindler horizons for a 1+3 dimensional linearized gravity field in the Minkowski background. Especially, we give a general formula of holographic charge shift of supertranslation and superrotation induced by infalling matter absorption. Gravitational wave absorption cannot make transition between different charged states.

~MASSAGE (III) of THIS TALK~

By using quantum gravitational memory charges, we claim that the holographic pixel on every Rindler horizon is an emergent concept, which is subjective to quantum measurement contexuality. The no-cloning paradox of quantum information between matter inside of the horizon and holographic charges on the horizon may not arise.

【*M. Hotta, J. Trevison and K. Yamaguchi arXiv:1606.02443* 】

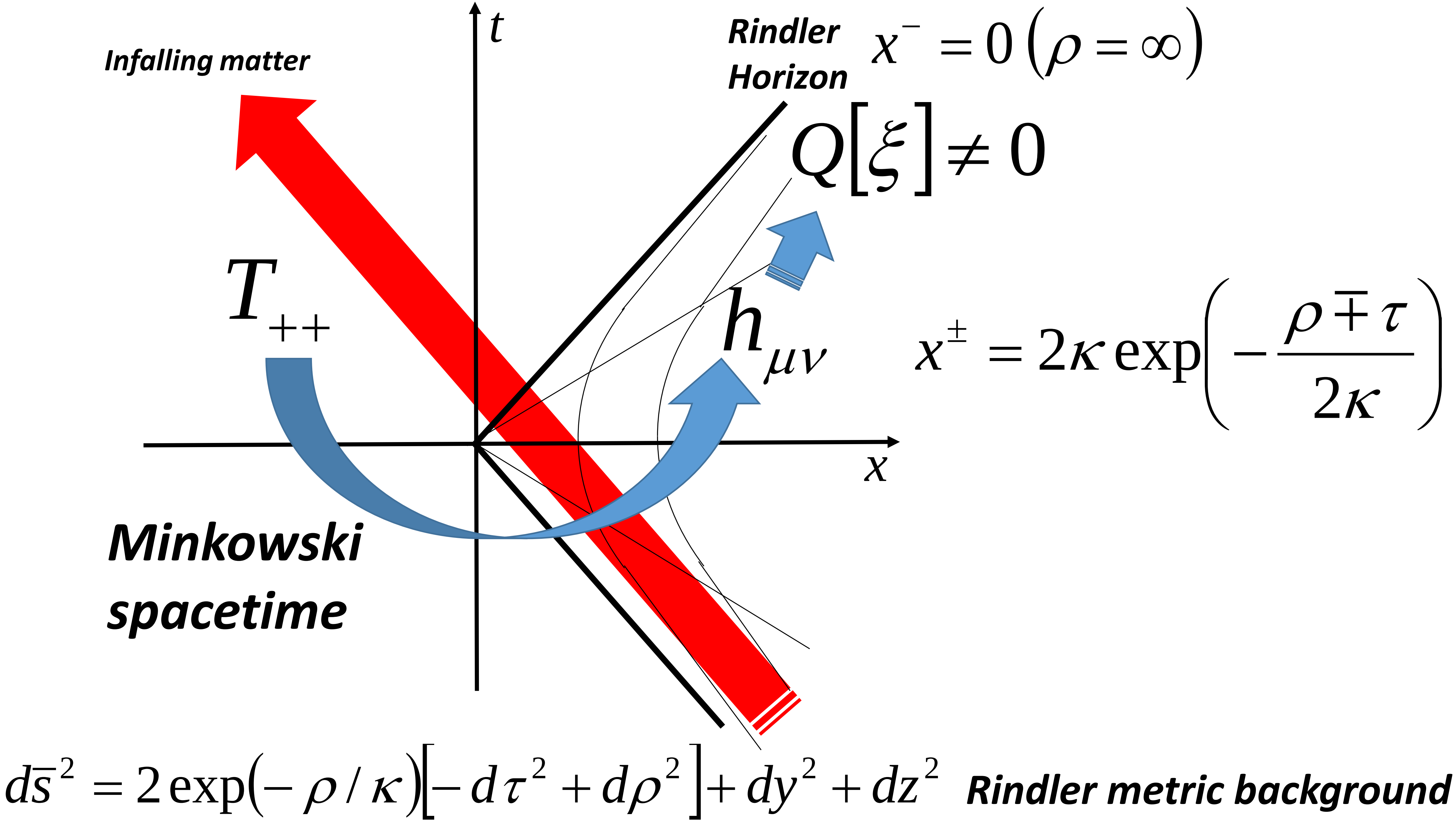
Accelerating clocks as a metric detector observe BH soft hair in this room, as well as Hawking-Unruh thermal bath!



Non-ontological holographic screen

Main Results

【*M. Hotta, J. Trevison and K. Yamaguchi arXiv:1606.02443* 】


Infalling matter
t
Rindler Horizon
$x^- = 0\,(\rho = \infty)$
$Q[\xi] \neq 0$
T_{++}
$h_{\mu\nu}$
$x^{\pm} = 2\kappa \exp\left(-\frac{\rho \mp \tau}{2\kappa}\right)$
x
Minkowski spacetime
$d\bar{s}^2 = 2\exp(-\rho/\kappa)\left[-d\tau^2 + d\rho^2\right] + dy^2 + dz^2$
Rindler metric background

Asymptotic symmetry near a horizon:

$$\delta_\xi \tau = \xi^\tau(y,z), \quad \delta_\xi \rho = 0, \quad \delta_\xi y = \xi^y(y,z), \quad \delta_\xi z = \xi^z(y,z).$$

Supertranslation Charge on Horizon

$$Q_{st}\left[\xi^\tau\right] = -\frac{1}{2\kappa}\int dydz\,\xi^\tau(y,z)\int_0^\infty x^+ T_{++}\left(x^+, x^- = 0, y, z\right)dx^+$$

Superrotation Charge on Horizon

$$\left(\kappa = \sqrt{16\pi G}\right)$$

$$Q_{sr}\left[\xi^y, \xi^z\right]$$

$$= \frac{1}{4\pi}\int dydz\int dy'dz'\xi^A(y,z)\partial_A \ln\left[\frac{(y-y')^2 + (z-z')^2}{\kappa^2}\right]$$

$$\times \int_0^\infty \partial_- T_{++}\left(x^+, x^- = 0, y', z'\right)dx^+$$

Cf: 't Hooft's blackhole S matrix

$$T_{++} = 0 \quad \Rightarrow \quad Q[\xi] = 0$$

Weak gravitational waves cannot make transitions between physical states with different charges. Horizon as a holographic screen does not store the information at all.

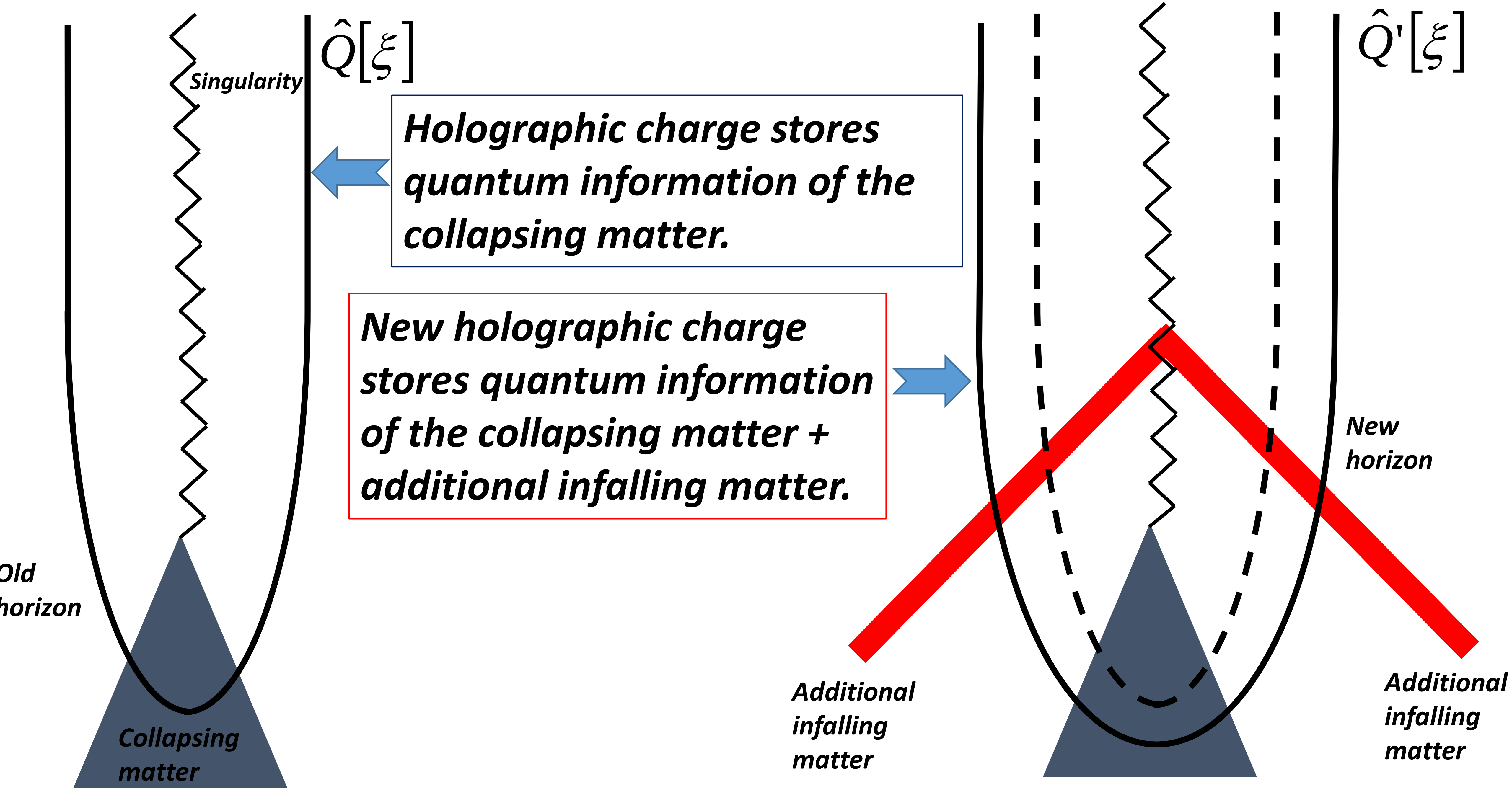
⇒ doubt of HPS resolution of the information loss problem.

→ The result is still consistent with the scenario of zero-point fluctuation partner of Hawking particle
for a resolution of the information loss problem.

(Wilczek 1992, Hotta-Schüzhold-Unruh 2015, Hotta-Sugita 2015)

About the No-Cloning Paradox

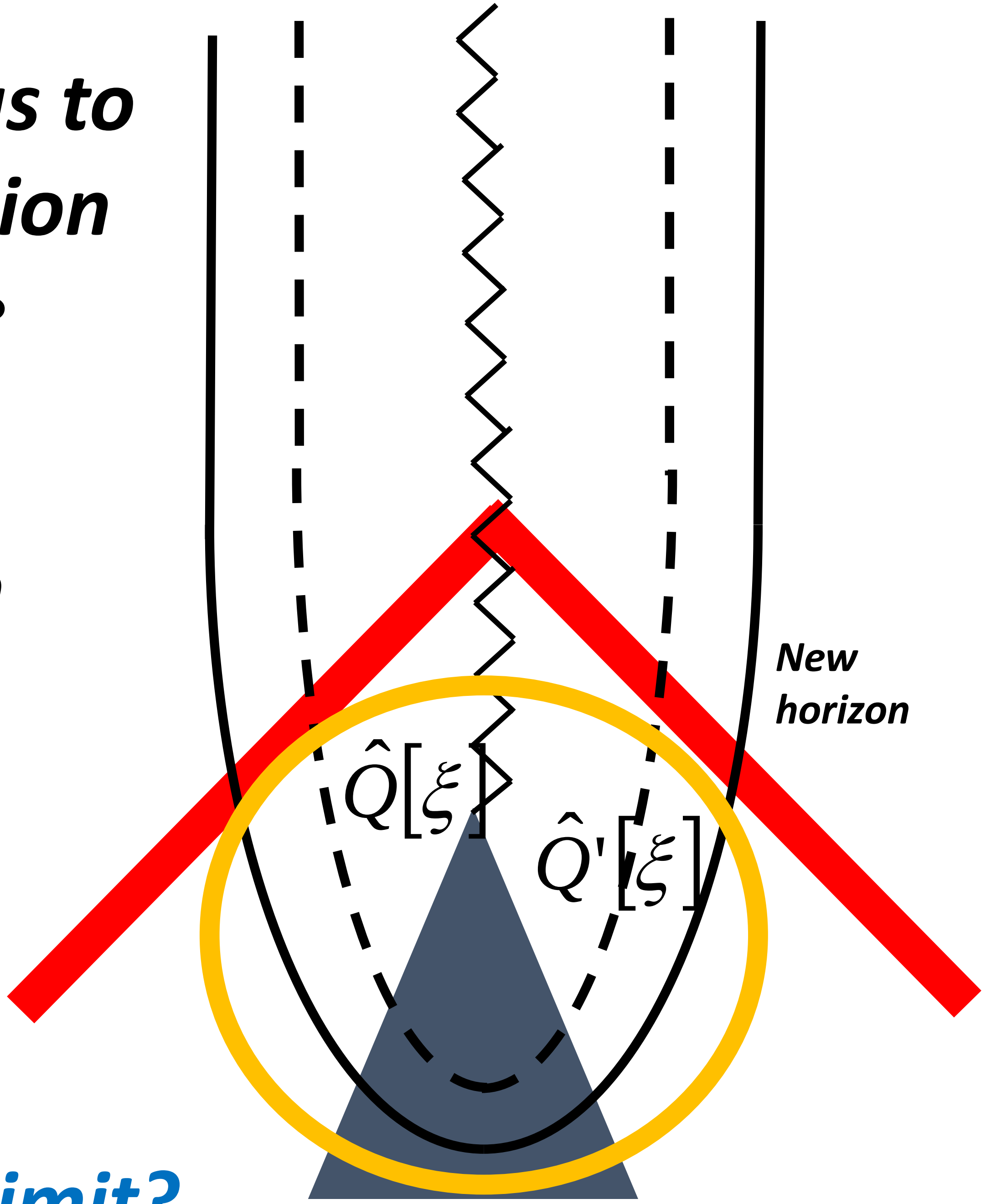
No-cloning paradox between two quantum gravitational memories



$\hat{Q}[\xi]$
Singularity
Holographic charge stores quantum information of the collapsing matter.
New holographic charge stores quantum information of the collapsing matter + additional infalling matter.
$\hat{Q}'[\xi]$
New horizon
Old horizon
Collapsing matter
Additional infalling matter
Additional infalling matter

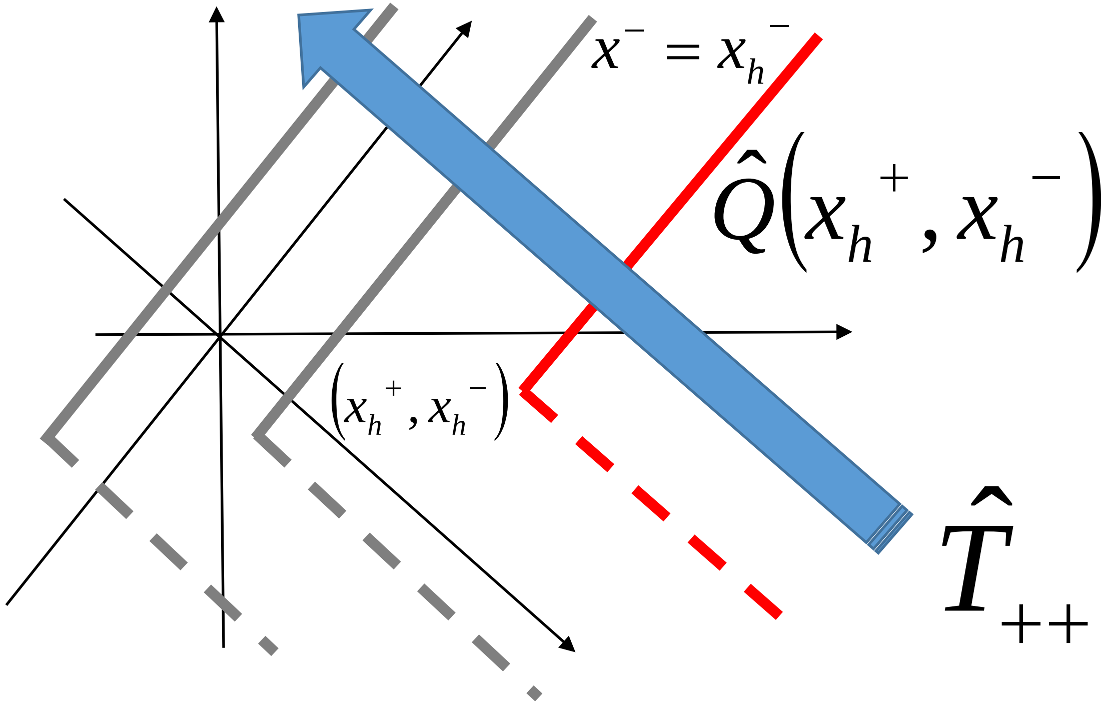
In HPS, new holographic charge has to store whole the quantum information of the collapsing matter before the additional matter comes in!

Duplicate quantum information on two different horizons.



No-cloning paradox between two gravitational memories even in large BH mass limit?

Resolution: Noncommutative Gravitational Memory Charges on Different Rindler Horizons



$$\left[\hat{Q}\left(x_h^+, x_h^-\right), \hat{Q}\left(x'^+_h, x'^-_h\right)\right] \neq 0$$

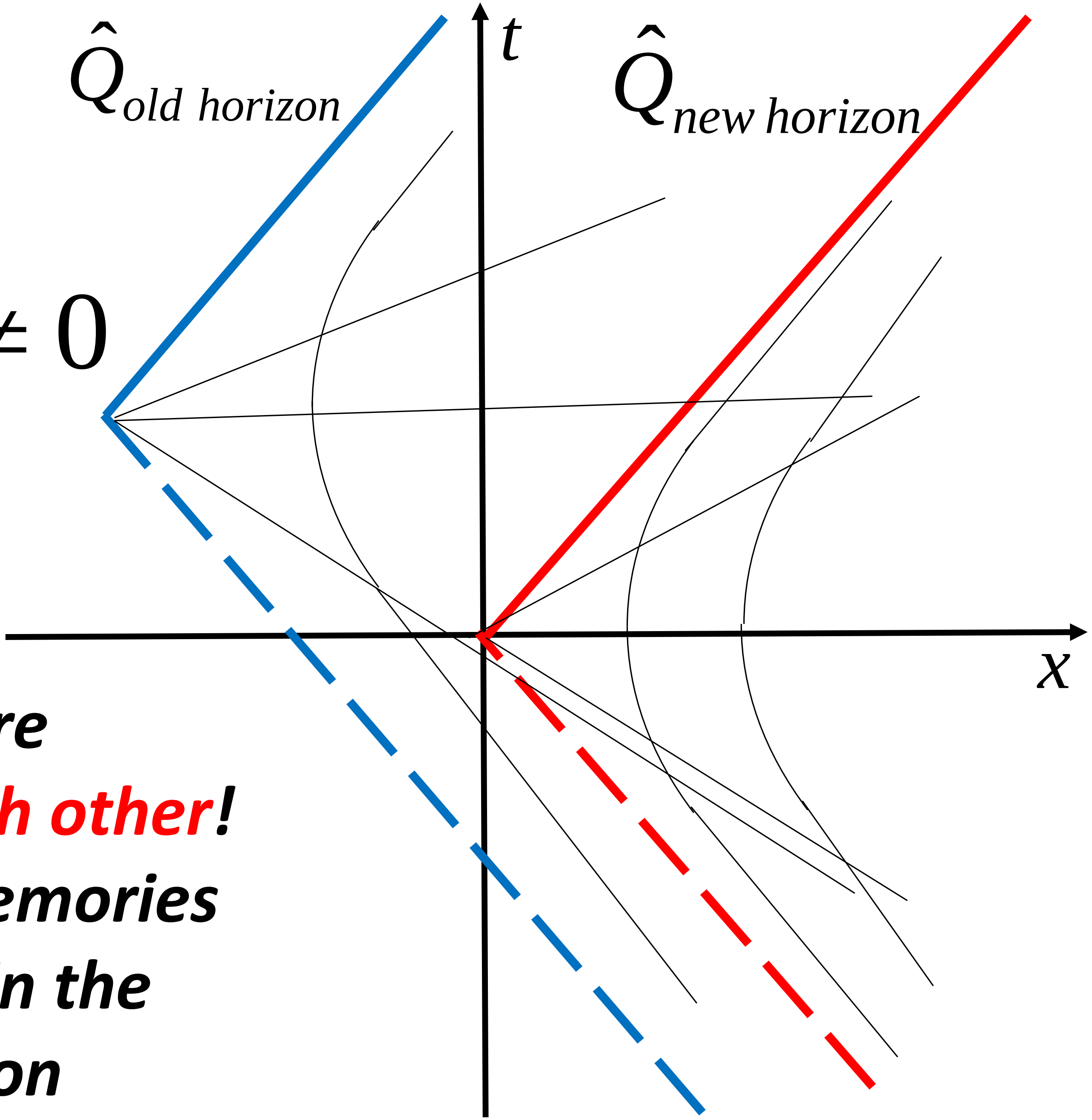
$$\hat{Q}\left(x_h^+, x_h^-\right)$$

$$= -\frac{1}{2\kappa}\int dydz\,\xi^\tau(y,z)\int_0^\infty\left(x^+ + x_h^+\right)\hat{T}_{++}\left(x^+ + x^+{}_h, x_h^-, y, z\right)dx^+$$

$$+\frac{1}{4\pi}\int dydz\int dy'\,dz'\,\xi^A(y,z)\partial_A \ln\left[\frac{(y-y')^2+(z-z')^2}{\kappa^2}\right]$$

$$\times\int_0^\infty \partial_- \hat{T}_{++}\left(x^+ + x^+{}_h, x_h^-, y', z'\right)dx^+$$

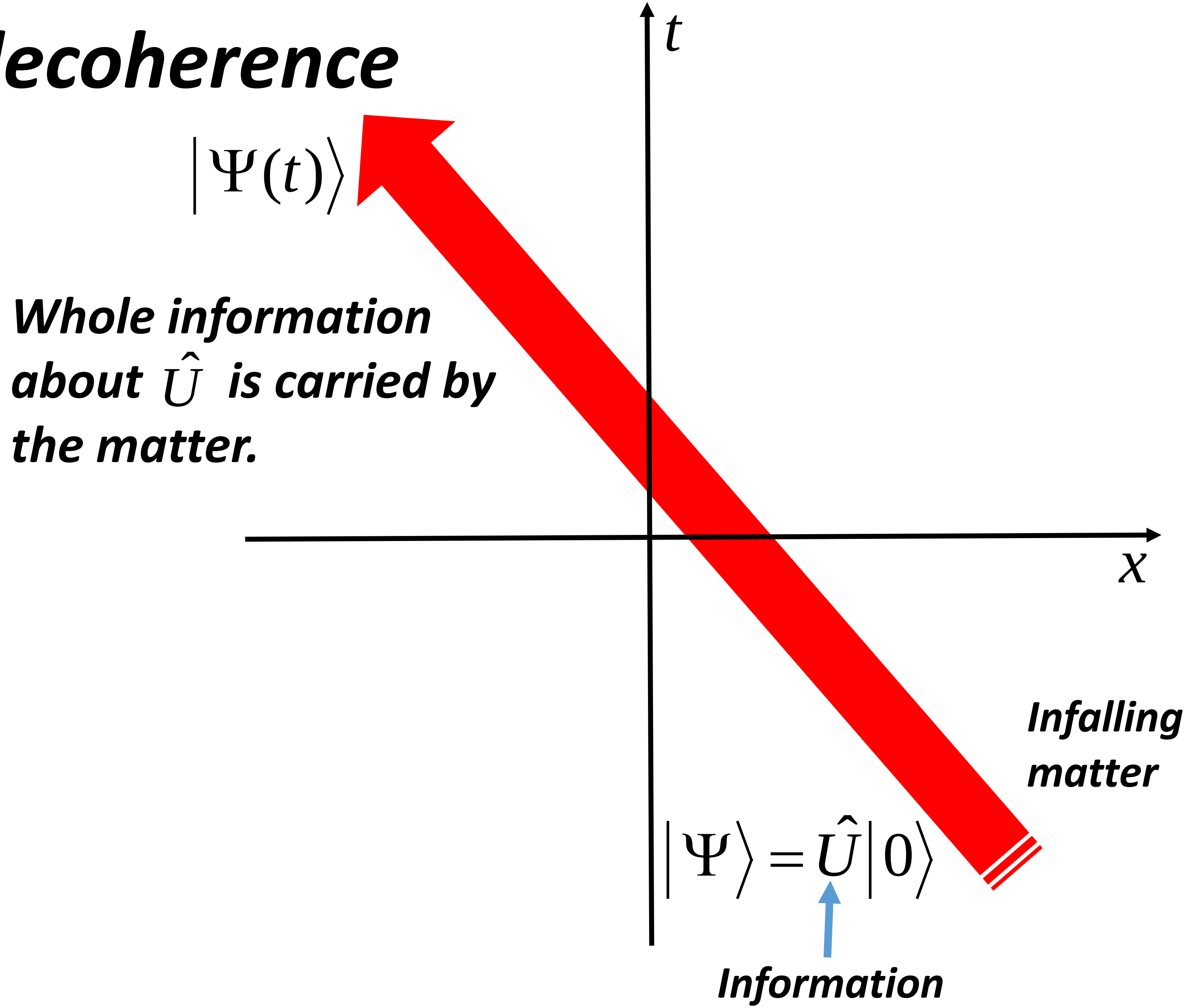
$$\left[\hat{Q}_{old\ horizon}, \hat{Q}_{new\ horizon}\right] \neq 0$$

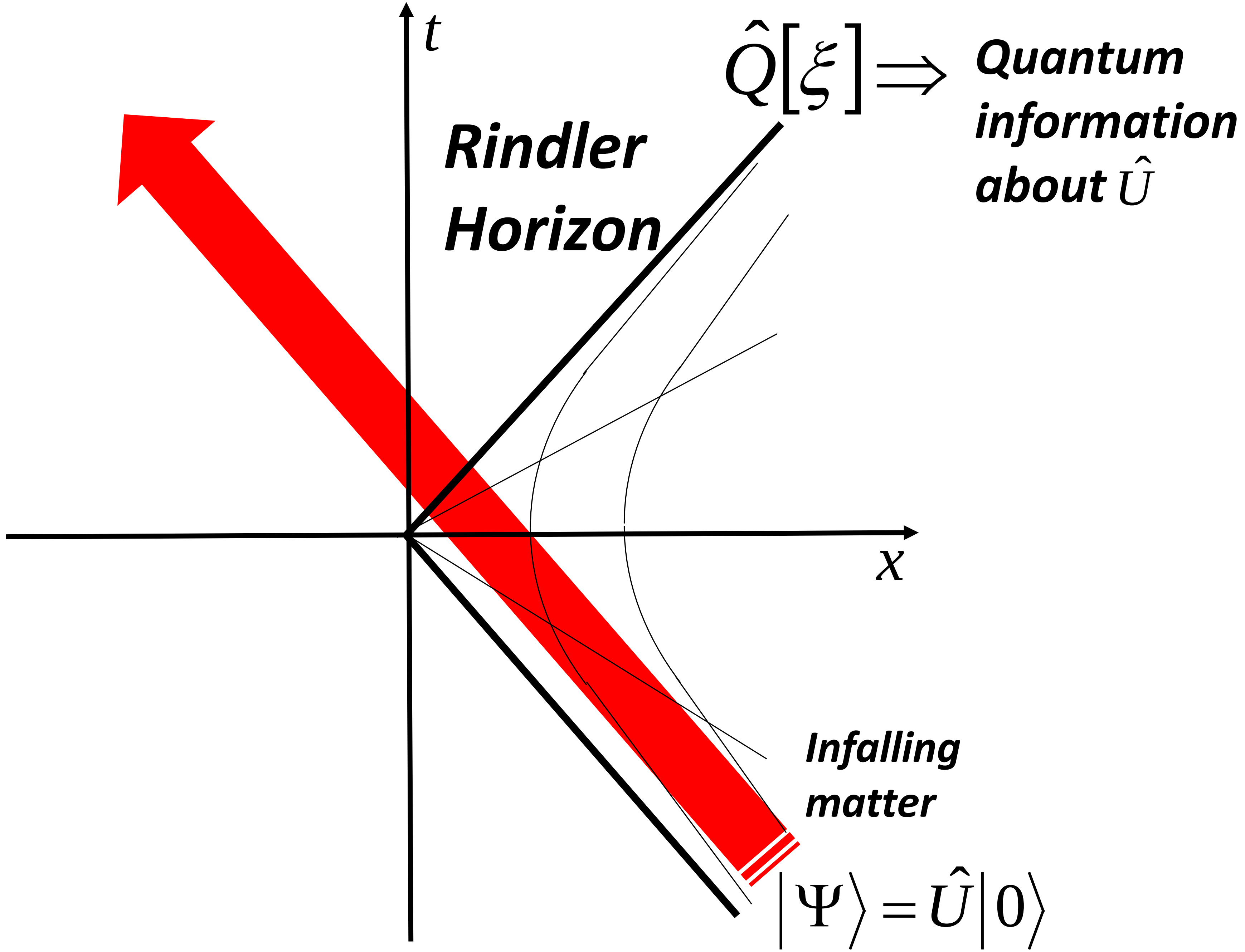


Two gravitational memories are observables dependent on each other! Measurement of one of the memories deletes quantum information in the other memory via wave function collapse.

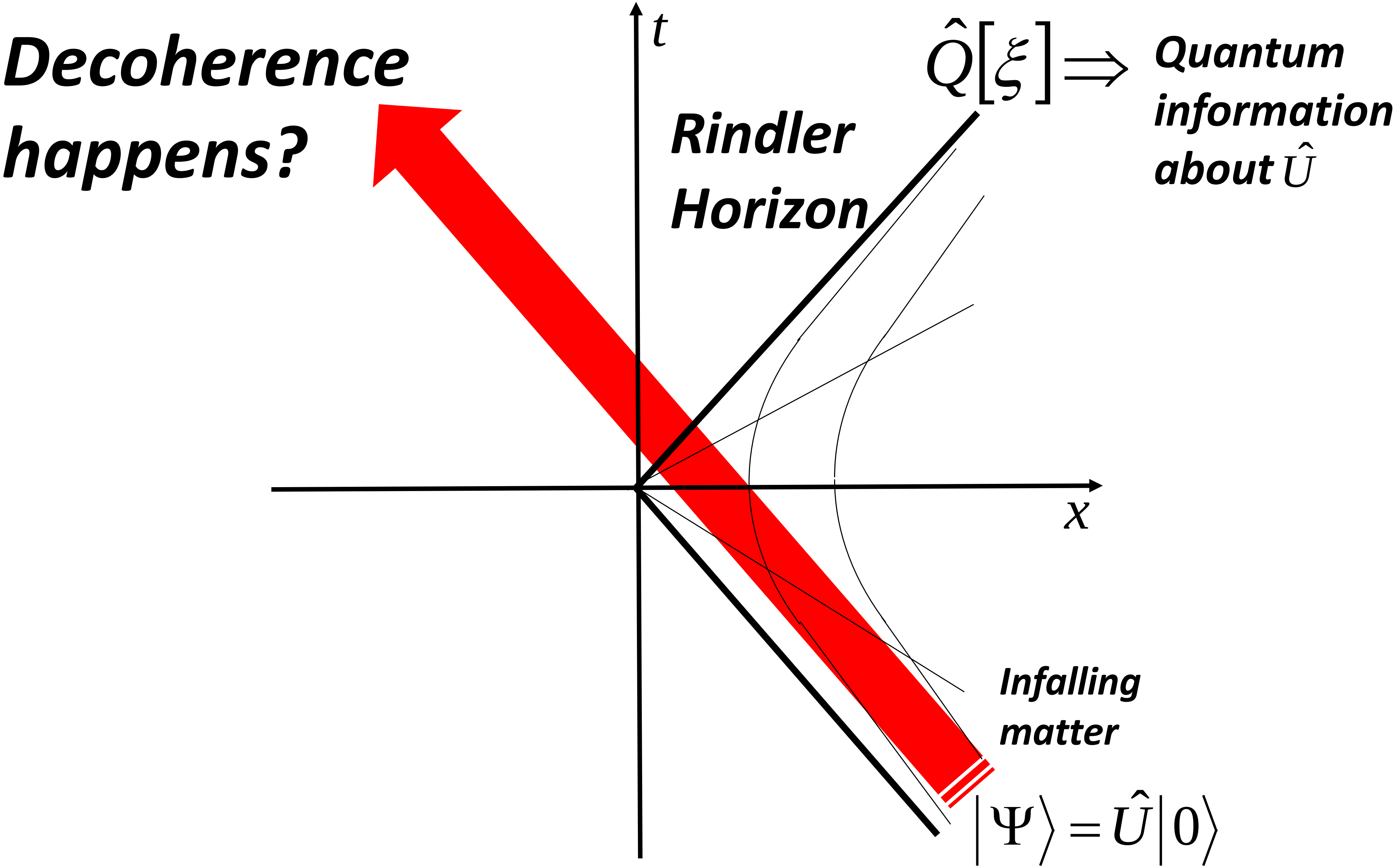
How about no-cloning paradox between absorbed matter and quantum gravitational memory?

No decoherence





t
$\hat{Q}[\xi] \Rightarrow$
Quantum information about $\hat{U}$
Rindler Horizon
x
Infalling matter
$|\Psi\rangle = \hat{U}|0\rangle$

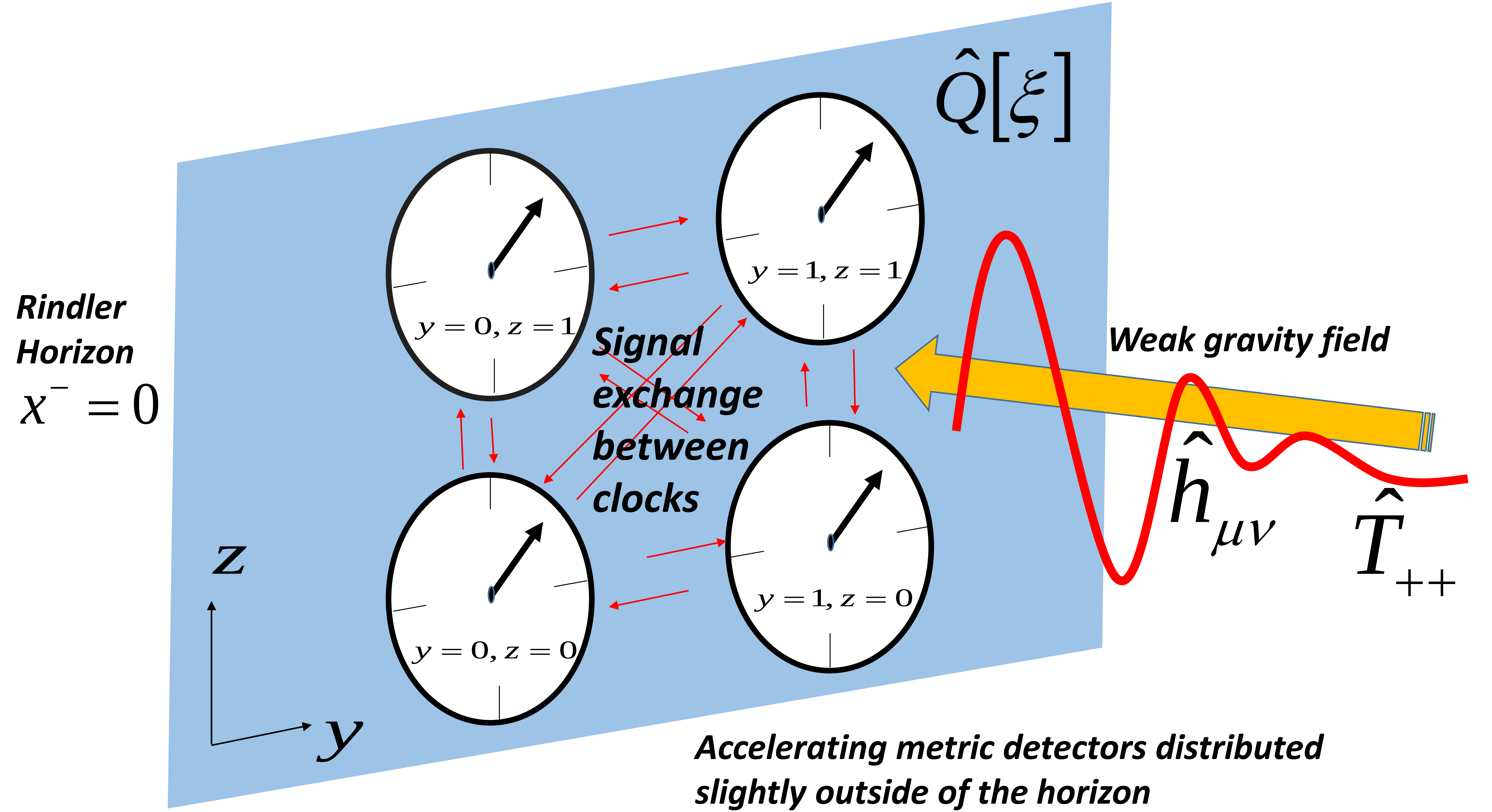

Decoherence happens?
t
Rindler Horizon
$\hat{Q}[\xi] \Rightarrow$
Quantum information about $\hat{U}$
x
Infalling matter
$|\Psi\rangle = \hat{U}|0\rangle$

Resolution:

In order to measure the information stored in the holographic charges, metric detectors are required.

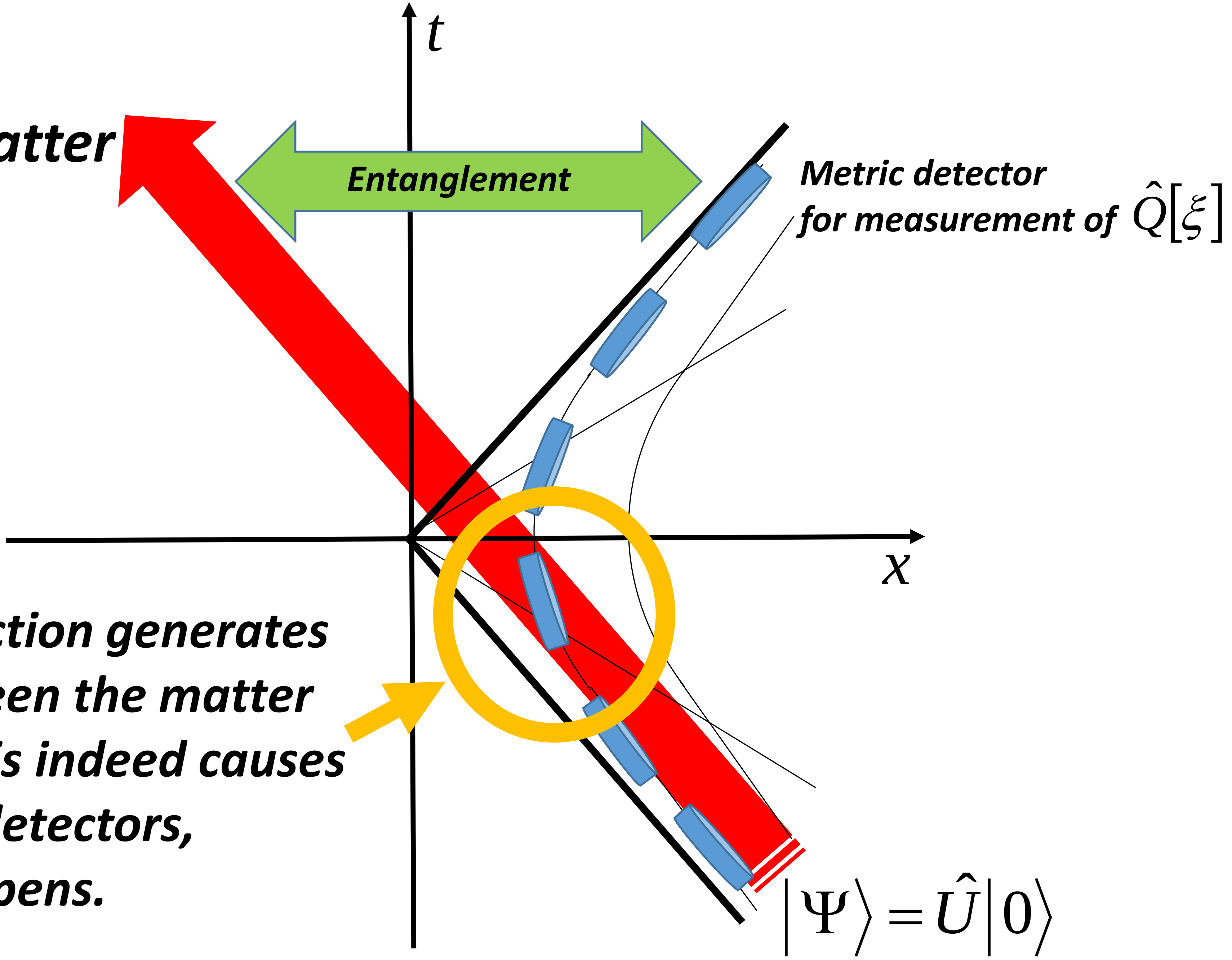
However, the detectors inevitably interact with the infalling matter and share quantum entanglement.

This causes decoherence of the infalling matter, and no exact duplicate quantum information exists. This evades the no-cloning paradox.



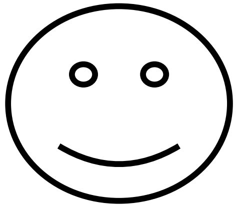
$\hat{Q}[\xi]$
Rindler Horizon
$x^- = 0$
$y = 0, z = 1$
$y = 1, z = 1$
$y = 0, z = 0$
$y = 1, z = 0$
Signal exchange between clocks
Weak gravity field
$\hat{h}_{\mu\nu}$
$\hat{T}_{++}$
z
y
Accelerating metric detectors distributed slightly outside of the horizon

Decohered **infalling matter**



Gravitational interaction generates entanglement between the matter and the detector. This indeed causes decoherence. If no detectors, no decoherence happens.

【Status Summary of HPS Scenario】

○ **Black Hole Entropy Problem** → 

(Hotta 2002, Hawking-Perry-Strominger 2016, Hotta-Trevison-Yamaguchi 2016)

○ **Black Hole Information Loss Problem** → 

(Hotta-Trevison-Yamaguchi 2016)

Soft hair on horizon may be so thick that the black hole entropy problem is resolved, but too thin to resolve the information loss problem.

For the resolution of information loss, the scenario of zero-point fluctuation partner of Hawking particle remains fascinating.

Wilczek 1992 Hotta-Schüzhold-Unruh 2015 Hotta-Sugita 2015

Summary

- *In a Rindler coordinate system implemented by accelerating block-numbered clocks distributed in the space, stationary black holes indeed carry non-vanishing classical charges of supertranslation and superrotation. Similarity to Unruh effect.*

- *General theory of gravitational holographic charges on Rindler horizons for a 1+3 dimensional linearized gravity field in the Minkowski background. General formula of holographic charge shift of supertranslation and superrotation induced by infalling matter absorption. No information of gravitational waves are stored in the leading order.*

- *Holographic pixel is an emergent concept, which is subjective to quantum measurement contexuality. The no-cloning paradox of quantum information between matter inside of the horizon and holographic charges on the horizon may not arise.*