Title: A Hunt for the Physical Manifestation of Black Hole Unitarity

Speakers: Hyo Jung Park

Collection/Series: Perimeter Institute Graduate Students' Conference 2024

Date: September 13, 2024 - 2:50 PM

URL: https://pirsa.org/24090194

Abstract:

The black hole information paradox is a fundamental conflict between the quantum-mechanical and thermodynamic descriptions of black holes, specifically of their particle-emission process known as the Hawking radiation. The paradox concerns whether the radiation of a black hole is a unitary time evolution or a thermal process that erases most information about the initial state of the black hole. Multiple black hole models (e.g. [1,2]) were shown to exhibit the Page curve behavior, suggesting the unitarity of the Hawking radiation. However, without a verified theory of quantum gravity, the exact structure of black holes remains undetermined, and we need a model-independent way to test black hole unitarity. My project thus aims to develop a general framework for testing black hole unitarity by searching for its physical signatures. In particular, we employ the "hybrid" RST model [3], which possesses a Page-curve behavior, and study whether the unitarity is manifested in the transition rate of the Unruh-DeWitt particle detector.

[1] Hong Zhe Chen, Robert C. Myers, Dominik Neuenfeld, Ignacio A. Reyes, Joshua Sandor. Quantum Extremal Islands Made Easy, Part II: Black Holes on the Brane".
https://doi.org/10.48550/arXiv.2010.00018.

[2] Yohan Potaux, Sergey N. Solodukhin, and Debajyoti Sarkar. "Spacetime Structure, Asymptotic Radiation, and Information Recovery for a Quantum Hybrid State.” Physical Review Letters 130, no. 26 (June 30, 2023): 261501. https://doi.org/10.1103/PhysRevLett.130.261501.

[3] Yohan Potaux, Debajyoti Sarkar, and Sergey N. Solodukhin. "Quantum States and Their Back-Reacted Geometries in 2D Dilaton Gravity.” Physical Review D 105, no. 2 (January 12, 2022): 025015. https://doi.org/10.1103/PhysRevD.105.025015.

PERIMETER SCHOLARS INTERNATIONAL

A Hunt for Physical Manifestation of Black Hole Unitarity

Hyo Jung Park

September 13, 2024

PI Graduate Students' Conference

Ongoing work with
Prof. Robert B. Mann

PERIMETER INSTITUTE

UNIVERSITY OF WATERLOO

Hawking, S. W. Nature 248, no. 5443: 30–31.

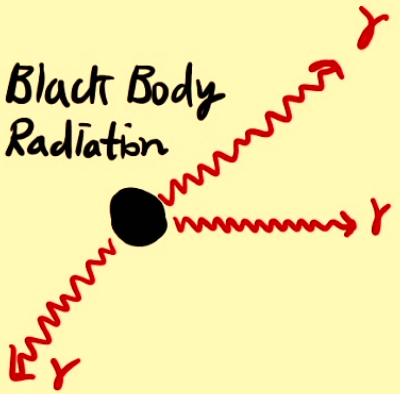
Prelude to Black Hole Information Paradox

Hawking (1974)

Classical BH metric + *Quantum* matter ψ

Assume BH radiates particles…

"QFT particle production"



$$\langle N \rangle \propto \frac{1}{e^{2\pi\omega/\kappa} - 1}$$

$$B_\omega(T) \propto \frac{\omega^3}{e^{\hbar\omega/k_B T} - 1}$$

2

Carlip, S. Int. Journ. of Mod. Phys. D 23, no. 11: 1430023.

Debate!! on Black Hole Unitarity

Hawking (1974) — "Radiation is *thermal* … also at micro"

Unitarity?!? — **Non-unitarity ⇒ Initial info forever lost!!**

$$\hat{\rho}_{\text{pure}} = |\text{Rad., BH}\rangle\langle\text{Rad., BH}| \xrightarrow{\text{No } \hat{U}(t_0,t)} \hat{\rho}_{\text{mixed}}$$

Hawking radiation

Carlip, S. Int. Journ. of Mod. Phys. D 23, no. 11: 1430023.
Page, Don N. Phys. Rev. Lett. 71, no. 23: 3743–46.

Debate!! on Black Hole Unitarity

Hawking (1974)

Unitarity?!?

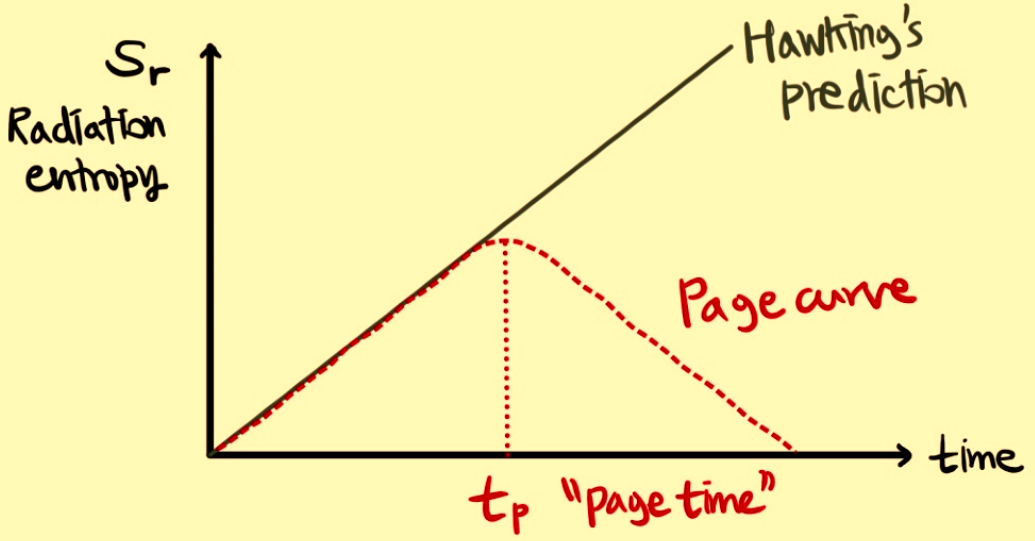
Page (1993)

"Radiation is *thermal* … also at micro"

Non-unitarity ⇒ Initial info forever lost!!

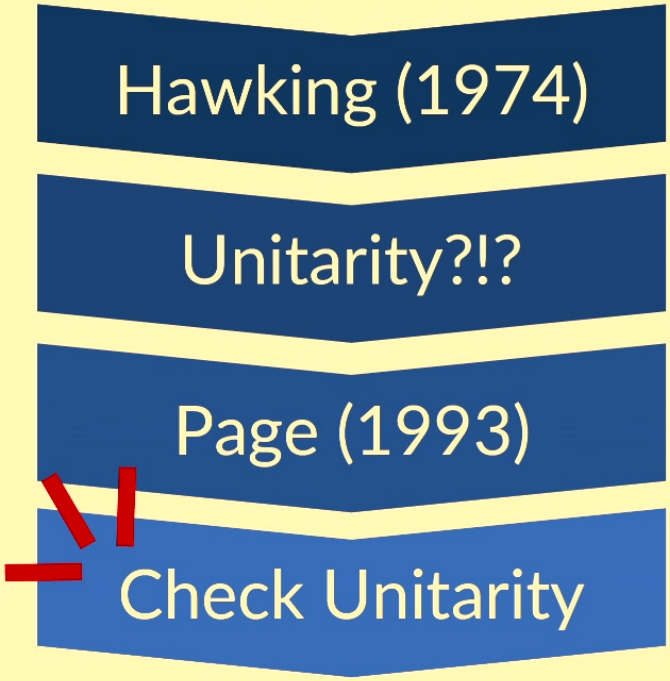
If starts & *stays* pure …

$$S_r = -\mathrm{tr}_r(\rho_r \log \rho_r),$$
$$\rho_r = \mathrm{tr}_{BH}\rho_{r,BH}$$
$$\rho_{r,BH} = |\mathrm{r,BH}\rangle\langle\mathrm{r,BH}|$$



Carlip, S. Int. Journ. of Mod. Phys. D 23, no. 11: 1430023.
Page, Don N. Phys. Rev. Lett. 71, no. 23: 3743–46.

Debate!! on Black Hole Unitarity



"Radiation is *thermal* … also at micro"

Non-unitarity ⇒ Initial info forever lost!!

Unitarity ⇒ Page curve behavior

Models yield Page curve; exact S calculated

Chen, Myers, Neuenfeld, Reyes, Sandor. arXiv.2010.00018.
Russo, Susskind, Thorlacius PRD 1992, 1993
Potaux, Solodukhin, Sarkar. PRL 130, no. 26: 261501.
. . .

Carlip, S. Int. Journ. of Mod. Phys. D 23, no. 11: 1430023.
Page, Don N. Phys. Rev. Lett. 71, no. 23: 3743–46.

Debate!! on Black Hole Unitarity

Hawk… (1974) "Radiation is *thermal*… also at micro"

Uni… er lost!!

Pag…

Chec… calculated

So… end of debate?
No, need a verified QG theory!!

Regardless of models, aim to test unitarity!!
… without calculating exact S?

Chen, Myers, Neuenfeld, Reyes, Sandor. arXiv.2010.00018.
Russo, Susskind, Thorlacius PRD 1992, 1993
Potaux, Solodukhin, Sarkar. PRL 130, no. 26: 261501.
. . .

Operational Approach to Black Hole Unitarity

Goal: *Test* BH unitarity by probing its physical manifestation

Q. How will an observer outside a BH “feel” the unitarity?

Operational Approach to Black Hole Unitarity

Goal: *Test* BH unitarity by probing its physical manifestation

Q. How will an observer outside a BH "feel" the unitarity?

an external observer

Unruh-DeWitt Detector
⇒ Transition Rate

BH with Page curve

"Hybrid RST Model":
Classical spacetime
+ Quantum matter

Russo, Susskind, Thorlacius PRD 1992, 1993
Potaux, Solodukhin, Sarkar. PRL 130, no. 26 (2023): 261501

Operational Approach to Black Hole Unitarity

Goal: *Test* BH unitarity by probing its physical manifestation

Q. How will an observer outside a BH "feel" the unitarity?

Stay tuned!!

an e

ob

Unruh-DeWit

Detector

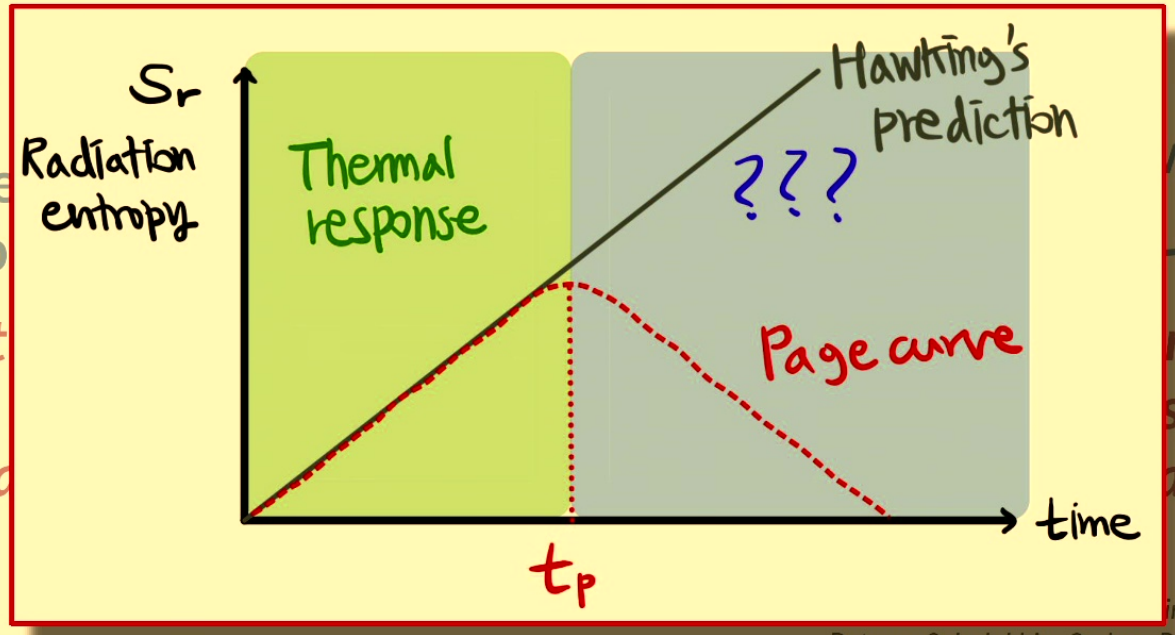
⇒ *Transition Ra*

with Page curve

rid RST Model":

sical spacetime

antum matter



ind, Thorlacius PRD 1992, 1993

Potaux, Solodukhin, Sarkar. PRL 130, no. 26 (2023): 261501