

Black Hole Information Loss Paradox

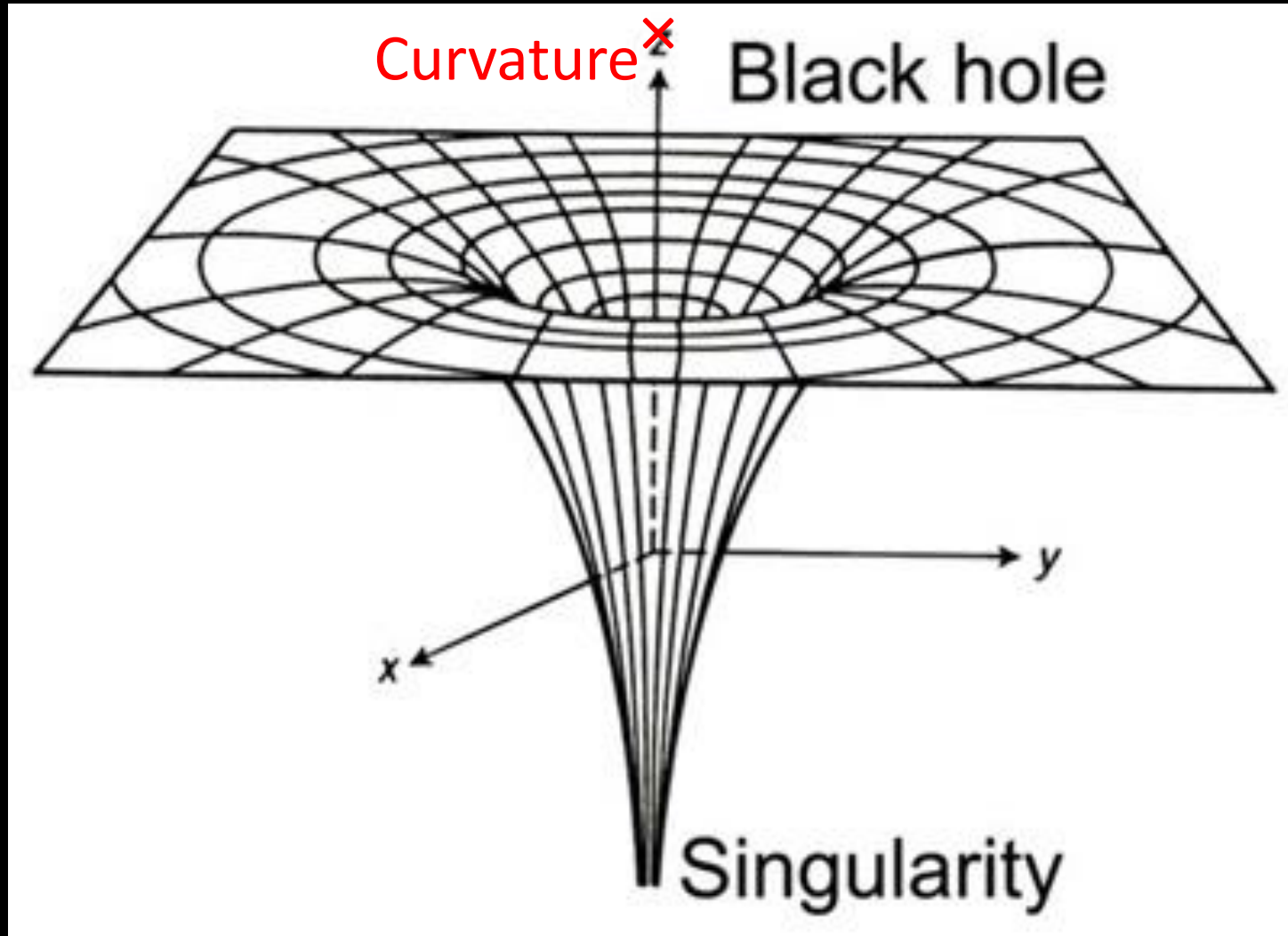
— The War Continues to Rage —

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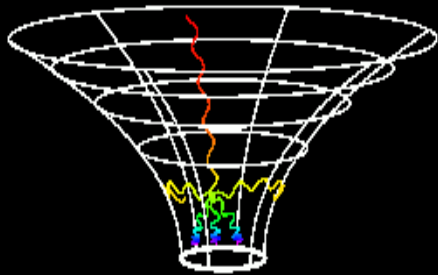
General relativity predicts the existence of black holes



The first black hole solution (1916): Non-rotating BH

$$ds^2 = - \left(1 - \frac{2GM}{c^2 r} \right) c^2 dt^2 + \left(1 - \frac{2GM}{c^2 r} \right)^{-1} dr^2 + r^2 (d\theta^2 + \sin^2 \theta d\phi^2)$$

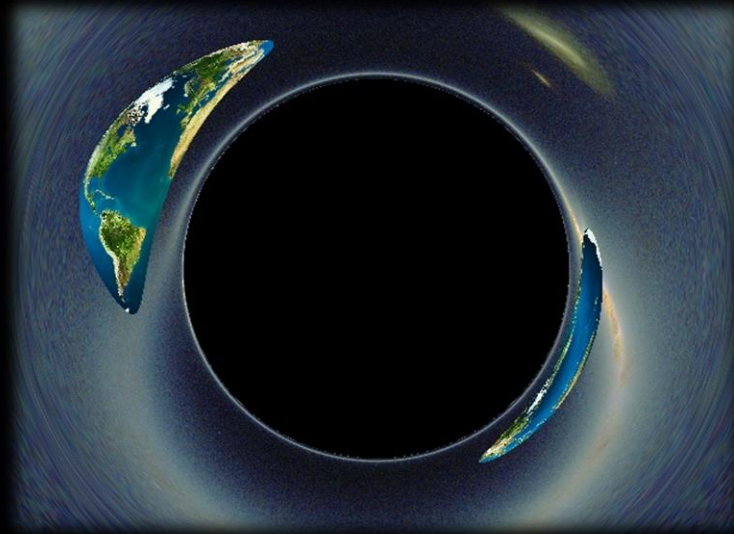
Diverges: $\frac{1}{0} \rightarrow \infty$



Event Horizon
(事件视界):

$$r_h = \frac{2GM}{c^2}$$

Schwarzschild radius



Karl Schwarzschild

Schwarzschild = 黑盾

Golden Age of classical black hole

1963 – 1973

Spinning black hole solution (Roy Kerr, 1963)

$$ds^2 = -\frac{D}{r^2} \left(dt - a \sin^2 q df \right)^2 + \frac{\sin^2 q}{r^2} \left(a dt - r_0 df \right)^2 + \frac{r^2}{D} dr^2 + r^2 dq^2$$

$$r^2 = r^2 + a^2 \cos^2 q, \quad r_0^2 = r^2 + a^2, \quad D = r^2 - 2Mr + a^2$$



Roy Kerr

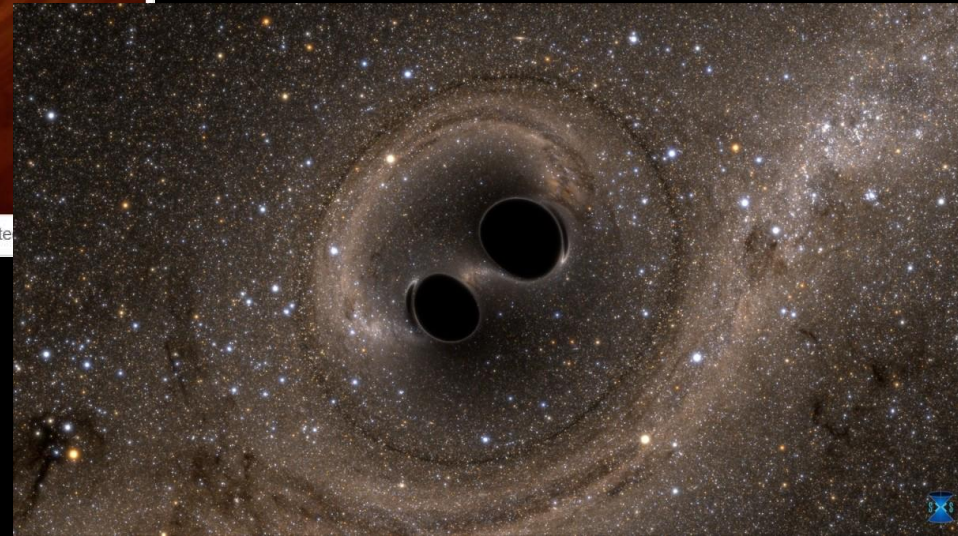


Three types of black holes

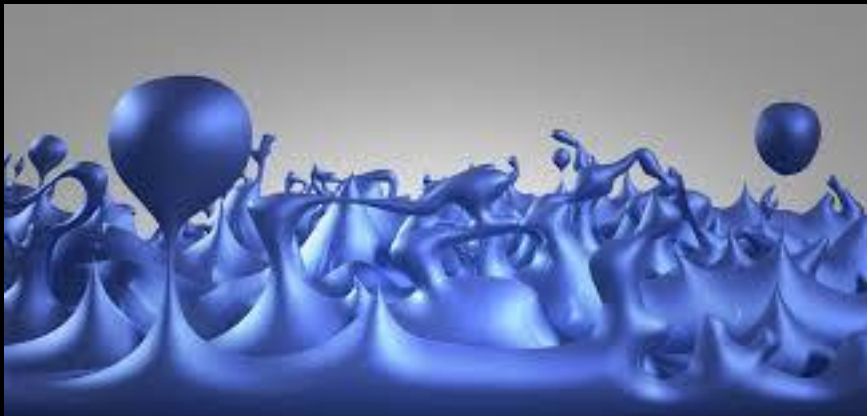


Artist's concept illustrating a supermassive black hole with millions to billions times the mass of our sun (Image: NASA/JPL-Caltech)

Supermassive BH (millions to billions of solar mass)



Stellar size BH (several to tens of solar mass)



Primordial BH (induced around Big Bang)

Black hole thermodynamics

1972 – 1973

“Thermodynamics is a funny subject. The first time you go through it, you don’t understand it at all. The second time you go through it, you think you understand it, except for one or two small points. The third time you go through it, you know you don’t understand it, but by that time you are so used to it, it doesn’t bother you any more.” — Arnold Sommerfeld.

Black hole thermodynamics

- Zeroth Law: The surface gravity of a non-rotating black hole is constant.
- First Law: The change of total energy equals to that of the area, angular momentum, and charge: $dE = \frac{k}{8\pi} dA + \Omega dJ + F dQ$
- Second Law: The area of the BH surface can only increase in time. $\frac{dA}{dt} \geq 0$
- Third Law: Zero surface gravity BH does not exist. In another word, k cannot be zero.

Black hole entropy

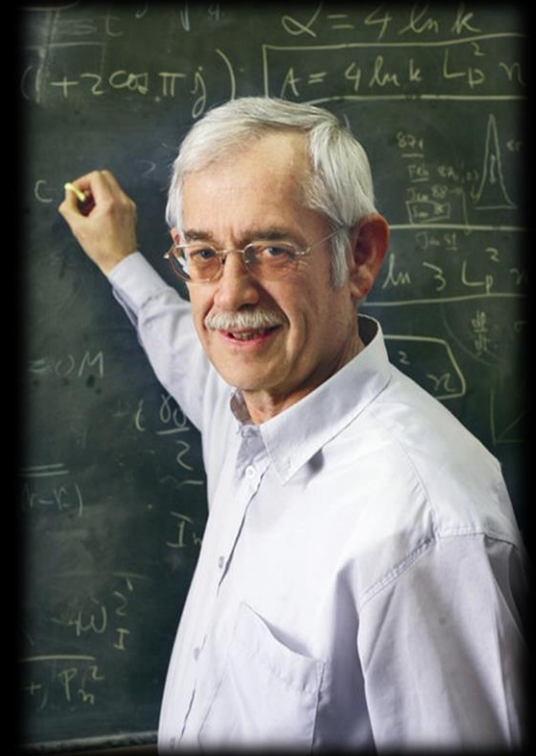
- Bekenstein-Hawking entropy:

$$S_{BH} = \frac{k_B A}{4l_P^2}$$



$$E = k_B T$$

Ludwig Boltzmann (1844-1906)



Jacob Bekenstein (1947-2015)

$$S = k \log W$$

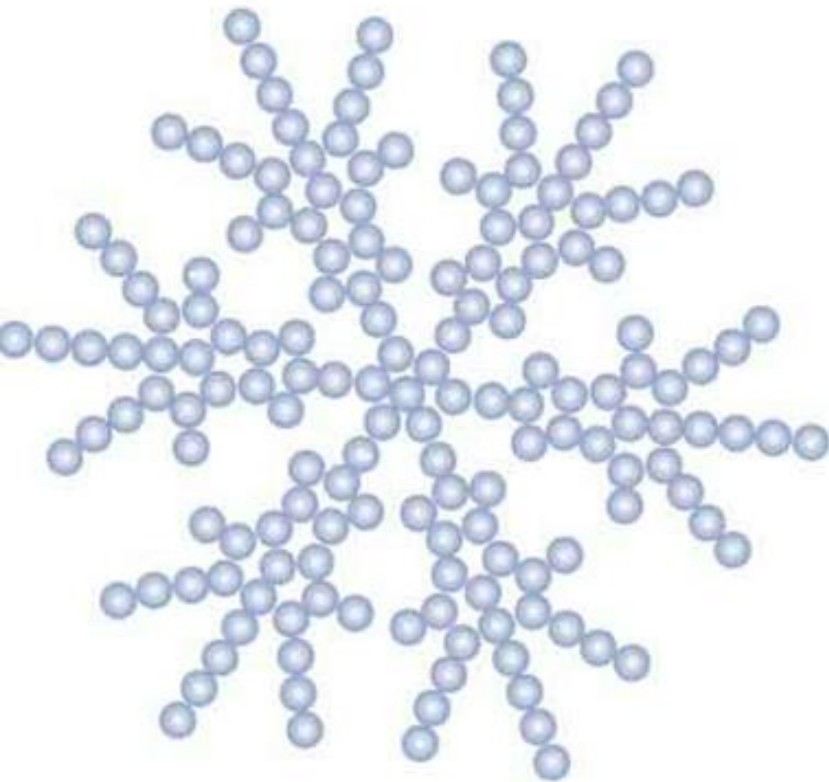


Tomb of Boltzmann in Vienna, Austria

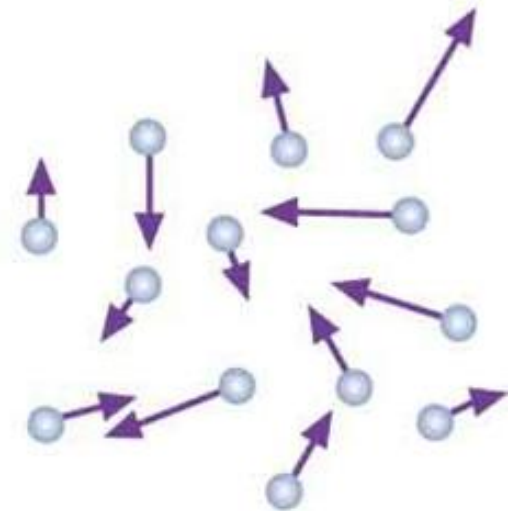
Entropy

Order

Disorder



Ice



Water

2nd law of thermodynamics



Black hole entropy: an amazing equation!

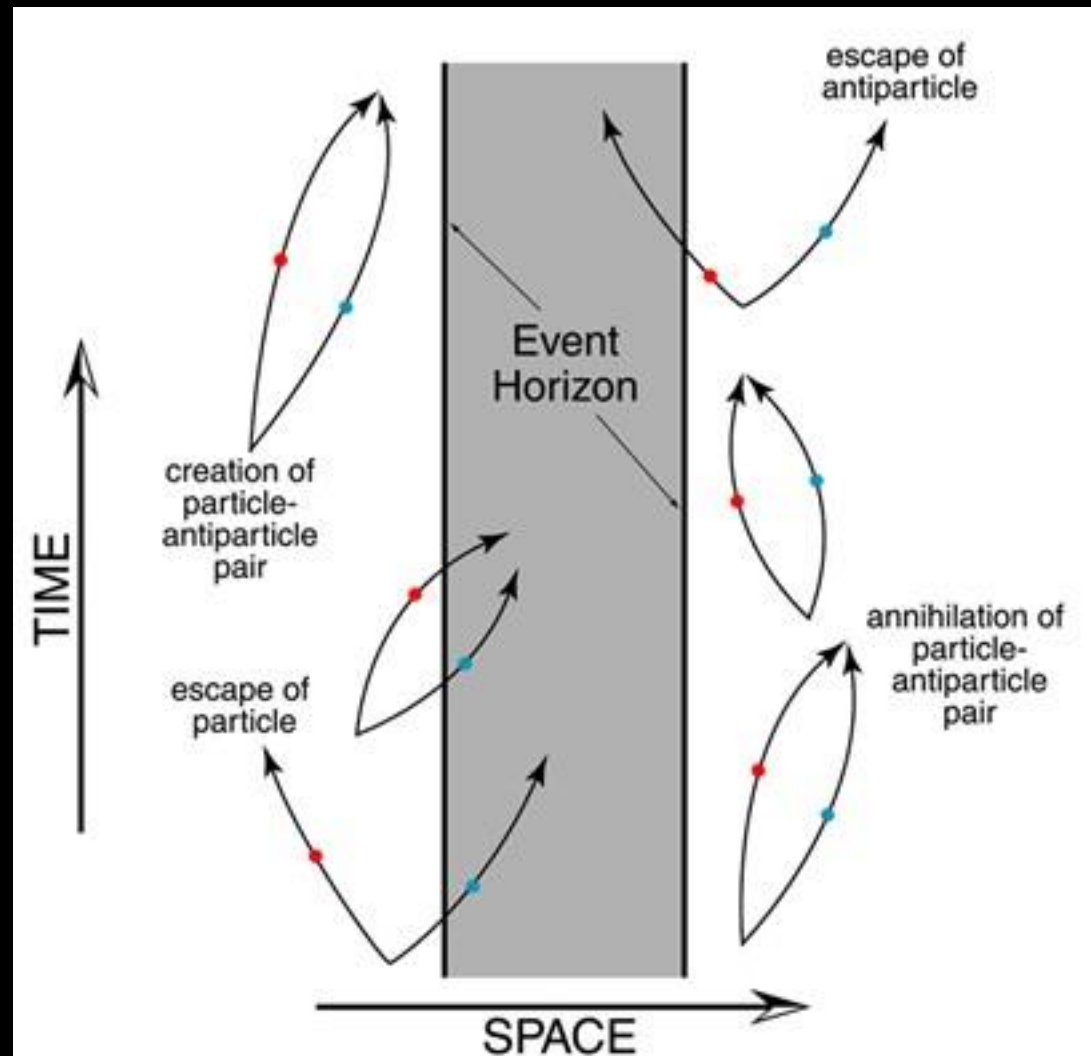
The diagram features the equation $S_{BH} = \frac{k_B A}{4l_P^2}$ in the center. Four colored arrows point towards the equation: a yellow arrow from 'Thermodynamics' points to k_B ; a purple arrow from 'Geometry' points to A ; a green arrow from 'General relativity' points to A ; and a blue arrow from 'Quantum mechanics' points to l_P^2 . A pink arrow from 'Gravity' points to l_P^2 . The labels are: Thermodynamics (yellow), Geometry (purple), General relativity (green), Gravity (pink), and Quantum mechanics (blue).

$$S_{BH} = \frac{k_B A}{4l_P^2}$$

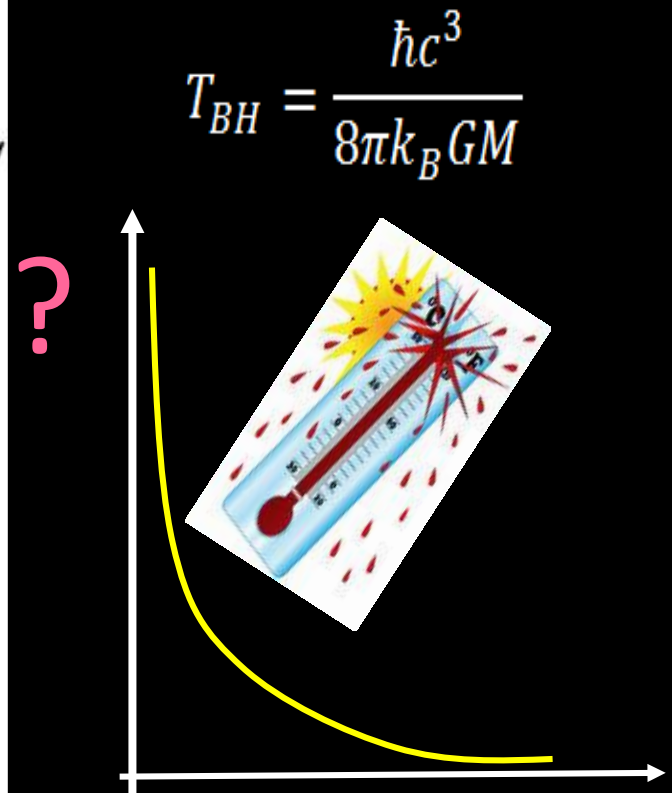
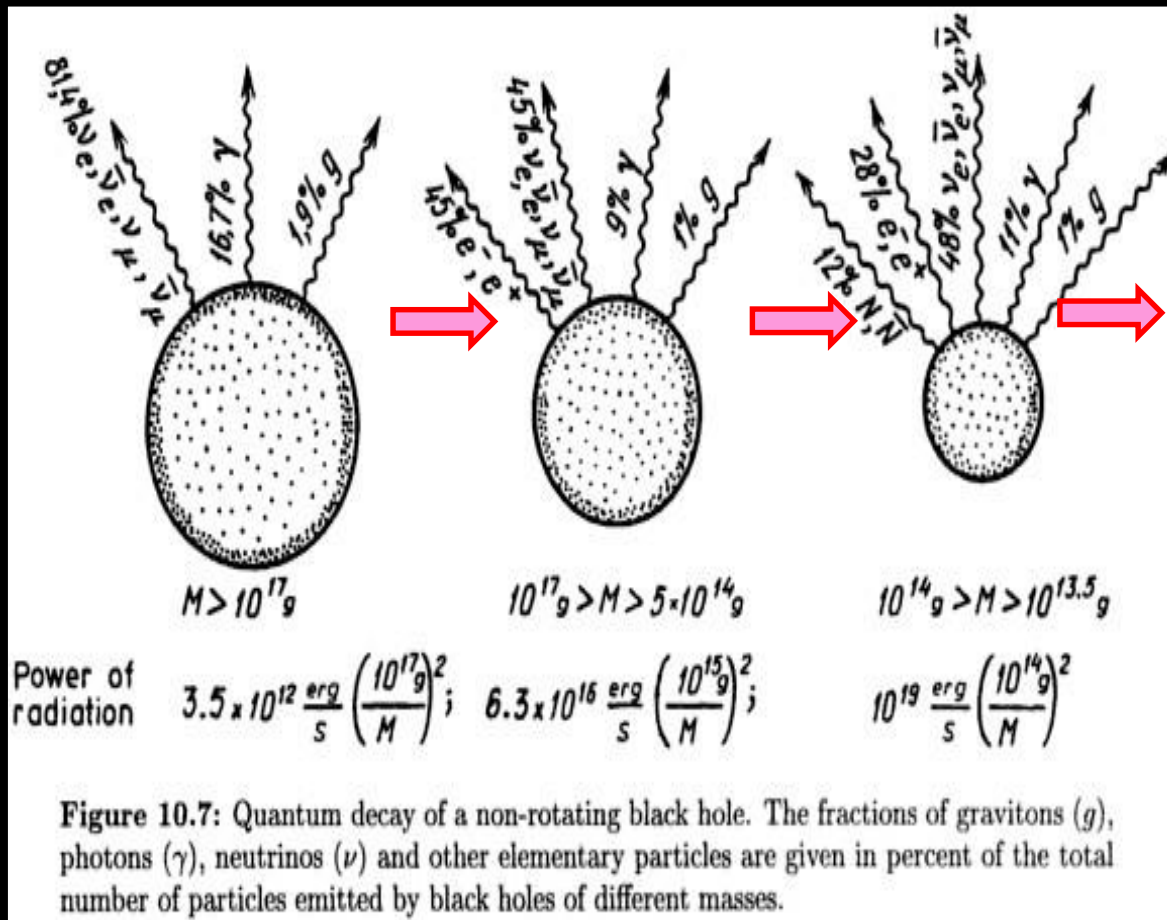
Worse yet, S is NOT proportional to the BH volume,
but its surface area!

Hawking evaporation: Linking GR, QM, and Stat Mech in one stroke

$$r_s = \frac{2GM}{c^2} \quad g = \frac{GM}{r_s^2}$$
$$k_B T_H = \frac{\hbar c^3}{8\pi GM} = \frac{\hbar g}{2\pi c}$$



Black hole evaporation



Frolov, V. V. P., Novikov, I. D. (1998). Black hole physics: basic concepts and new developments (Vol. 96). Springer

Lifetime of black holes

- Hawking temperature:

$$T = \frac{\hbar c^3}{8\pi G M k_B}$$

Planck's Constant [Quantum Mechanics] → $\hbar$

Relativity → c^3

Boltzmann's Constant [Thermodynamics] → k_B

Newton's Constant [Gravity] → G



- Stefan-Boltzmann law:

$$\frac{E}{A} = \sigma T^4 \propto \frac{1}{M^4}$$

Black hole surface area:

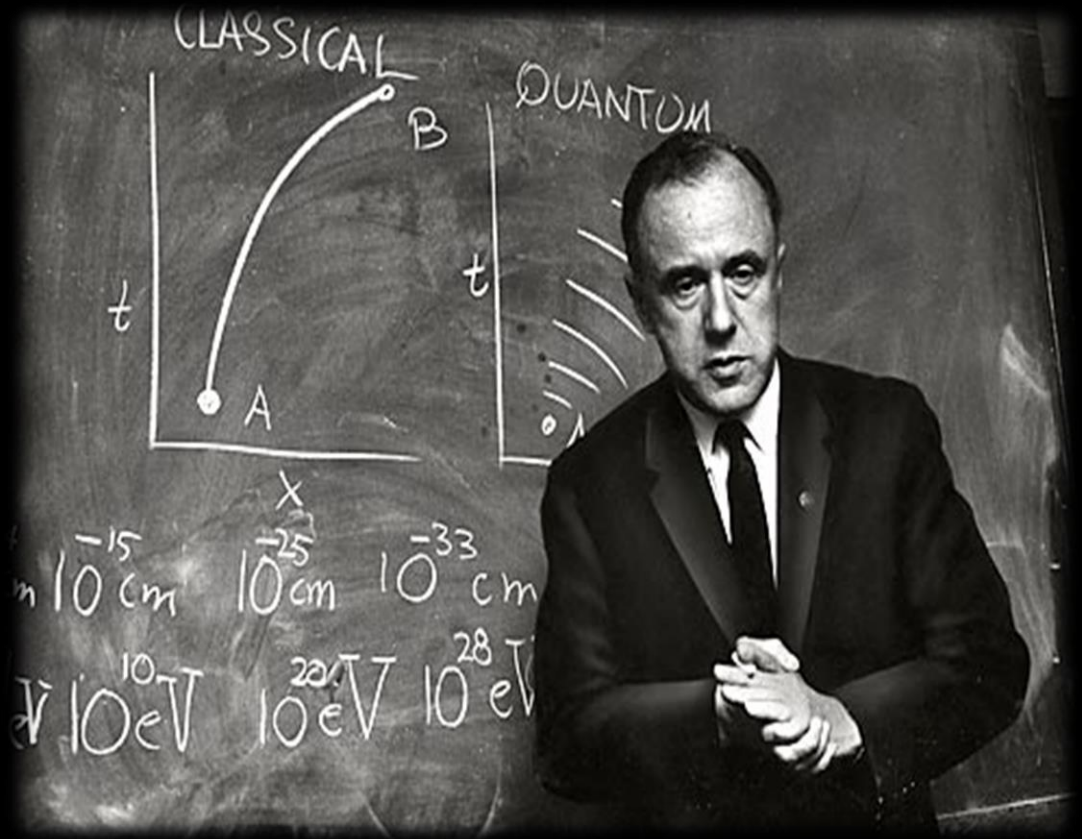
$$A = 4\pi r_h^2 \propto M^2$$

BH evaporation rate inversely proportional to mass squared:

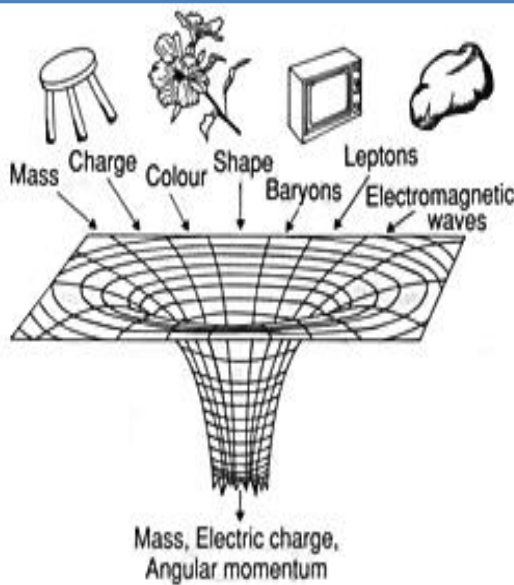
$$\frac{dM}{dt} \propto \frac{1}{M^2}$$

Lifetime of BH: Solar mass BH = 10^{67} years

Age of the universe = 1.38×10^{10} years



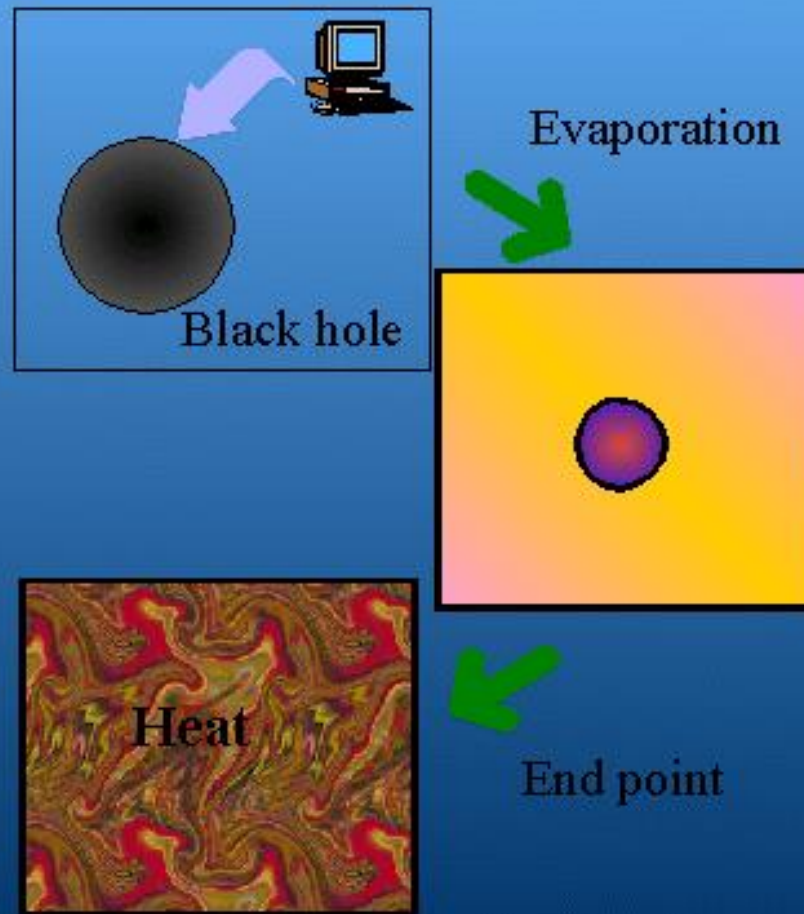
John Wheeler (who invented the name Black Hole):
 “What would happen if I drop my coffee into a black hole?”



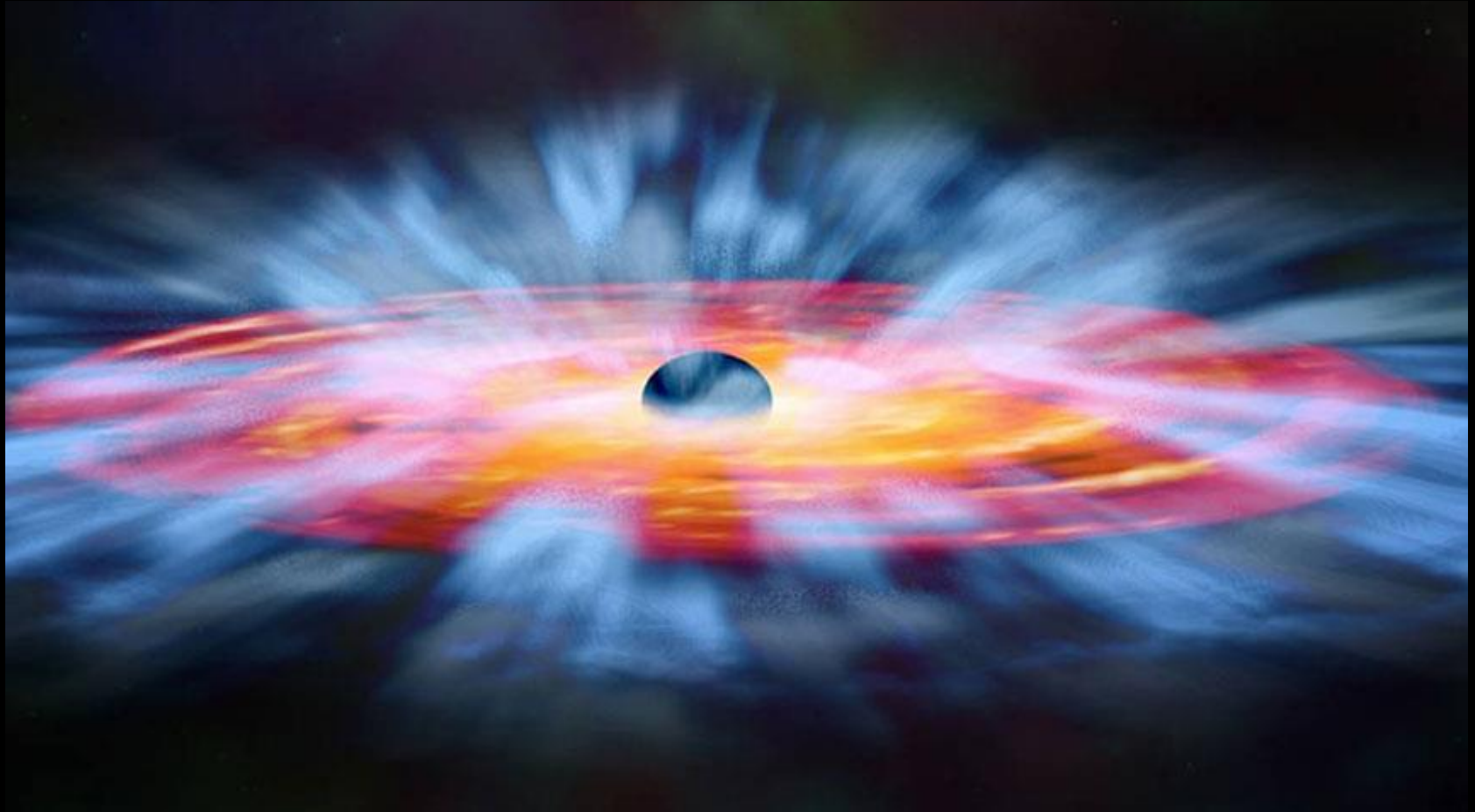
No-hair theorem

The information loss problem

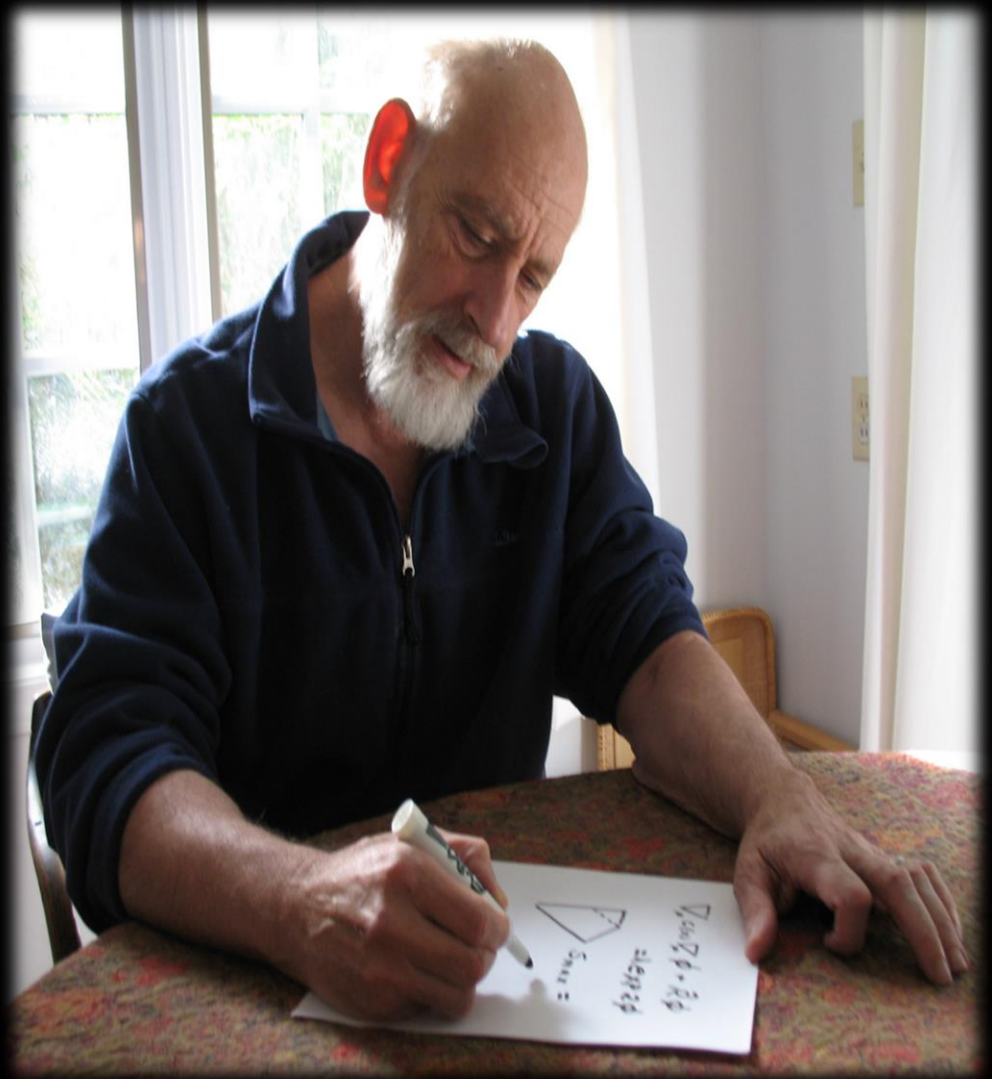
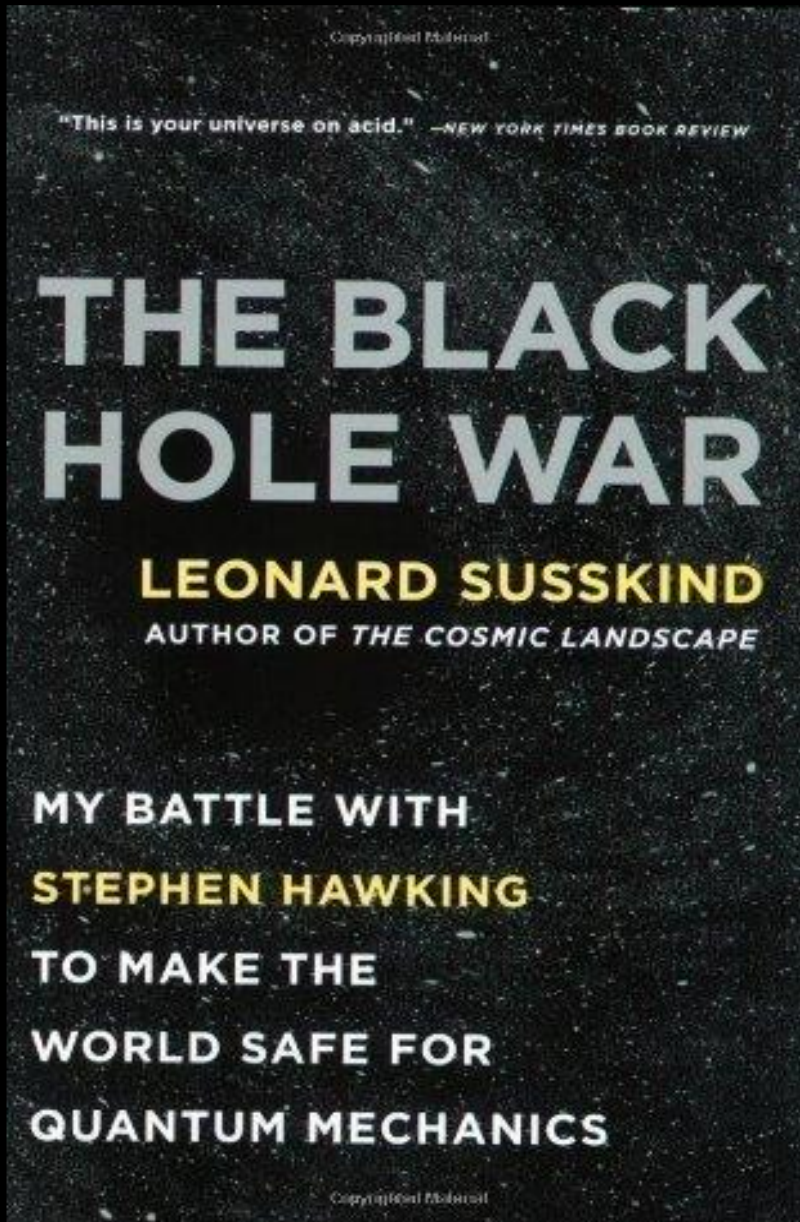
Information Loss



Can Hawking radiation carry out
information after all?

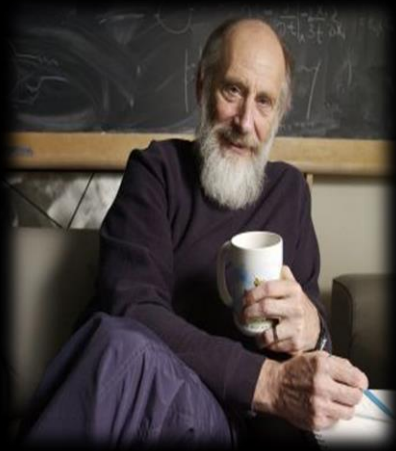


Recommend reading



BH Complementarity Principle

The basic requirement of natural law is that it is *consistent with causality*.

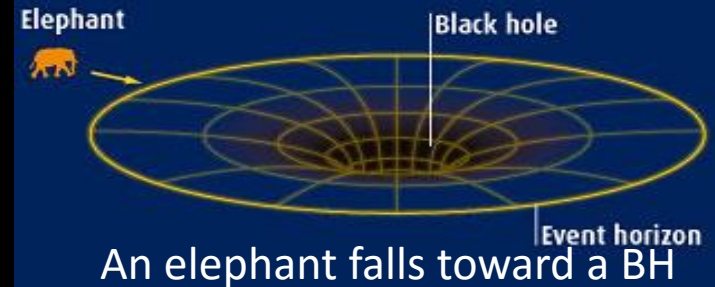


Leonard Susskind, Lárus Thorlacius, John Uglum, "The Stretched Horizon and Black Hole Complementarity"

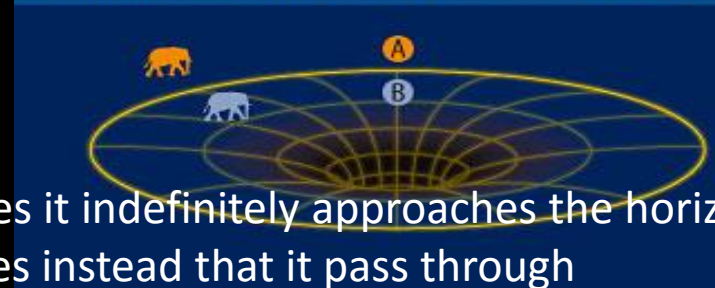
HOW TO BE IN TWO PLACES AT ONCE

Black holes challenge our notion of locality. If no observer can see information lost in the universe, then a thought experiment shows that an object's location in space-time depends on whether its observer is accelerating outside the event horizon or free-falling inside. That means information can be in more than one place at the same time

An elephant approaches a black hole



Observer A sees the elephant get closer and closer to the horizon, while observer B sees the elephant pass through

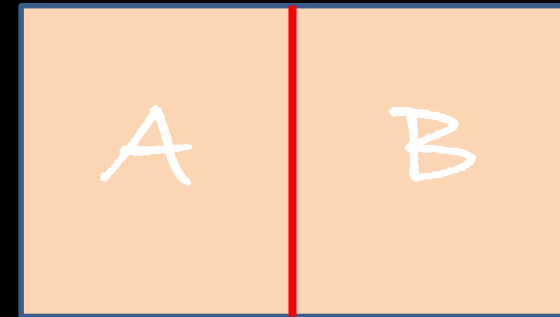
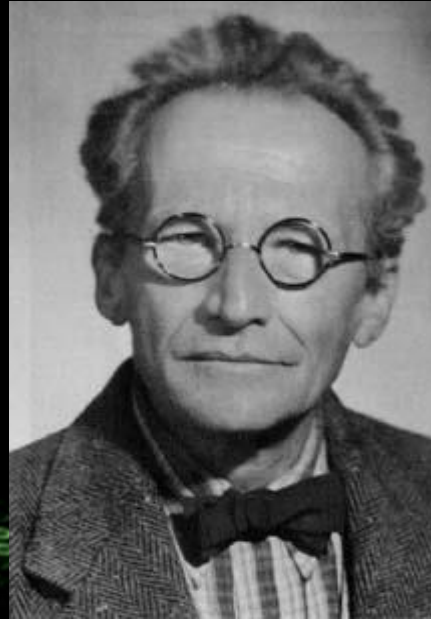


Observer A sees the elephant get thermalised and radiated back out, while B sees it continue to its doom

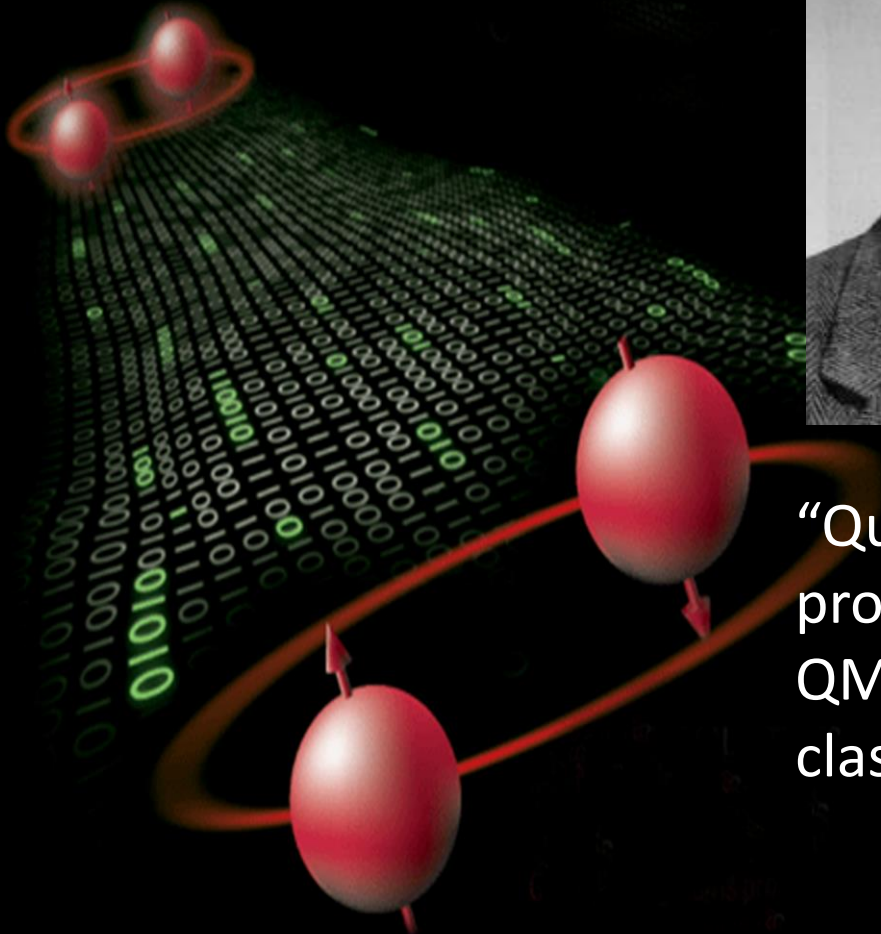


Quantum entanglement

Schrödinger: “*Verschränkung*” (1935) as a result of discussing with Einstein



“Quantum entanglement is not just a property of QM, it is THE character of QM. It fundamentally breaks QM from classical physics.



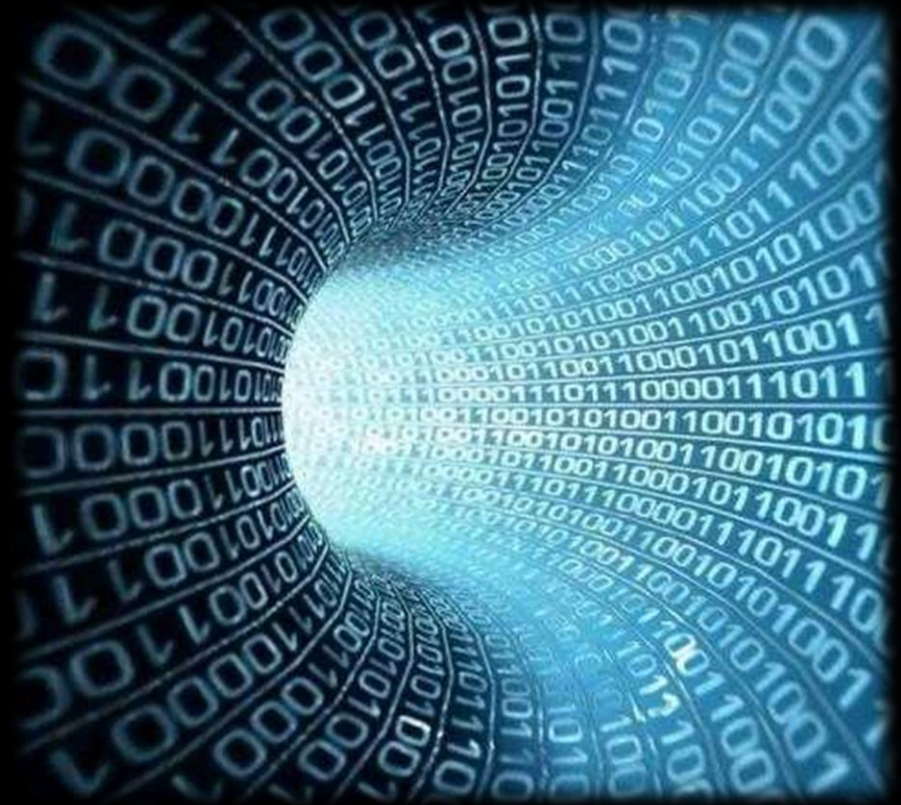
What is quantum entanglement?

Thermodynamics:

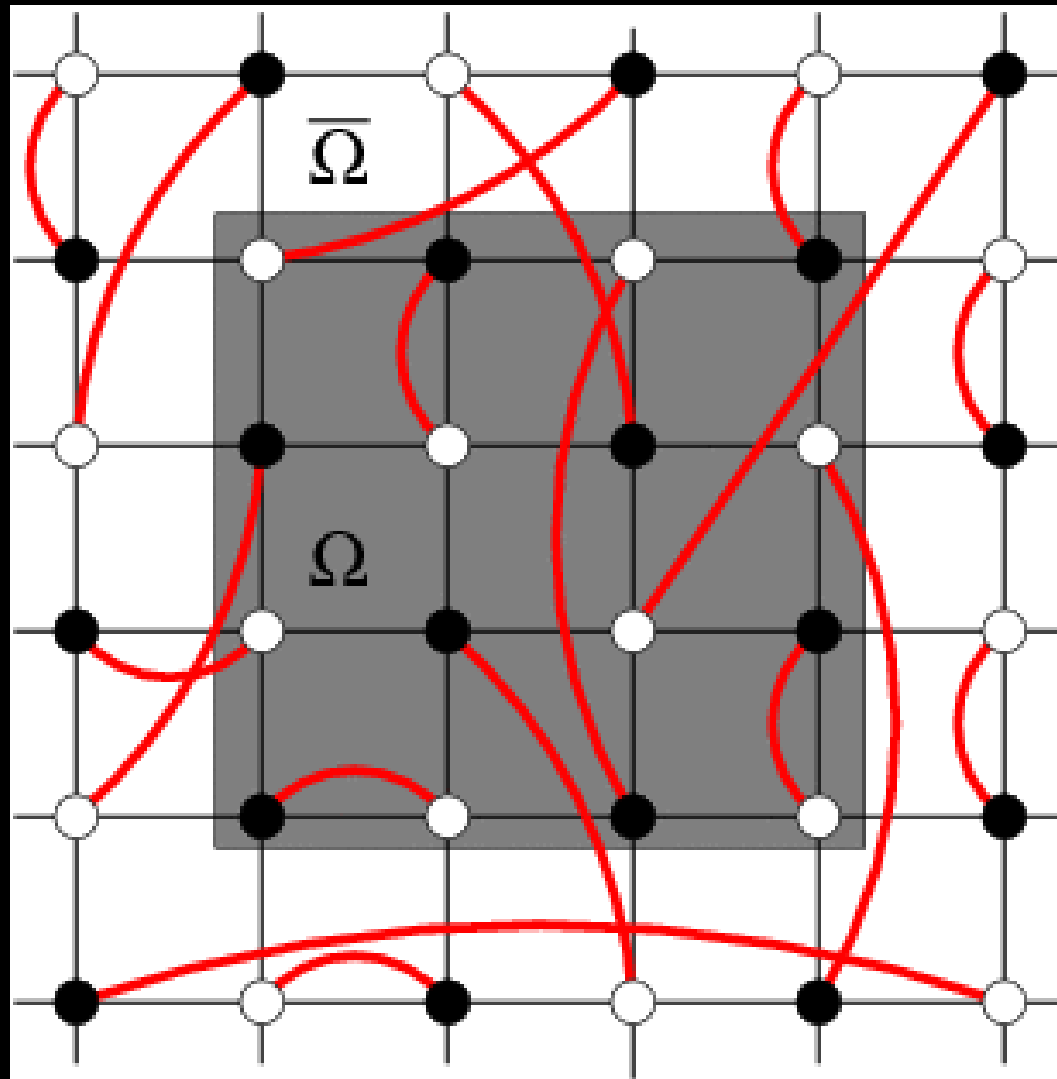
Entropy $\longleftrightarrow$ Disorder

Quantum Informatics:

Entanglement Entropy $\longleftrightarrow$ How tangled the system is



Monogamy of quantum entanglement



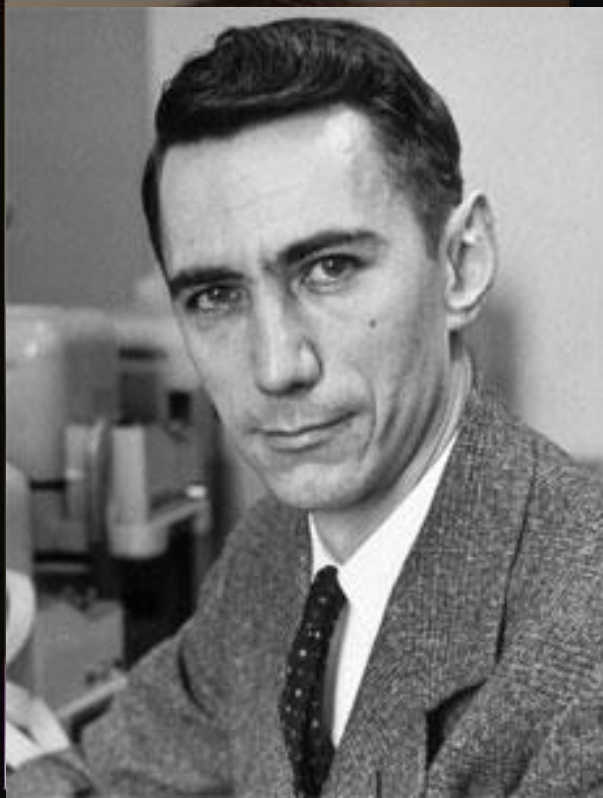
From Shannon entropy to von Neumann entropy



John von Neumann

Use entropy and you can never lose a debate,
von Neumann told Shannon - because no one
really knows what entropy is.

(William Poundstone)



Claude Shannon (1916-2001)

When would BH entanglement entropy come out?

Entanglement entropy

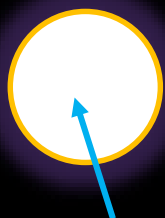
S_{ent}

Information

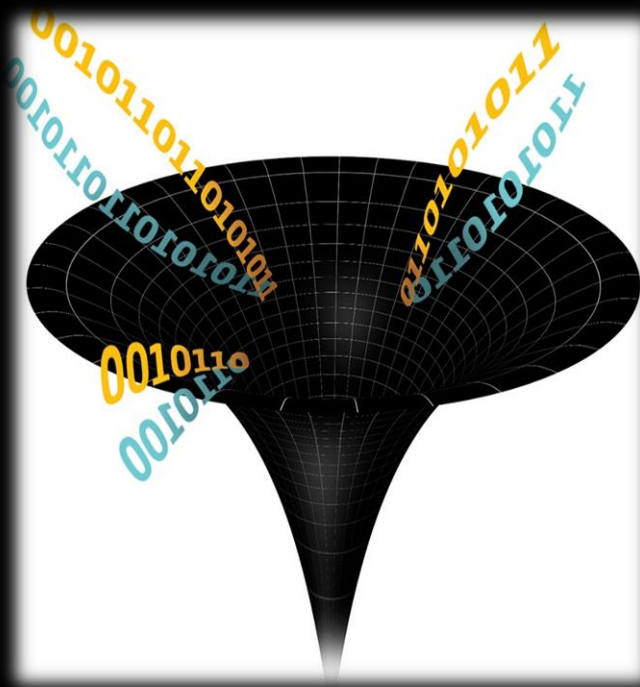
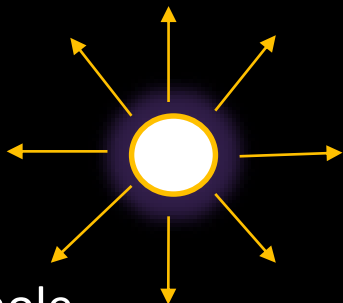
Young
Black
Hole

Old
Black
Hole

Page Time



Pure state black hole



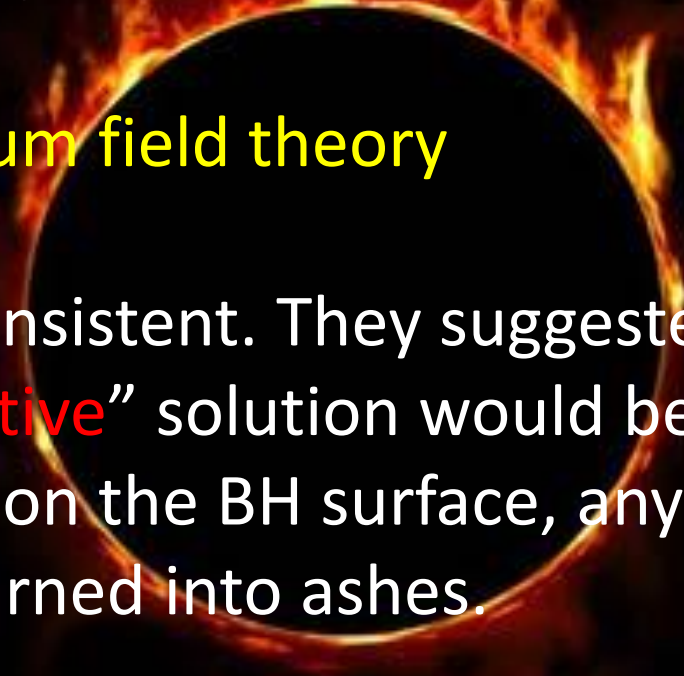
Don Page

AMPS firewall paradox

In 2012, four physicists (AMPS) argued that the 3 basic assumptions that led to the BH complementarity principle, namely,

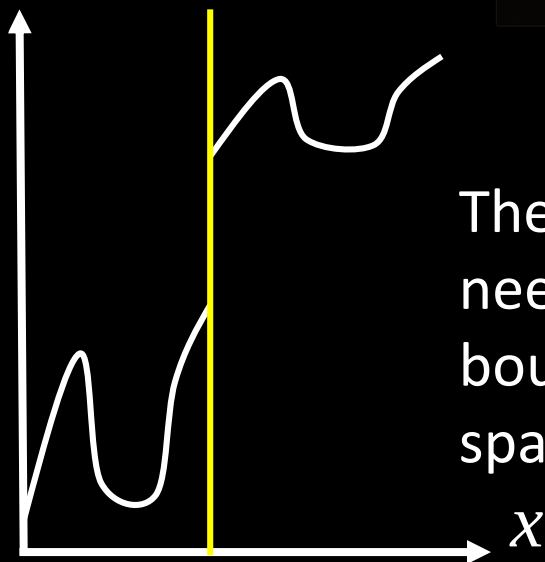
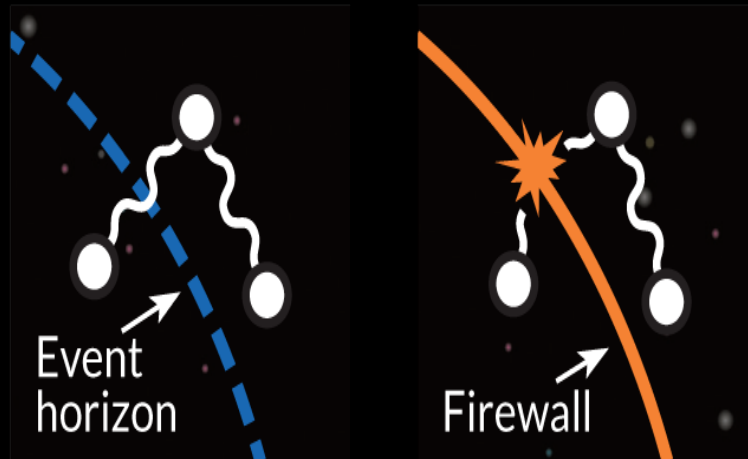
1. Unitarity
2. Local quantum field theory
3. No drama

cannot be all consistent. They suggested that the “**most conservative**” solution would be that there exists a firewall on the BH surface, anything falls into BH would be burned into ashes.



AMPS firewall paradox

The energy of a quantum field at a location x depends on the variation of the field value there.



The value of the quantum field needs not be continuous on a boundary across which the spacetime is not continuous.

- Ahmed Almheiri, Donald Marolf, Joseph Polchinski, James Sully,

“Black Holes: Complementarity or Firewalls?”, JHEP 1302 (2013) 062.

- Ahmed Almheiri, Donald Marolf, Joseph Polchinski, Douglas Stanford, James Sully,

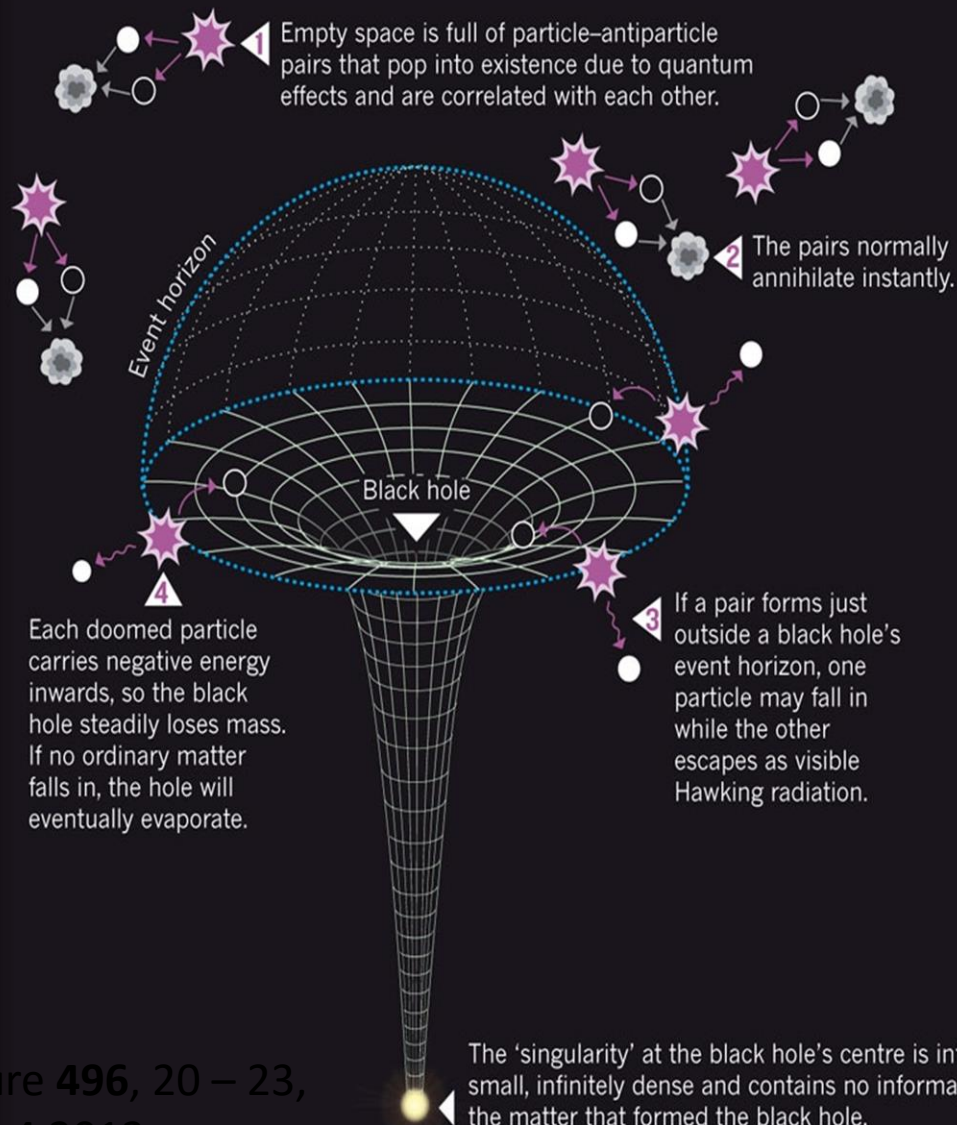
“An Apologia for Firewalls”, JHEP 1309 (2013) 018.

THE INFORMATION PARADOX

Matter falling into a black hole is crushed to an infinitely dense point at the centre. Two scenarios attempt to explain what happens to the information that matter holds.

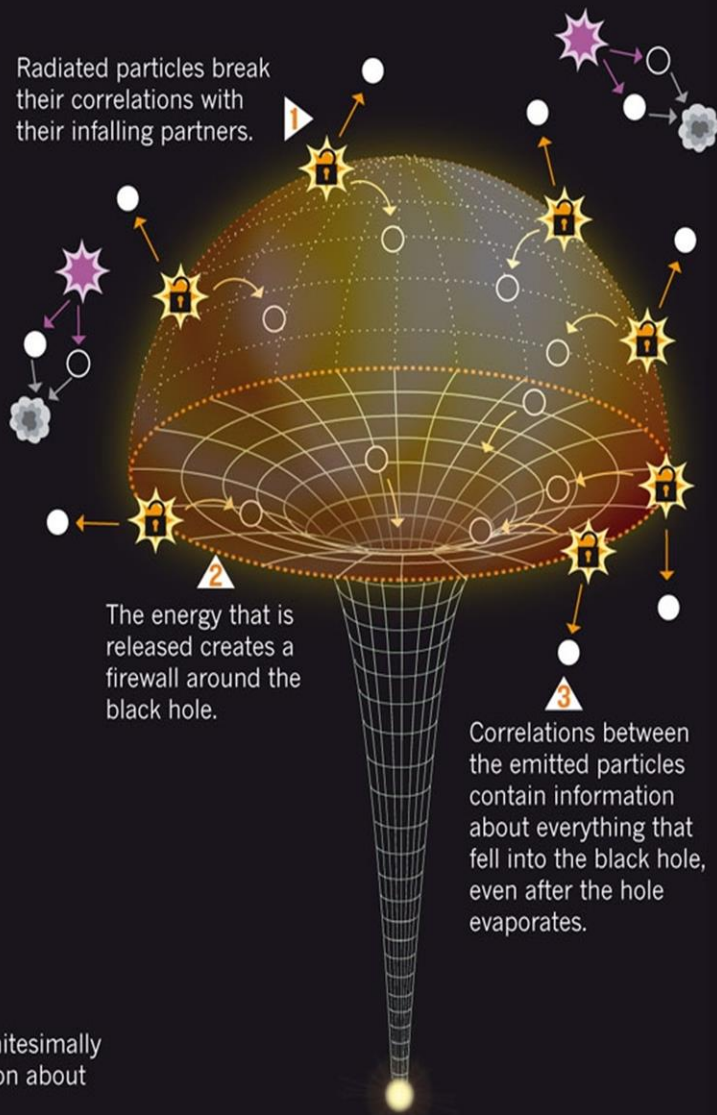
DISAPPEARANCE

When the hole evaporates, all the information disappears with it.



FIREWALL

The information is carried out by quantum correlations among all particles radiated from the black hole.

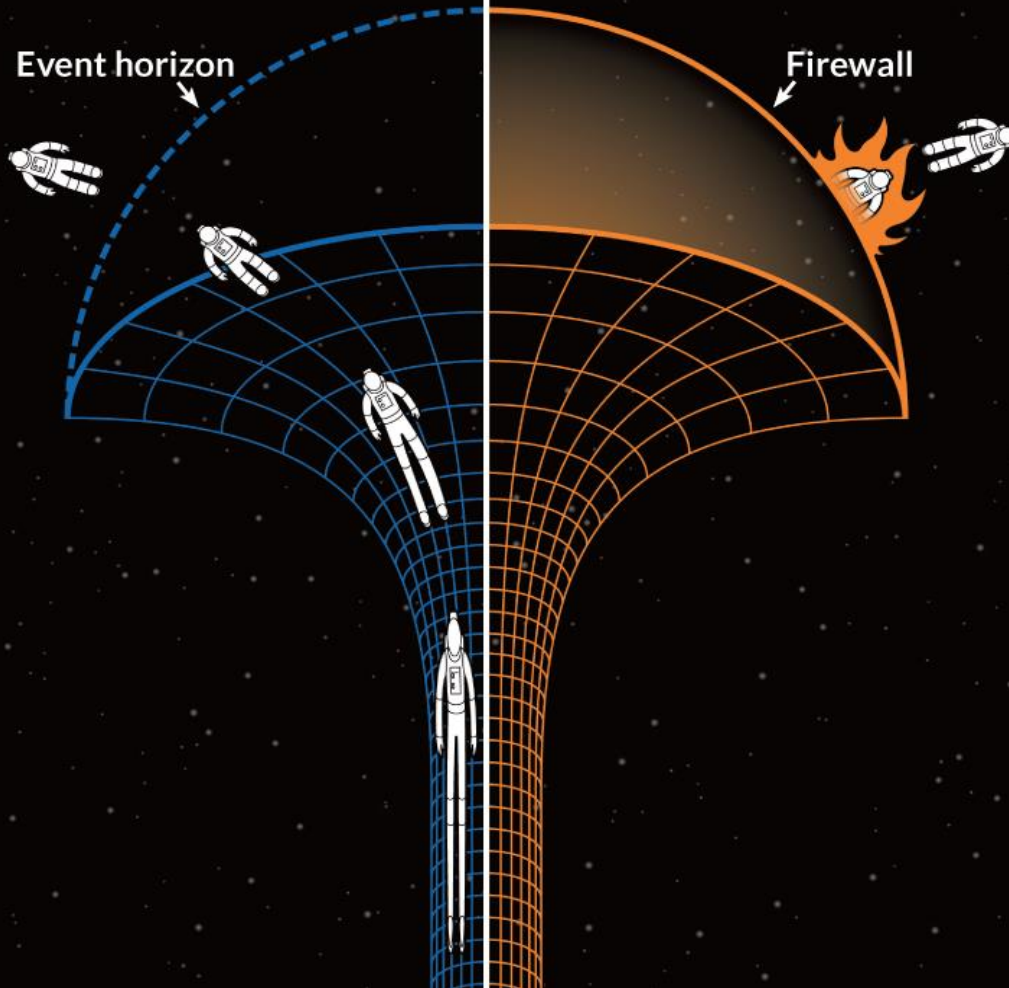


Complementarity

An astronaut falling into a black hole crosses the event horizon without incident, satisfying a prediction of general relativity. The astronaut continues floating along until, approaching the black hole's center, he is spaghettified.

Firewall

A wall of radiation incinerates the unlucky astronaut and blocks entry into the black hole. Information is preserved in this scenario (you can theoretically piece together the astronaut from his ashes), but general relativity is violated.



General relativity:

For a sufficiently large BH, whose curvature is small, objects should pass its horizon uneventfully — “No Drama”

AMPS firewall:

The requirement that Hawking radiation can bring information out from BH would result in the notion of firewall.

Conflict between QM and GR!

Quantum Mechanics

vs. General Relativity





Solutions to the Problem



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journal homepage: www.elsevier.com/locate/physrep

Black hole remnants and the information loss paradox[☆]

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ABSTRACT

Forty years after the discovery of Hawking radiation, the information loss paradox remains a central issue in quantum gravity. If Hawking radiation does indeed lead to information loss, it seems that unitarity is violated. On the other hand, attempts to resolve the paradox, such as the firewall controversy, Amidst this, the discovery of a “remnant” has remained a controversial topic. The “properties” of such an object, if it exists, must be carefully examined. Any proposal must be able to provide a timely review of the current thoughts regarding the information loss paradox. The importance of understanding the paradox remains a possibility. In this context, a black hole remnant that a remnant remains a possibility. The interior geometry, may help resolve the controversy. We hope that this review will shed light on the remnants more critically but also more thoroughly.



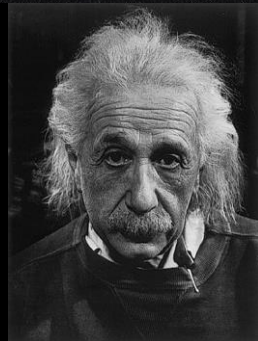
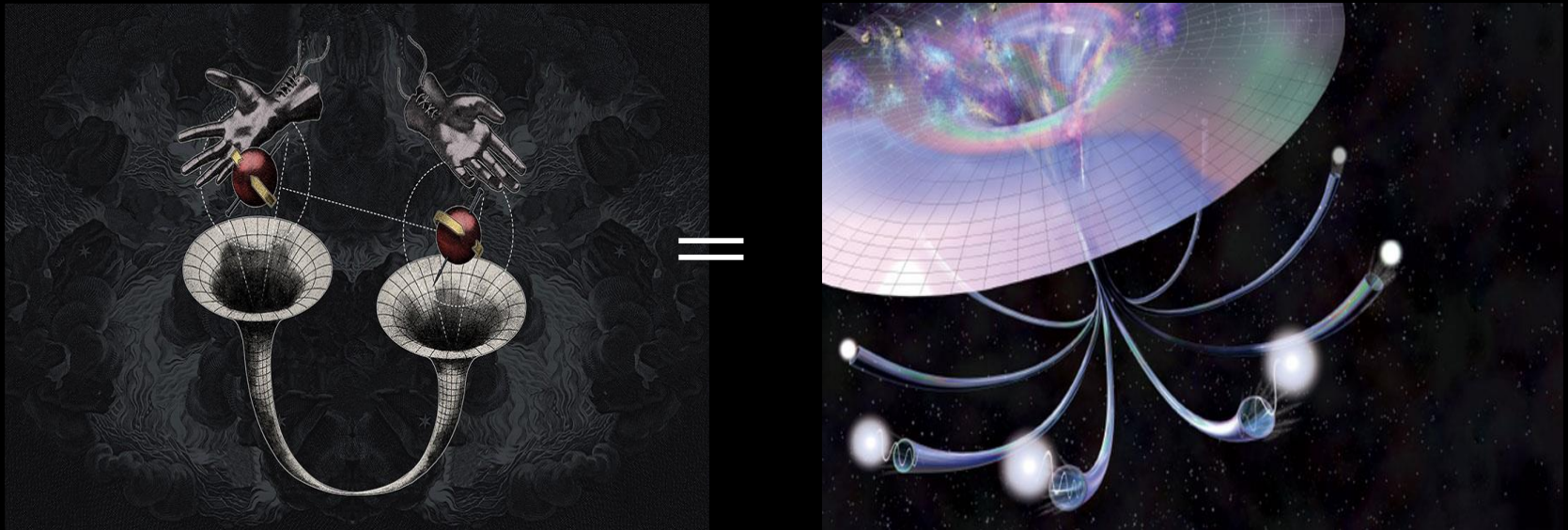
Solution 1: Horizon does not exist

- Media: Hawking said BH does not exist (2014).
- Actually what Hawking said was, Event Horizon may not exist, the only thing real is the Apparent Horizon.
- Apparent horizon can trap matter and lights, but as the BH evaporates, they will be released.
- However, the notion of apparent horizon depends on the choice of the coordinates, and so it's not an invariant statement.

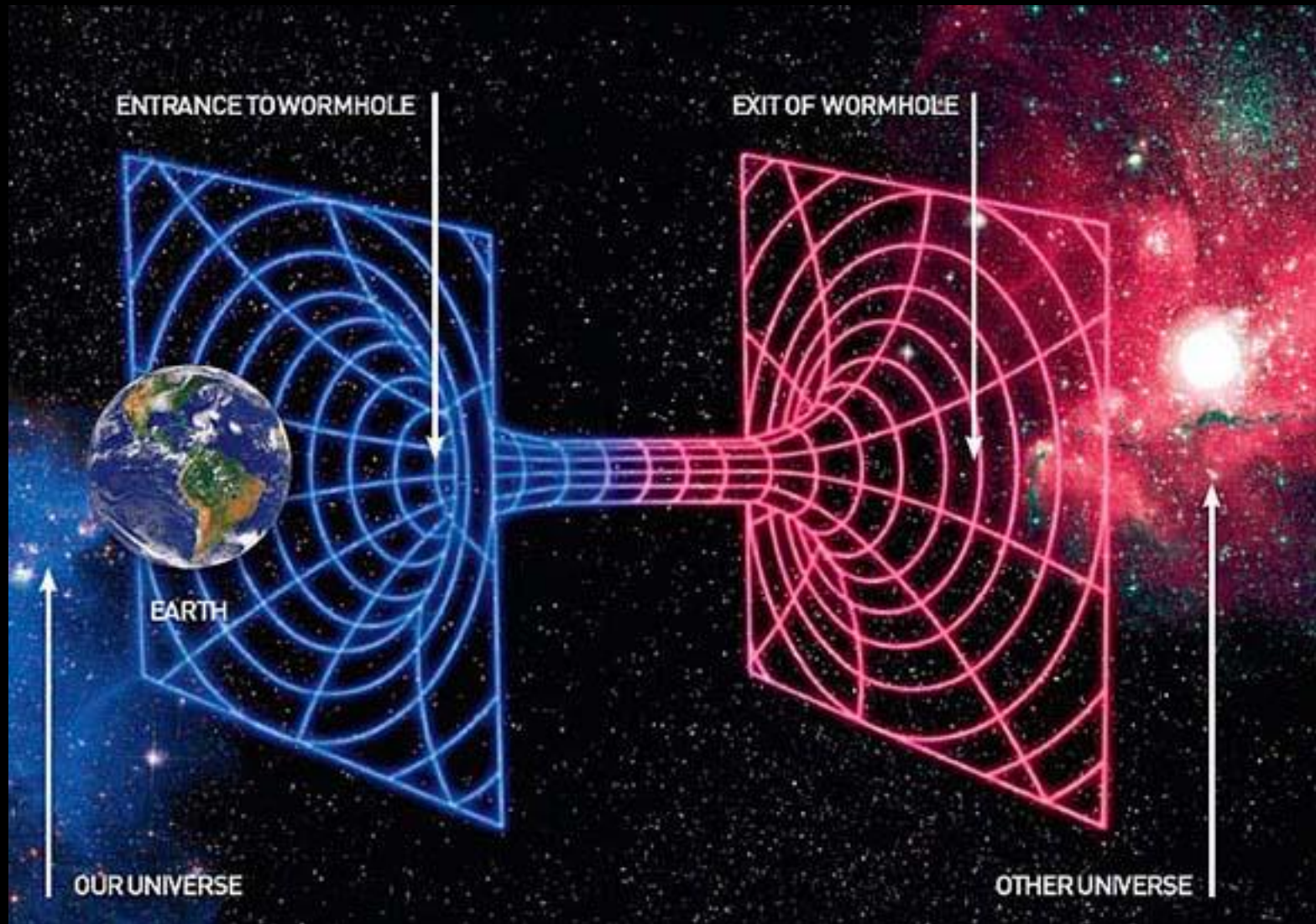


Solution 2: Quantum entanglement is actually equivalent to wormholes

ER (Einstein–Rosen) = EPR (Einstein–Podolsky–Rosen)



Wormhole



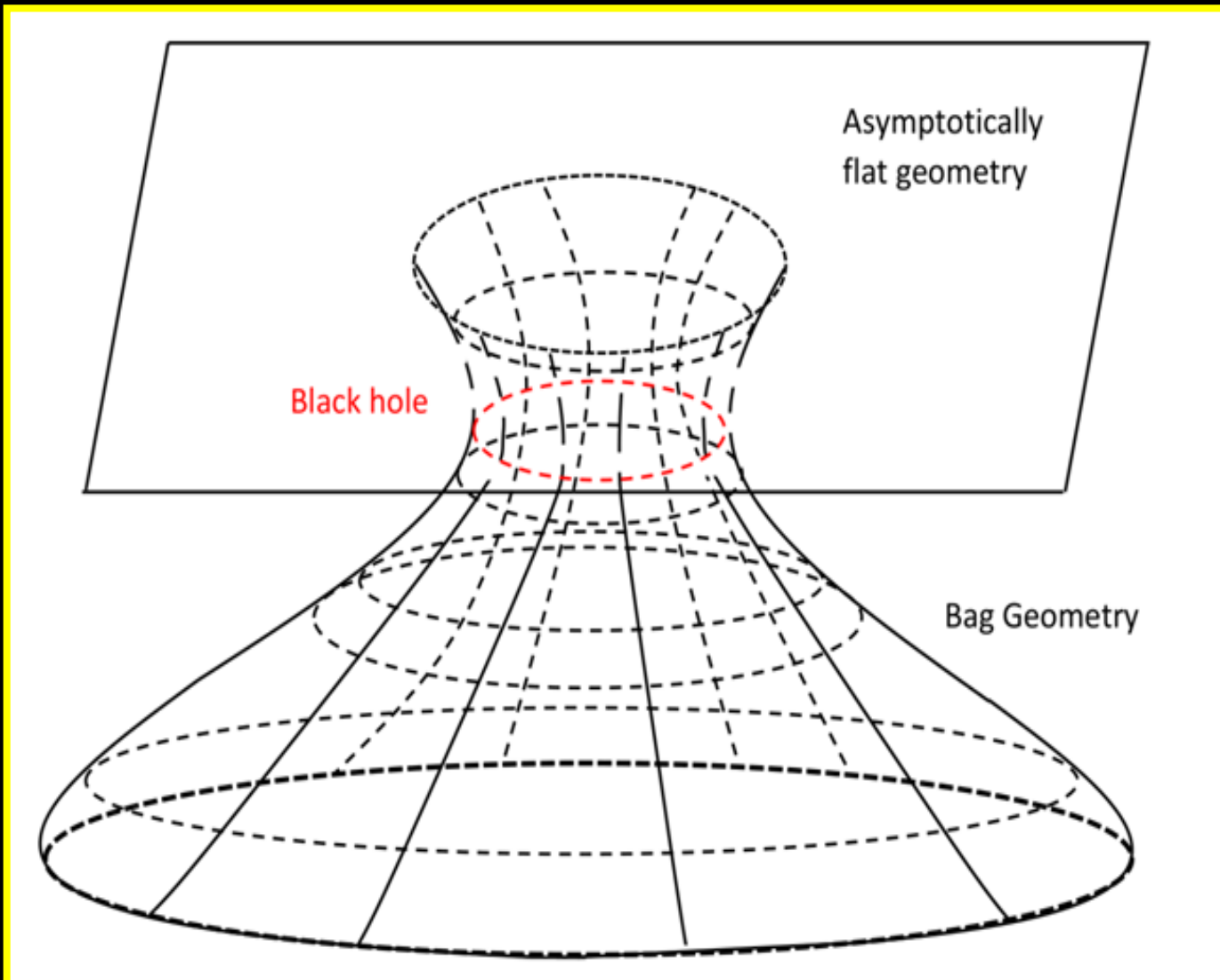
Solution 3: Decoding BH information would take extremely long time

D. Harlow, P. Hayden,
“**Quantum Computation
vs. Firewalls**”, JHEP 06
(2013) 085,
[arXiv:1301.4504 [hep-
th]].



The existence of firewall can only be revealed when the BH information is decoded, but that will take a time longer than BH's lifetime.

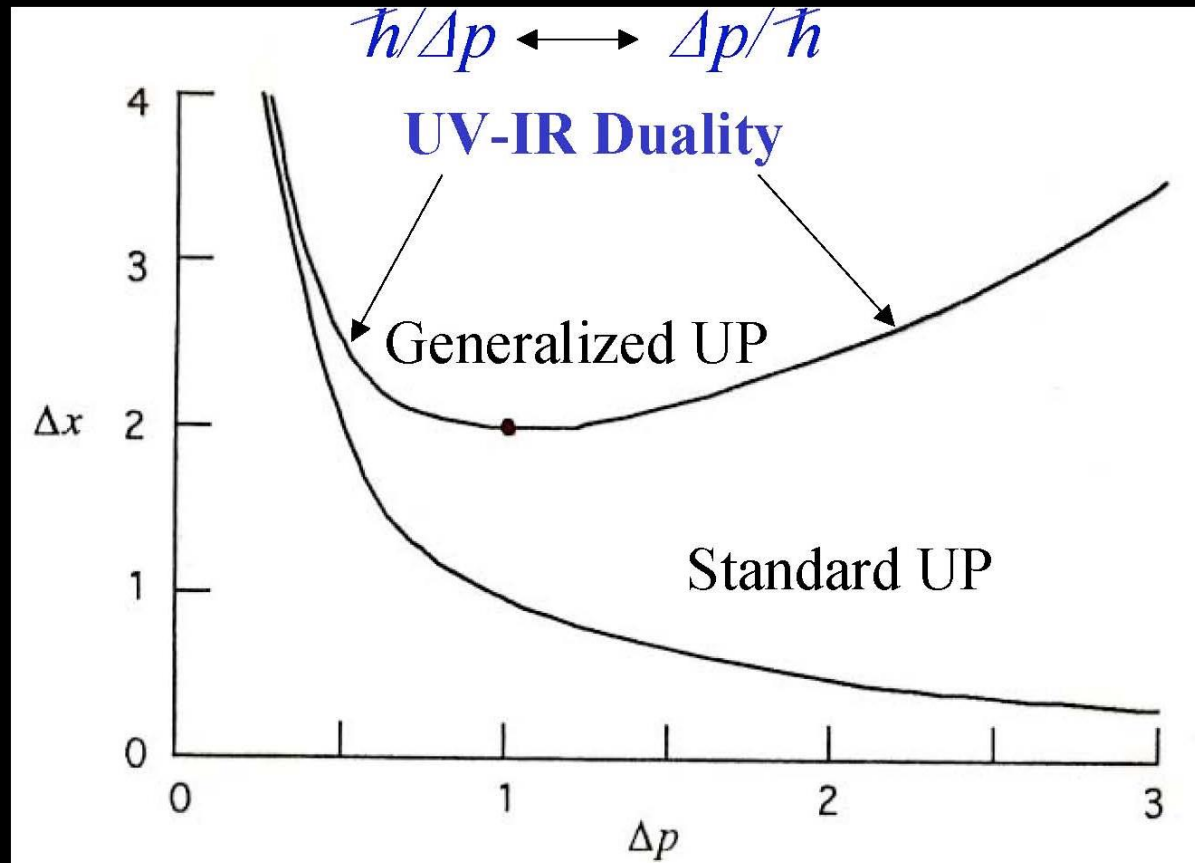
Solution 4: BH Remnant stores the missing information



Generalized uncertainty principle

- Gravitational correction to QM

$$\Delta x > \hbar/\Delta p + \xi^2 l_p^2 (\Delta p/\hbar)$$



GPU leads to BHR

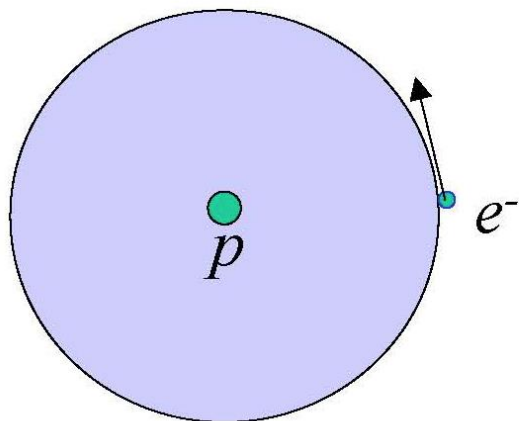
- Generalized uncertainty principle argues for the existence of a minimum length (Planck length)
- Repeating what Hawking did using standard UP, invoking GUP to BH evaporation.
 - ➡ Hawking evaporation would come to a stop when BH radius reaches Planck length
 - ➡ Black hole remnant
- BHR can be a throat to the “bag of gold”, a wormhole, a large interior volume.

- BHR is stable against further collapse due to its dynamics via GUP, not by symmetry principle.
- Analogy: Stability of Bohr atom protected by the standard uncertainty principle, not by symmetry.

Standard Uncertainty Principle

$$\left. \begin{array}{l} \Delta x \Delta p > \hbar \\ E = p^2/2m - e^2/r \end{array} \right\}$$

$$\delta E = 0 \rightarrow r_{\min} \sim \hbar^2/me^2 = r_{\text{Bohr}}$$

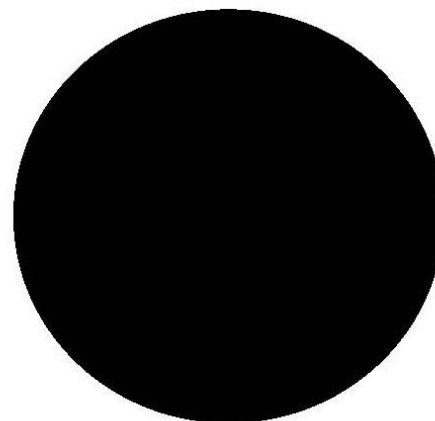


Bohr Atom

Generalized Uncertainty Principle

$$\left. \begin{array}{l} \Delta x > \hbar/\Delta p + \xi^2 l_p^2 (\Delta p/\hbar) \\ M_{\text{BH}} = c^2 r_s/2G \end{array} \right\}$$

$$\delta M_{\text{BH}} = 0 \rightarrow r_{\min} \sim 2\xi G m_p/c^2 = \xi l_p$$



Black Hole Remnant

After Black Hole Evaporates

臺大校訊
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[illegible]

下於臺灣創辦。華教探源過去兩年在臺灣、香港、新加坡、馬來西亞、中國大陸、甚至歐洲各地，都引起華教熱的風潮。這兩年他來到臺灣，其實有非常多熱情且極具創見能量的在亞洲各國講學的經驗中，華教探源發現臺灣老師們的教學熱誠，其實在亞洲確係許多國家。

而不成其說呼歐美國家社會不隻只看到一些表現不好的老師，更應該看到臺灣老師許多為了孩子而費盡心機、努力創立新教學的好老師，給他們的肯定。如果社會能多體惜這些好老師，臺灣的教育就會有好的未來！

Artio's concept illustrating a supermassive black hole with millions to billions times the mass of our sun (Image: NASA/JPL-Caltech)

這聽起來可能像是一本很俗的言情小說，但物理學家卻用「赤裸」(naked)、「黑戲劇性」(no-drama)這一類的形容詞，企圖完整描述宇宙間最炙手可熱的話題，那就是人類認知宇宙中最奇詭的物體——黑洞。

過去四十年裡，物理學家在研究黑洞物理的數學結構時，提出一個怪異的想法：黑洞其實應該有「一道火牆」(firewall)，任何東西如舉例

圖「翻牆」進入黑洞，它徹底摧毀。然而，在著名《物理評論》(Physical Review Letters) 文章《赤裸的黑洞》(Naked Black Holes)，對這個觀點質疑。該論文共同作者臺灣大學物理系陳正解稱，這篇文章的目的，想以一個更奇怪的想法，那些導致「火牆悖論」黑洞物理基本悖論。

此篇論文共同作者包括北歐理論物理研究中心(Nordita)研究員王元鼎(Yen-Chin Ong)博士、加拿大阿爾伯塔大學(University of Alberta)傑學(Don Page)教授、京都大學佐佐木謙(Misao Sasaki)教授、及臺大梁次震宇宙學中心研究員陳東柏(Dong-Ian Yeom)博士。人類對於黑洞的概念來自愛因斯坦的相對論：一個使時空扭曲的巨大物體，當於

拉拔或壓縮。如果一個不穩定的物體有了一個穩定事件區域，它就會被「穩定」這個模型，他就會流變成另一個模型。

先不說這是明顯的謊化，自以來黑爾姆德是迷入這人以描述，1970年代霍金（Stephen Hawking）發現黑洞並非黑，實際上某些區域可以透過光線傳遞而逃出從中。這也說明了霍金所說的「霍金輻射」自此以後黑物物理的領域就成了在奇異現象的源起，需要量子理論與相對論相結合的數學才能完整解釋。在黑物物理過去幾十年的40年中，有一突出而尚未決的問題，「信息喪失悖論」，這也是霍金提出的，這個悖論是說，如果一個以光速以光速的數學切入大爆炸，如拿阿爾伯特大爆炸與量子物理

<http://www.esguides.org/photoshop-tutorials/fire-cloud.html>

A circular ring of fire with a black center, set against a black background. The fire is bright orange and yellow, with a black center. The ring is perfectly circular and has a thick, glowing border. The background is solid black.

此一假設很讓愛因斯坦的廣義相對論陷入困境。它意味著，當一個物體遭遇過事件界時該物體將會以何種異常狀態，為了解決這個矛盾，他們提出最保守的解決方案：在黑洞的表面上確實有「火牆」的存在，它變化成任何一個普通宏觀的物體。這個主張絕對嚇唬人吃驚，因為一個相當大的黑洞，例如馬中微授授最近發現的超大黑洞，它的速率幾乎是極乎其微，所以廣義相對論可以完全適用而不需要加入量子場論。

因此我們期待任何物質在穿越過事件界時該物質不應變而不應該被強制焚化。陳正淼教授指出：「所謂的「火牆」指的是我們所認為的廣義相對論表面，有一個極高溫度區域，它會破壞任何穿入的東西。

[illegible]

圖 1 為與會者與有關同事在討論「Yukawa Institute for Theoretical Physics」。

圖 1 為與會者與有關同事在討論「Yukawa Institute for Theoretical Physics」。圖中人物包括：左起：Prof. Dr. Hui Dong, Yoon, Wei-Chi Cheng, Philip Chen, Chin-Ping, Yutaka Nakano, and Mitsuo Nakano。

個部分，依然是個謎。

在量子力學中，基於量子「確定性」和「可逆性」這兩個原則，信息在任何物理過程中，始終被保留。然而，由於物質帶訊息落入黑洞，在穿越事件視界的過程中，物質中的信息顯然被消滅。一段時間，這個表面上的矛盾一直困擾著物理學家。一個悖論本身的出現就是導向於量子輻射。這表明物質可以從黑洞輻射出，但是分析顯示，在輻射的初期並沒有大量攜帶原先掉進黑洞的信息。

在2012年，一群物理學家研究這個悖論時發現，導致這一悖論的三個基本假設不可能都是一致的。也就是說「統一性」與「局部量子場論」這兩個基本原則與「無創制」的假設相互矛盾。

陳教授於 2015 年輪休，並赴京都大學「湯川理論物理研究所」(Yukawa Institute for Theoretical Physics)擔任訪問學者，期間主辦了一個小型研討會 (Molecular-Type Workshop)，邀請多國際專家研究「黑洞資訊遺失悖論」，《赤裸的黑洞遺產》論文即是這次研討會的成果。



Molecular-type Workshop on Black Hole
Information Loss Paradox, YITP, Kyoto, May 2015

Hideki Yukawa Memorial Hall



Yukawa Institute for Theoretical Physics



The five authors of the paper with another colleague during the discussion at the Yukawa Institute for Theoretical Physics: (L to R) Dong-han Yeom, Yen Chin Ong, Pisin Chen, Don Page, Yasusada Nambu, and Misao Sasaki.

$$\Delta M \sim \sqrt{N} \omega \sim \sqrt{f M^2} \frac{1}{M} = \sqrt{f}$$

$$\text{At } f \sim \frac{1}{M}, \Delta M \sim \frac{1}{\sqrt{M}}$$

$$\sim 10^{-19} \sim \text{GeV}$$

$$\Delta R \sim \Delta M \sim \sqrt{f}$$

Each particle localizes to

$$\bar{\delta R} \sim M; N \text{ to } \delta R \sim \frac{M}{\sqrt{N}} \sim \frac{1}{\sqrt{f}}$$

In this case $\Delta R = \delta R$ at $f=1$,
where $\Delta R \sim \delta R \sim 1$

$$\Delta t_{\text{evap}} \sim M^2$$

BH LHR EHR

Each particle has $p \sim \frac{1}{M}$.

$M \rightarrow (1-f)M$, fraction f evaporated

Number of particles $N \sim f M^2$

$$\Delta P \sim \sqrt{N} p \sim \sqrt{f M^2} \frac{1}{M} \sim \sqrt{f}, \Delta v \sim \frac{\Delta P}{M} \sim \frac{\sqrt{f}}{M}$$

$$t \sim f M^3, \Delta x \sim \Delta v t \sim f^{3/2} M^2$$

Each particle localizes to $\delta x \sim M$

$$N \text{ particles } \delta x \sim \frac{M}{\sqrt{N}} \sim \frac{M}{\sqrt{f M^2}} = \frac{1}{\sqrt{f}}$$

$$\Delta x \sim \delta x \text{ at } f^{3/2} M^2 \sim f^{-1/2} \Rightarrow f^2 M^2 \sim 1, f \sim \frac{1}{M}$$

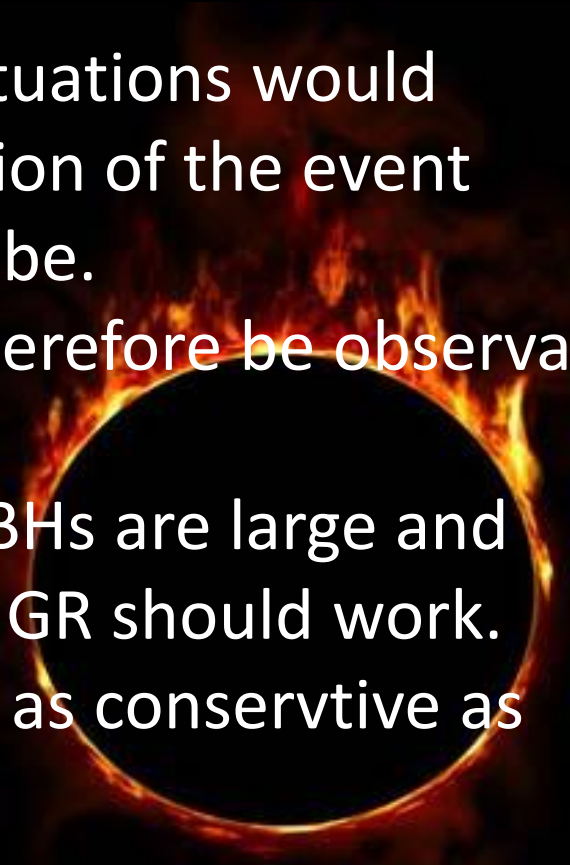
$$\text{There } \Delta x \sim M^{-3/2} M^2 = M^{1/2}$$

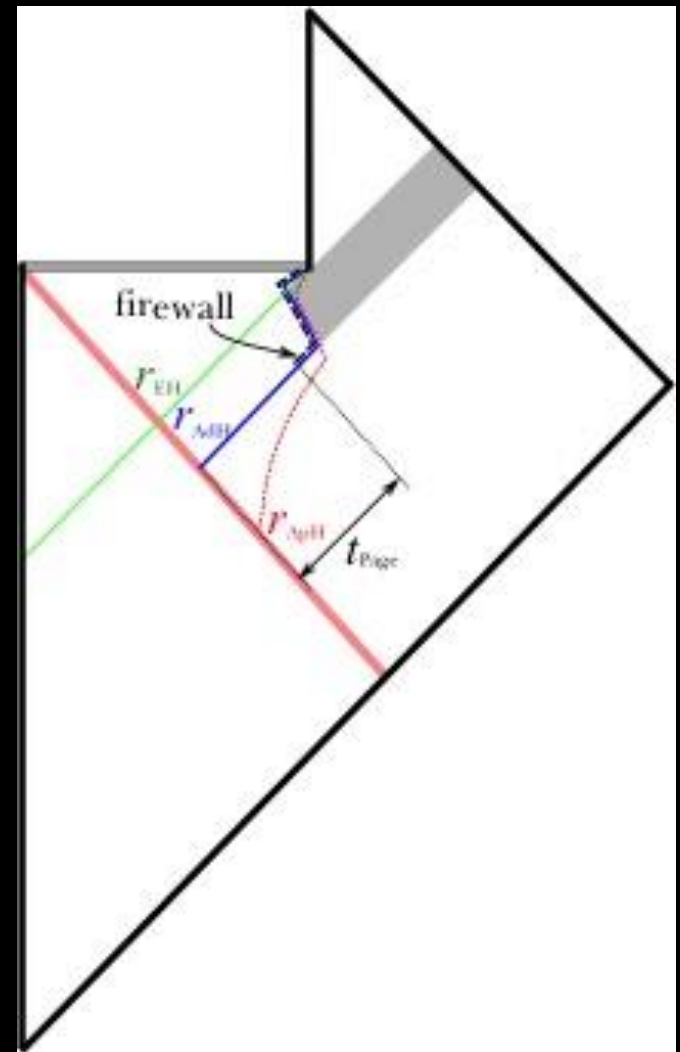
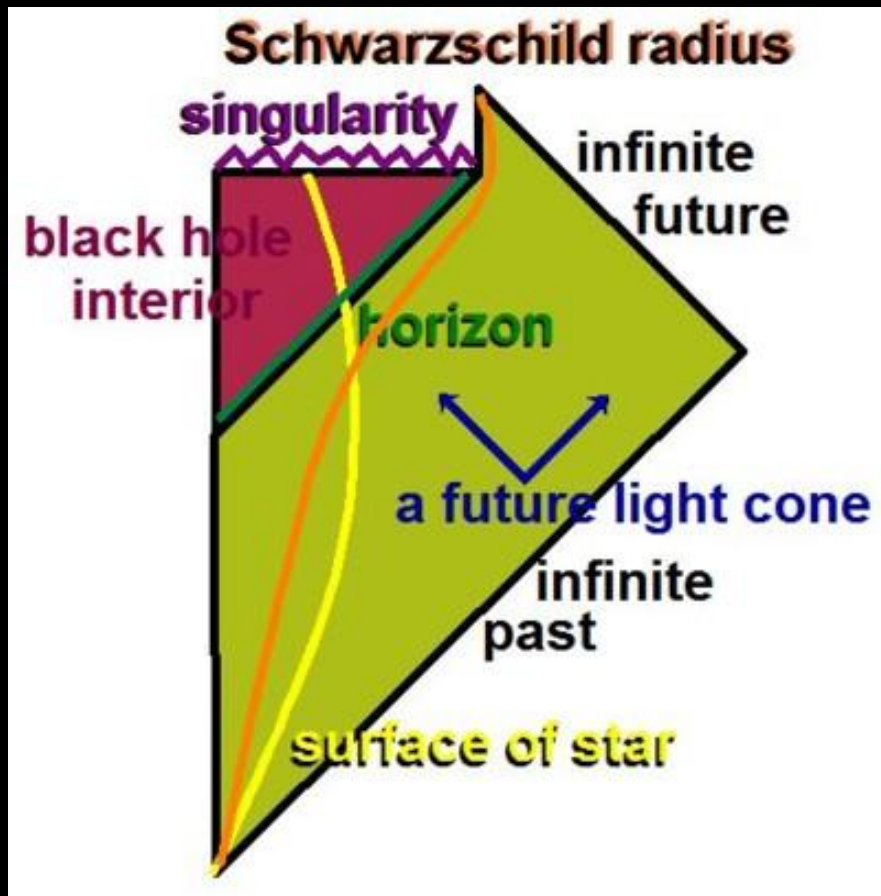
$$\delta x \sim \frac{1}{\sqrt{f}} \sim M^{1/2} \rightarrow M_0^{1/2} \sim 10^{\frac{38}{2}} = 10^{19} \sim 10^{-14} \text{ cm}$$

$$N \sim f M^2 \sim M \sim 10^{38} \quad \frac{\delta x}{M} \sim \frac{1}{\sqrt{f} M} \ll 1 \text{ for } f \gg \frac{1}{M^2}, N \gg 1$$

How would firewalls become naked?

- As a quantum process, fluctuations are inevitable in Hawking radiation.
- BH's backreaction to these fluctuations would “teleologically” cause the migration of the event horizon inside of where it would be.
- The supposed firewall would therefore be observable to distant observers, or “naked”.
- On the other hand, stellar size BHs are large and have small curvatures; therefore GR should work.
- So the notion of firewalls is not as conservative as AMPS argued.



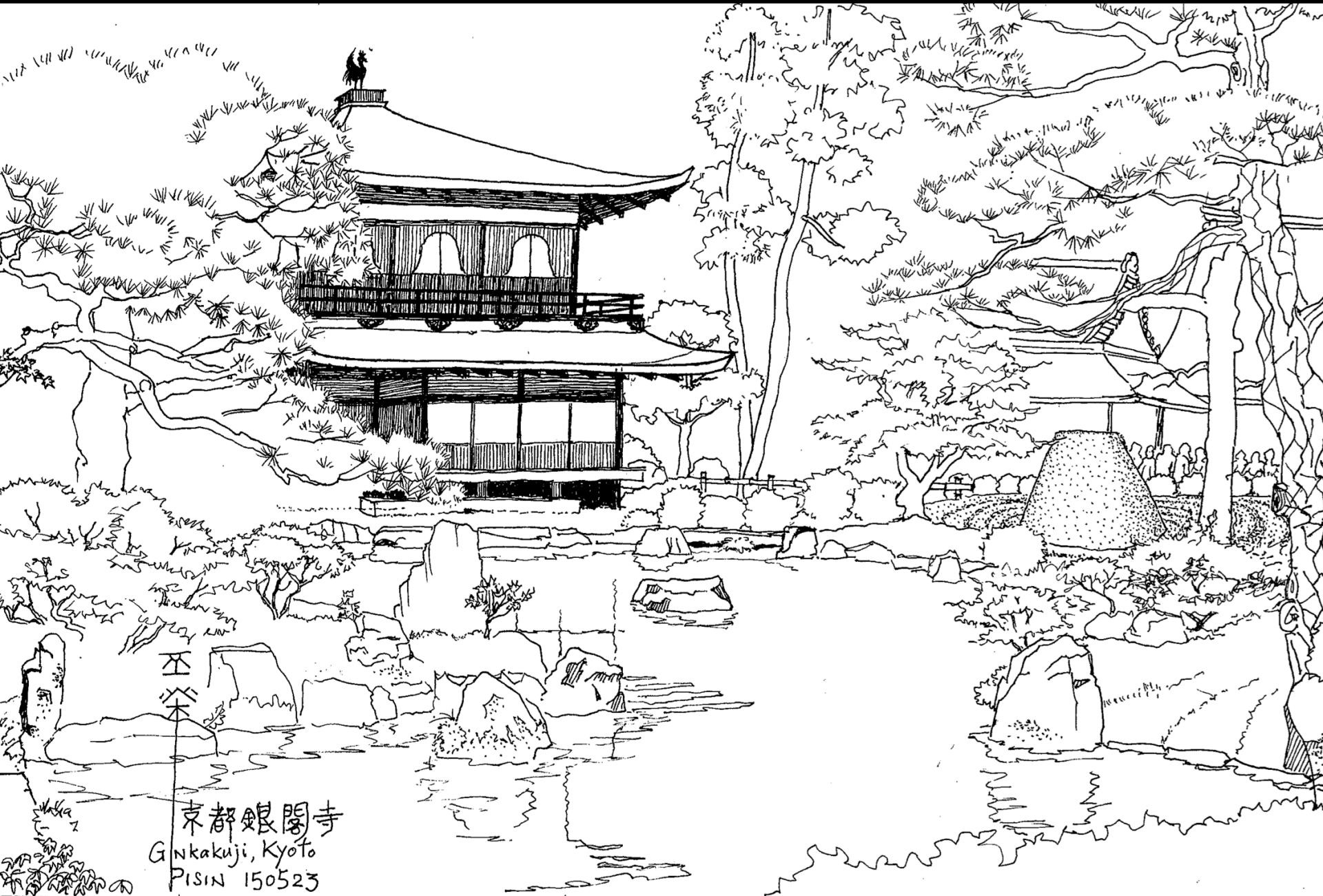


A conceptual Penrose diagram illustrating the formation of a Schwarzschild black hole from a collapsing null shell, and its subsequent Hawking evaporation. Here, the event horizon (r_{EH}) has been shifted inward some distance from the adiabatic horizon (r_{AdH}) due to a quantum fluctuation. This renders the firewall (denoted by the dashed curve that appears after the Page time t_{Page}) naked. The apparent horizon (r_{ApH}) is also shown for comparison, but light rays can escape from inside it, since the black hole is shrinking.



Kyoto Ginkakuji Temple (銀閣寺)

Kyoto Ginkakuji Temple (銀閣寺)



京都銀閣寺
Ginkakuji, Kyoto
PISIN 150523

A photograph of the Kyoto Philosopher's Path. The path is a stone-paved walkway that curves gently through a lush, green environment. On the left side of the path, there is a calm canal with a small bridge in the distance. The path is flanked by large, mature trees with dense green foliage, creating a canopy effect. Sunlight filters through the leaves, casting dappled shadows on the path. To the right of the path, there are various green plants and a traditional Japanese building with a tiled roof. The overall atmosphere is peaceful and serene.

Kyoto Philosopher Path (哲學之道)

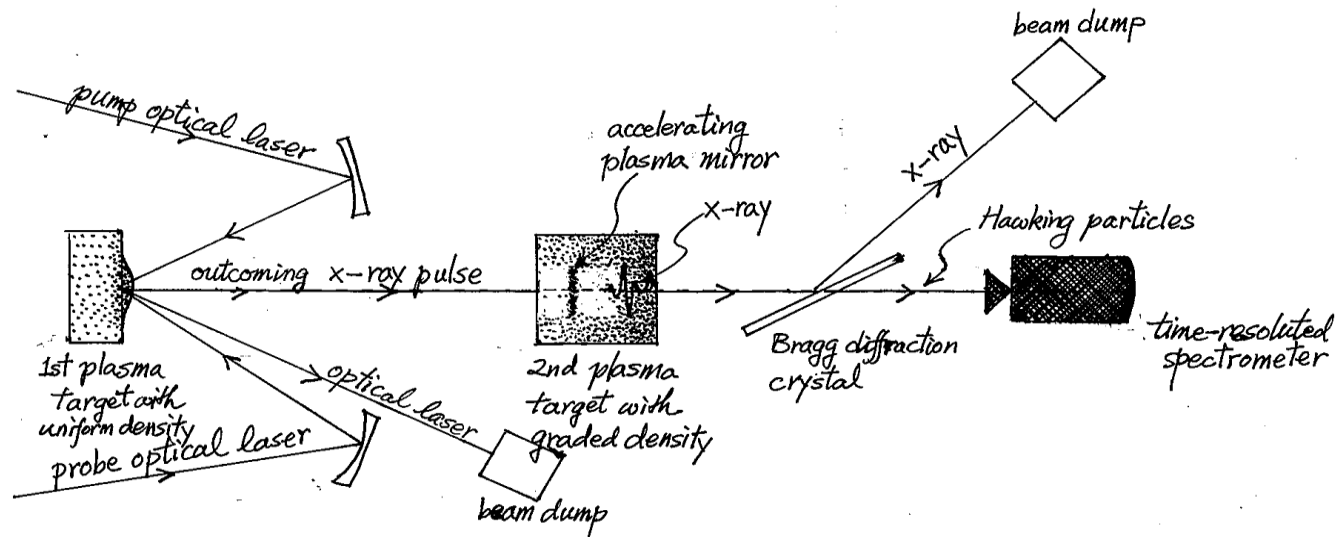
Kyoto Philosopher Path (哲學之道)



京都哲学の道
Philosopher Path, Kyoto
PISIN
50529

Accelerating Plasma Waves

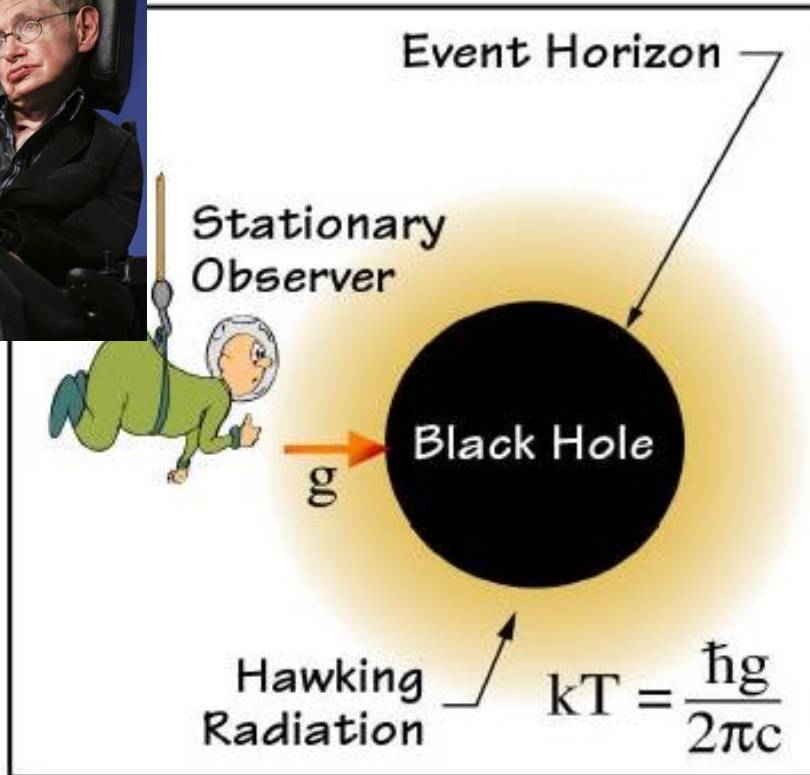
A conceptual design of the accelerating plasma mirror experiment



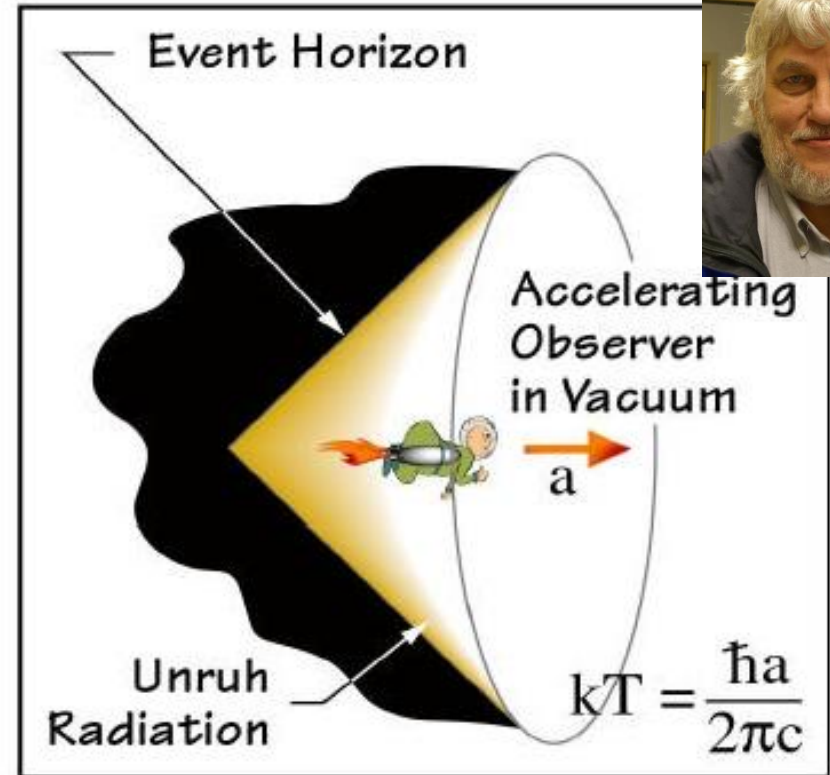
Schematic diagram for an accelerating plasma mirror experiment to investigate black hole information loss paradox

Unruh Effect vs. Hawking Effect

EVENT HORIZONS: From Black Holes to Acceleration

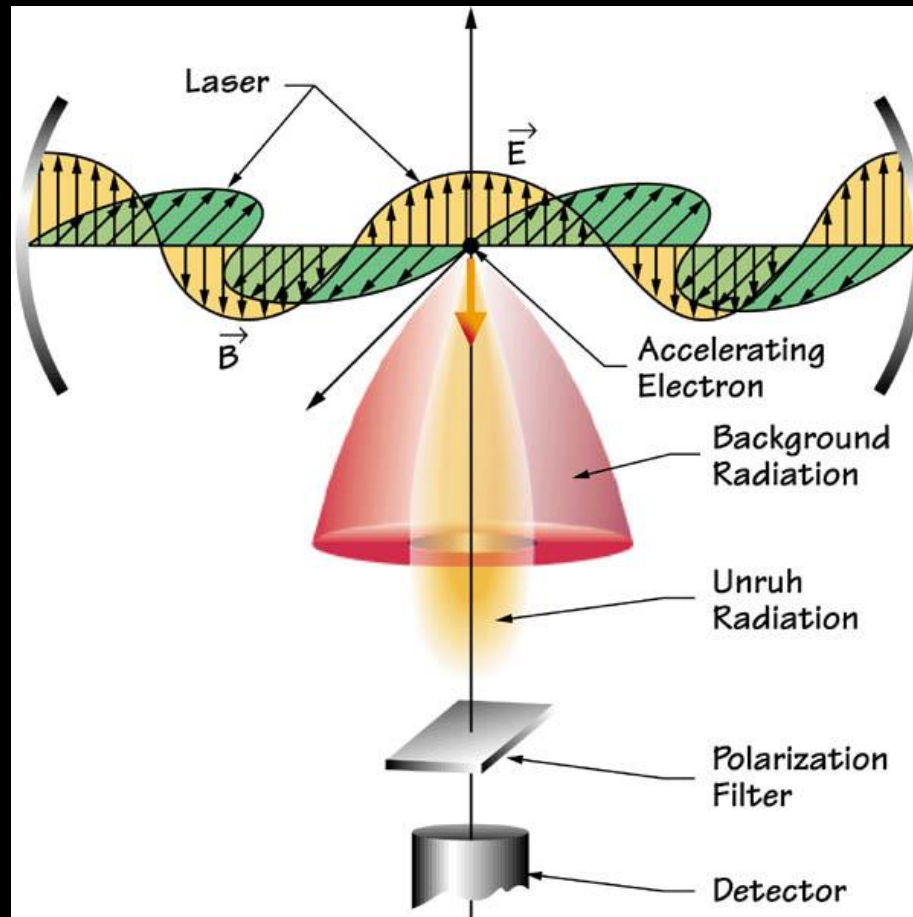


A stationary observer outside the black hole would see the thermal Hawking radiation.



An accelerating observer in vacuum would see a similar Hawking-like radiation called Unruh radiation.

Proposed Unruh effect experiment (Chen-Tajima, 1999)



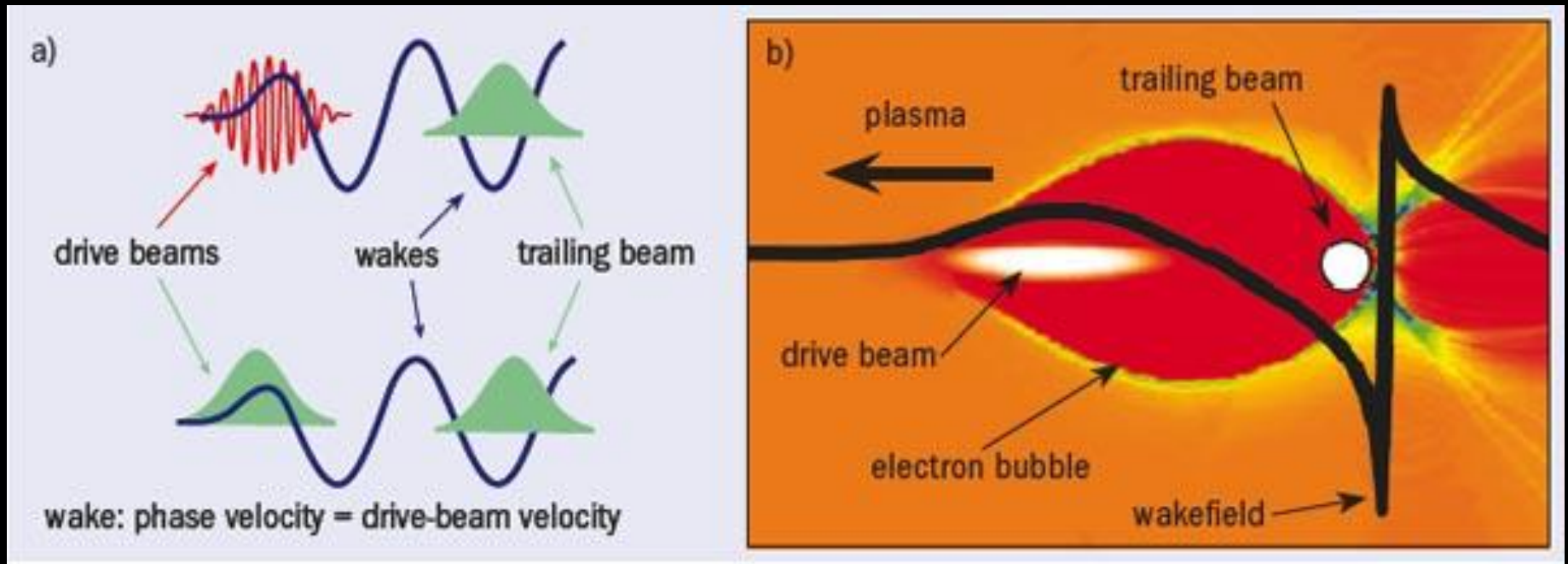
Schematic Diagram for Detecting Unruh Radiation

Fig. 2

Plasma wakefield acceleration

Tajima-Dawson (1979)- Laser driven

Chen-Dawson-Huff-Katsouleas (1985)- Particle beam driven



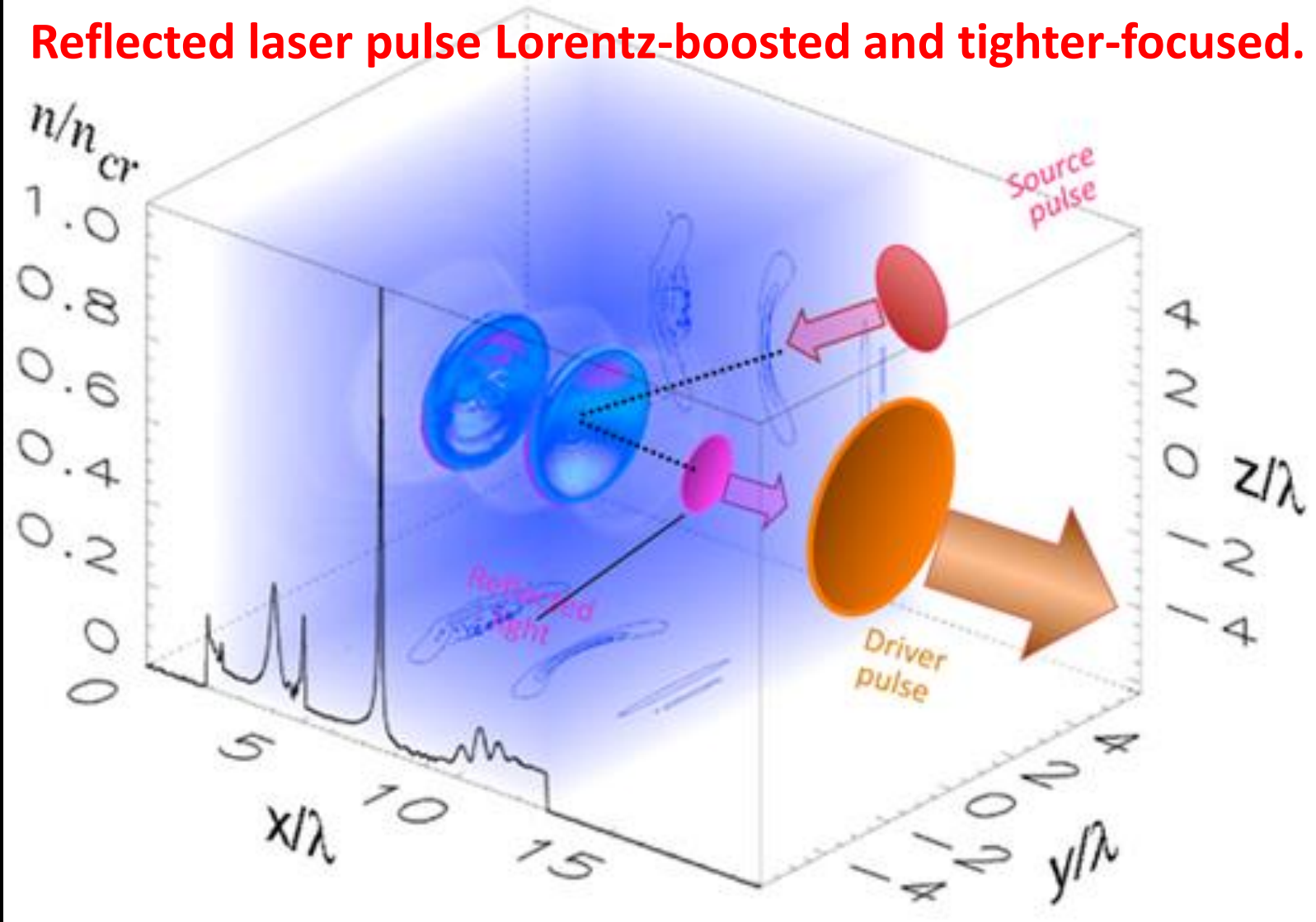
SLAC & LBL- Acceleration of O(100) GeV/m observed!

AWAKE- A new experiment at CERN

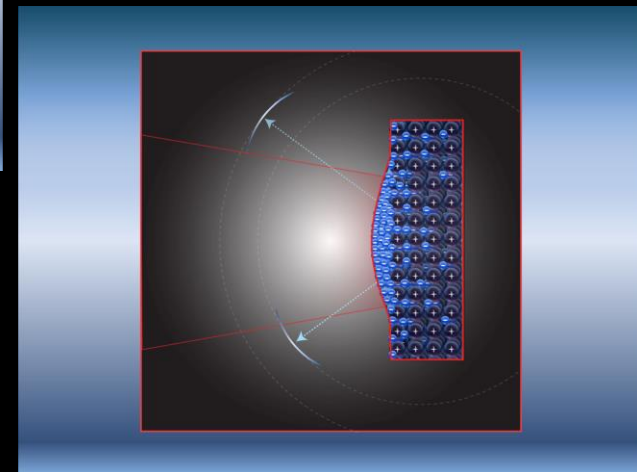
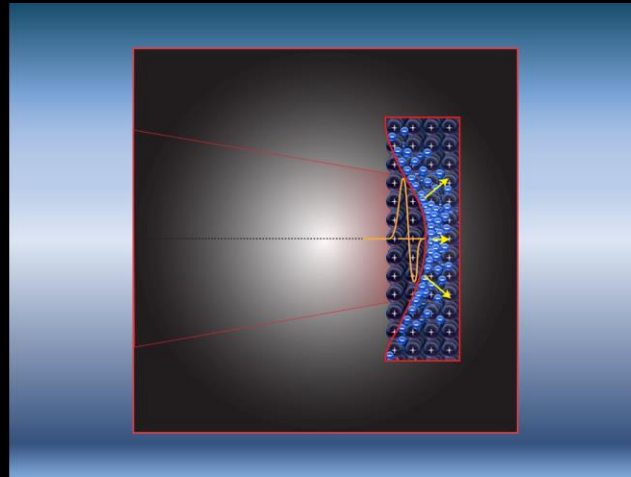
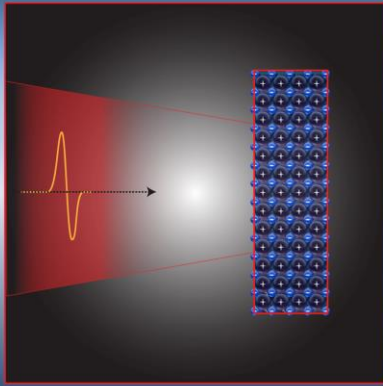
Relativistic Plasma Mirror

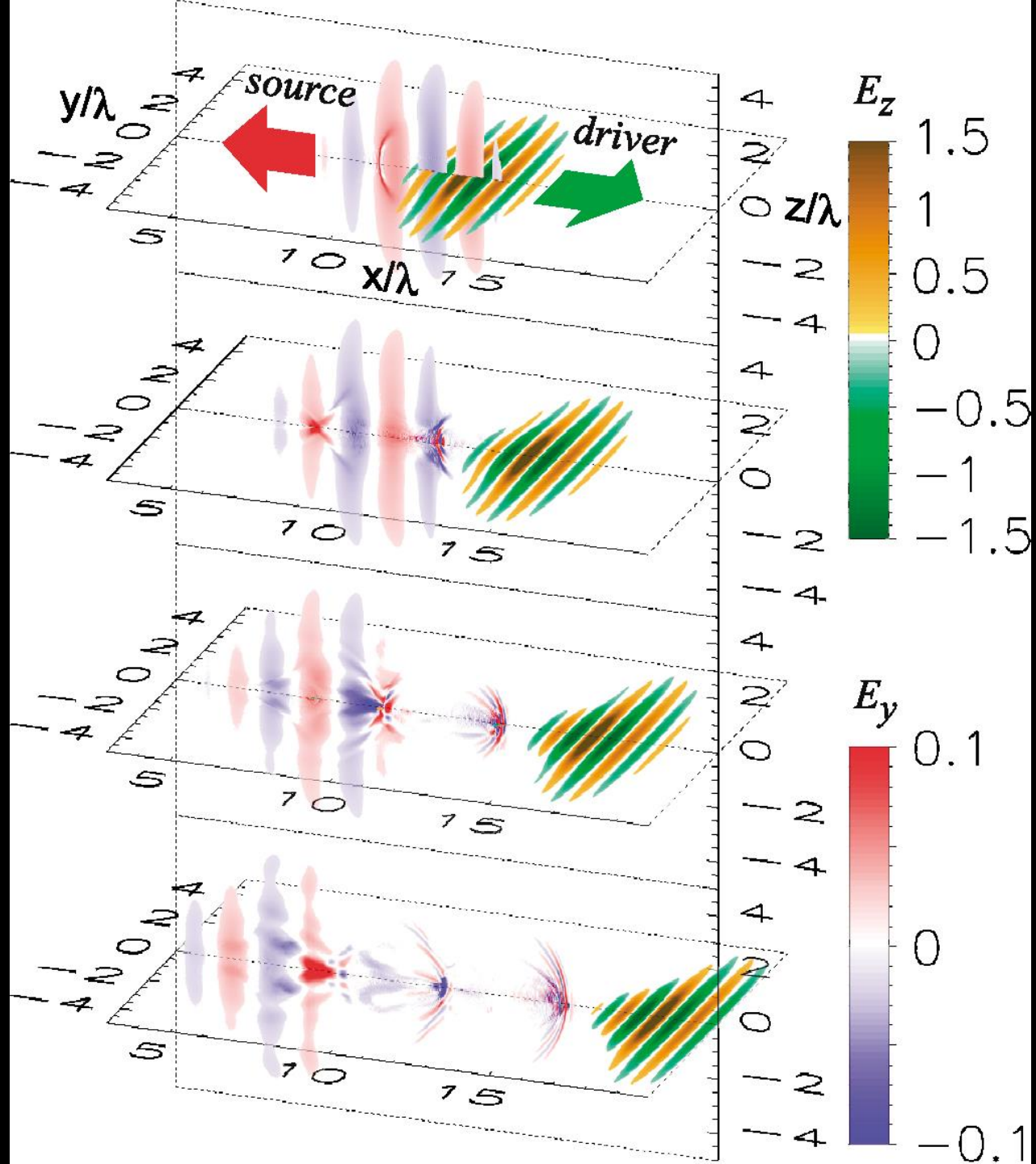
Bulanov, Esirkepov, Tajima (2003)

Reflected laser pulse Lorentz-boosted and tighter-focused.



Plasma mirror can also be created by laser bouncing off the target





Plasma wakefield in the nonlinear regime acts like a tsunami



Accelerating plasma mirror

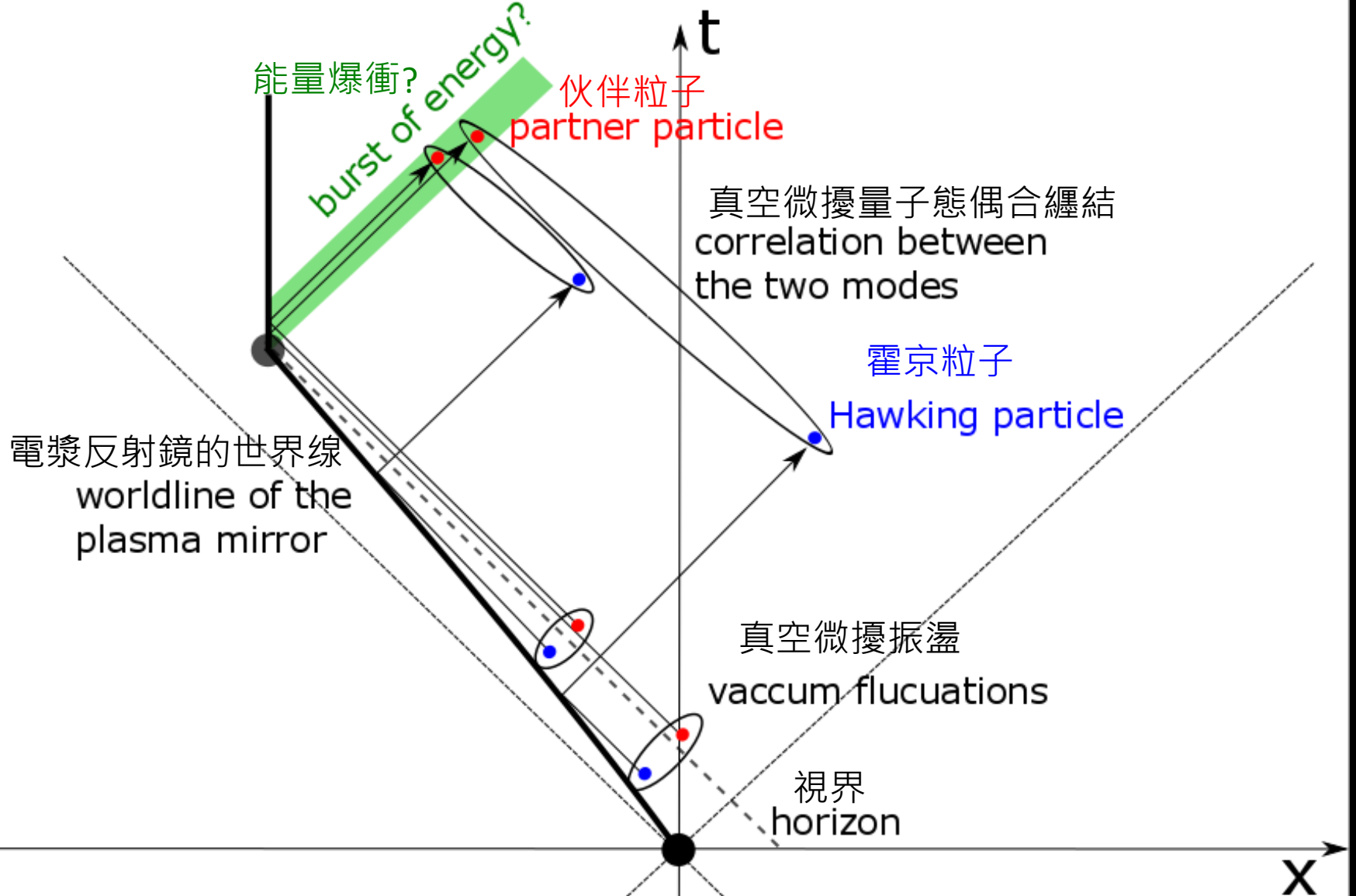
- Born relativistic
- Laser velocity in plasma can be accelerated and therefore its wakefield
- Acceleration can increase in time and stop abruptly

What can it offer?

- Investigation of correlation of partner modes and possible final outburst of energy

What it cannot offer?

- Being in flat space, unitarity preserved: no loss of information
- No singularity either



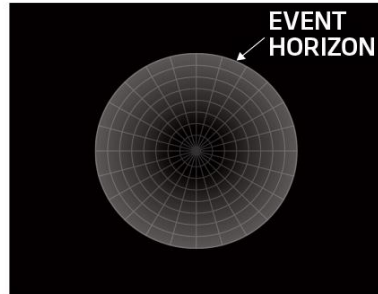
How would accel. plasma mirrors reveal the secrets of black hole information loss paradox?

Summary – The war continues to rage

Brief history of black holes

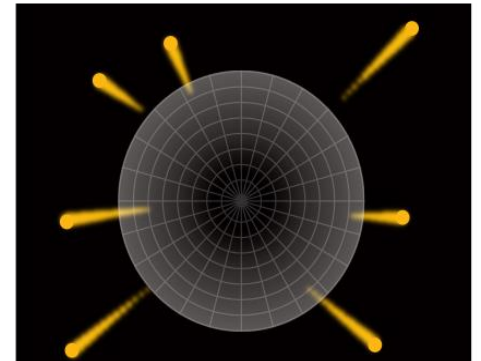
1916

Black holes emerge from general relativity: nothing, not even light, escapes the event horizon



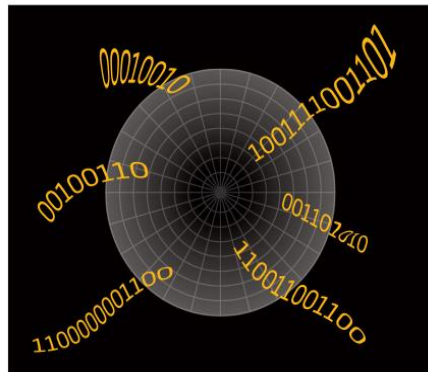
1974

Black holes emit **Hawking radiation** thanks to quantum mechanics



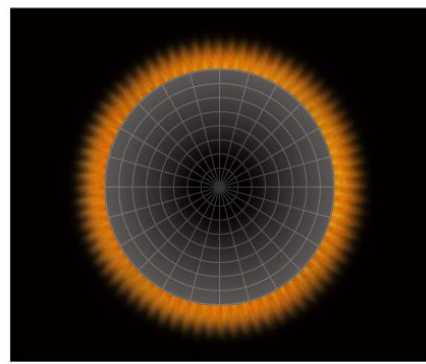
2004

Hawking accepts that **information escapes** from black holes



2012

Escaping information ignites **firewall**, which can't be reconciled with general relativity



2016

Firewalls would be naked

