

# Evolution of Charged Black Holes in Anti-de Sitter Spacetime and the Firewall Controversy

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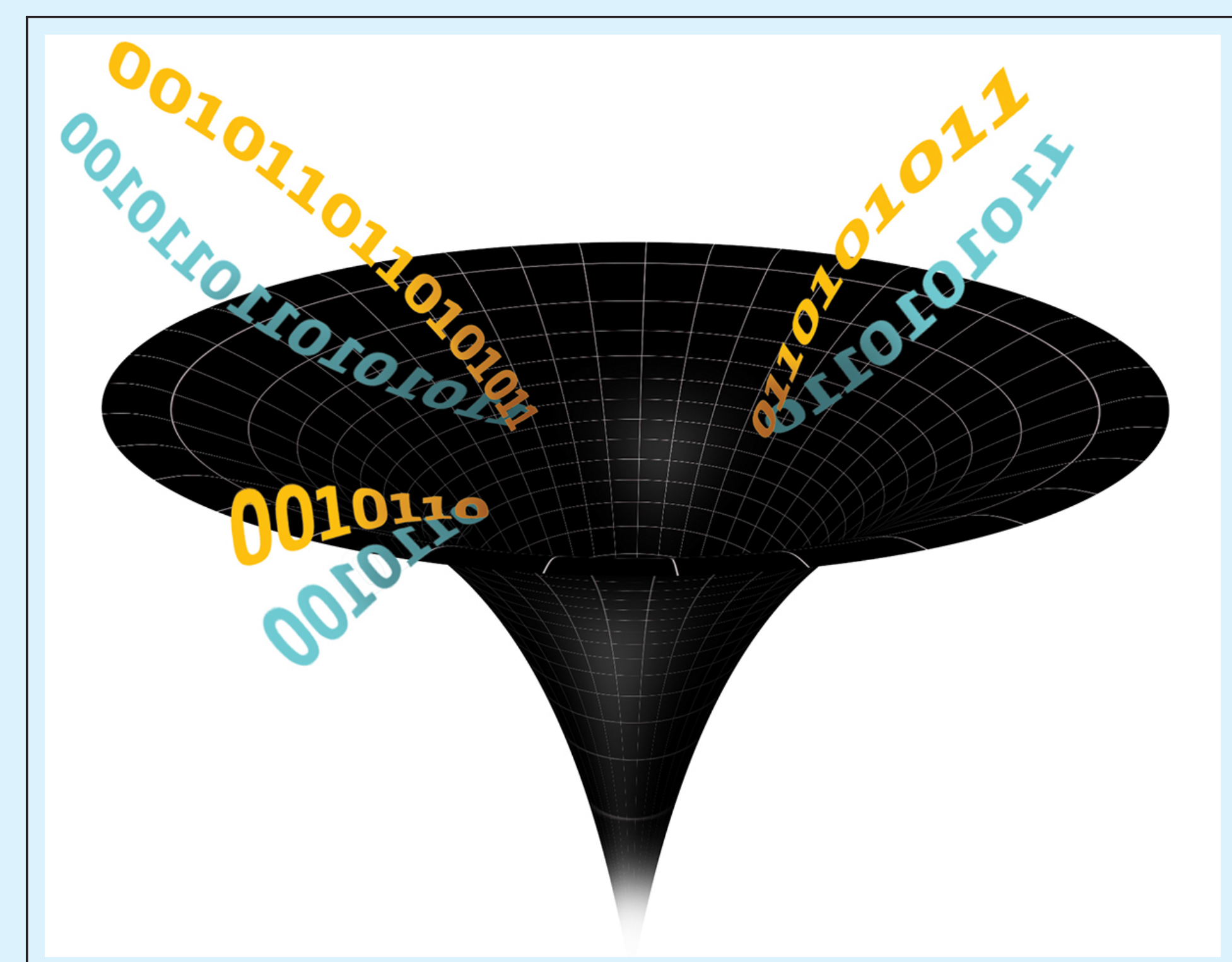
## Abstract

40 years since the discovery of Hawking radiation, its properties and consequences remain obscure. One important problem concerns the *entire evolution history* of evaporating black holes. This is of paramount concern in view of the Information Loss Paradox and the recent firewall controversy. Since black holes inevitably pick up electrical charges during their long life time, it is crucial to study the behavior of *charged* evaporating black holes. We study the evolution of charged asymptotically locally Anti-de Sitter [AdS] black holes with planar  $[\mathbb{R}^2]$  or toral  $[\mathbb{R}^2/\mathbb{Z}^2]$  horizon. Such black hole is dual [in the sense of AdS/CFT] to a field theory that behaves like Quark-Gluon Plasma, and constitutes one of the most well-understood quantum gravity systems, especially when charged black holes are concerned.

## The Firewall Controversy

Ahmed Almheiri, Donald Marolf, Joseph Polchinski and James Sully [1] had recently pointed out that in order for the highly scrambled information to be recovered at the end of Hawking evaporation [via subtle quantum entanglement among the late Hawking particles and the early ones], one must – in view of quantum monogamy theorem – break the quantum entanglement between ingoing and outgoing partner of the late Hawking pairs. Consequently the near horizon region is far from being a vacuum – any infalling observer burns up at the horizon. This is in stark contrast with what we expect from General Relativity, in which horizon is not a special place.

Daniel Harlow and Patrick Hayden [2] argued that the firewall argument involves decoding of quantum information, and that generically such a computation takes a very long time – exponential in the Bekenstein-Hawking entropy of the black hole – so that the black hole either completely evaporates, or are destroyed in some other ways, before the computation can be done. Regardless of whether decoding is essential in the firewall argument, it is important to investigate whether Harlow-Hayden conjecture holds, especially in the context of charged black holes.



**Figure 1:** Can quantum information be decoded from Hawking radiation of an evaporating black hole? **Source:** NewScientist, *Fiery Black Hole Debate Creates Cosmological Wild West*, Issue 2955 (2014).

## Modeling Charged AdS Black Holes with Flat Event Horizon

In four-dimensions, asymptotically locally AdS charged flat black holes have metric tensor of the form

$$g[\text{AdSRN}(k=0)] = - \left[ \frac{r^2}{L^2} - \frac{8\pi M^*}{r} + \frac{4\pi Q^{*2}}{r^2} \right] dt^2 + \frac{dr^2}{\frac{r^2}{L^2} - \frac{8\pi M^*}{r} + \frac{4\pi Q^{*2}}{r^2}} + r^2 [d\zeta^2 + d\xi^2]. \quad (1)$$

We extend the approach of Hiscock & Weems [3] — modeling the charge loss by Schwinger formula, and thermal mass loss via Stefan-Boltzmann law. This yields a coupled system of linear ODEs:

$$\frac{dQ^*}{dt} \approx - \frac{e^4}{64\pi^{11/2}\hbar m^2} \frac{Q^{*3}}{r_h^3} \exp \left[ - \frac{2\pi^{3/2}m^2 r_h^2}{\hbar e Q^*} \right], \quad \frac{dM^*}{dt} = - \frac{a}{4} L^2 T^4 + \frac{Q^*}{r_h} \frac{dQ^*}{dt}. \quad (2)$$

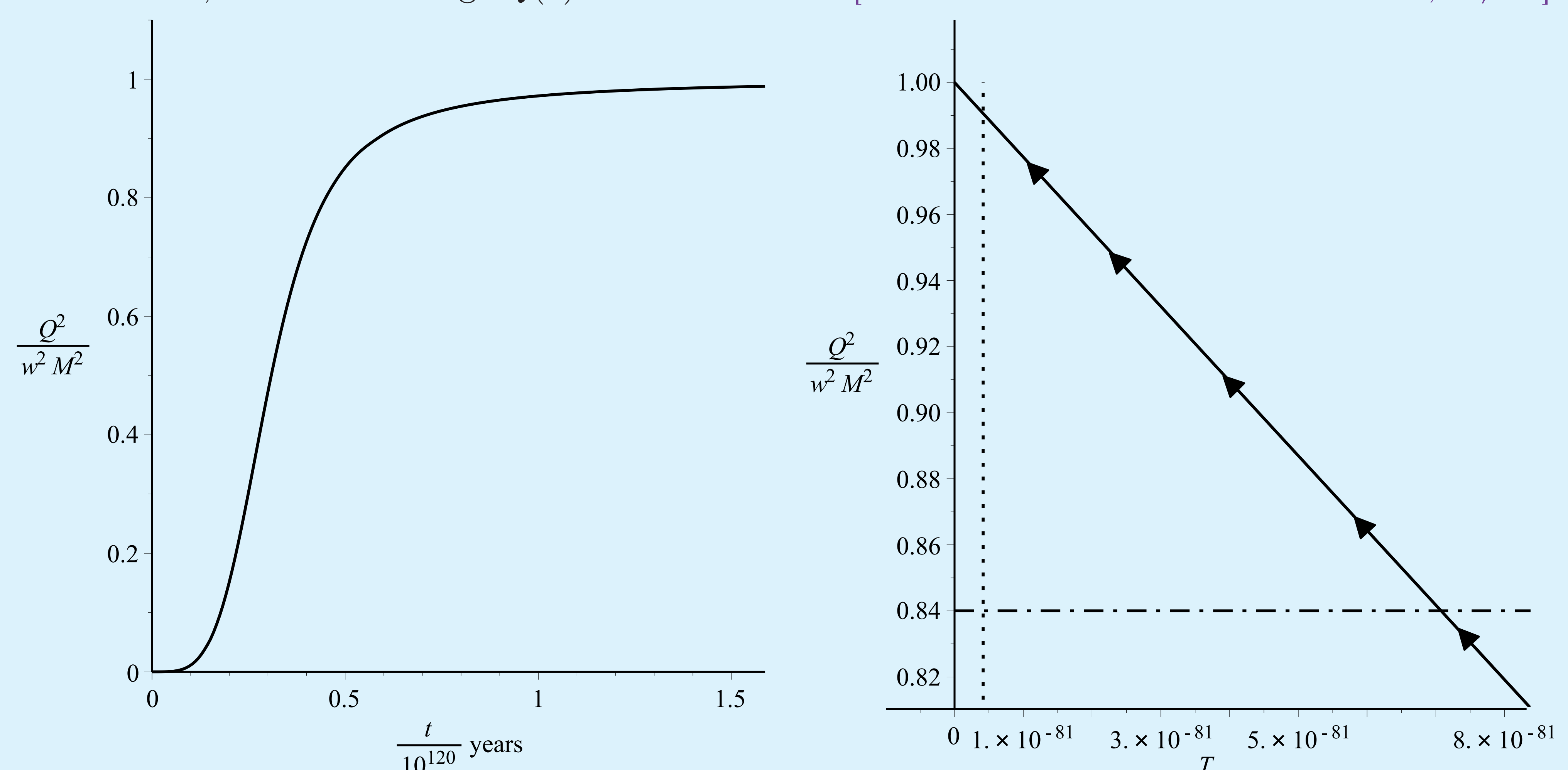
where  $e$  and  $m$  are electron charge and mass, respectively, and  $r_h$  locates the event horizon. This model is legitimate when AdS curvature length scale is large, specifically,  $L \gg 10^{10}$  cm.

## The Fate of Evaporating Charged Flat AdS Black Holes

We found that charge loss is always inefficient compared to mass loss, implying these black holes always evolve toward extremal limit. In the case of toral topology, two possible fates await the black holes, depending on the exact initial conditions. The evolution is solved numerically using **Maple**.

- (1) If the temperature drops below  $\hbar/(2\pi K L)$ , the black hole undergoes phase transition into soliton;
- (2) If 92% of extremal limit is reached, Seiberg-Witten brane action becomes negative and brane pair-production disrupts the spacetime geometry.

For planar topology, there is no phase transition — such black hole only gets destroyed by brane pair-production instability. Here we show the case with  $K = 1$  and  $L = 10^{15}$  cm, initial mass  $M(0) = 5.6 \times 10^{20}$  cm, and initial charge  $Q(0) = 6 \times 10^{-34}$  cm. [In “relativistic units” with  $G = c = 1$ ,  $\hbar \neq 1$ .]



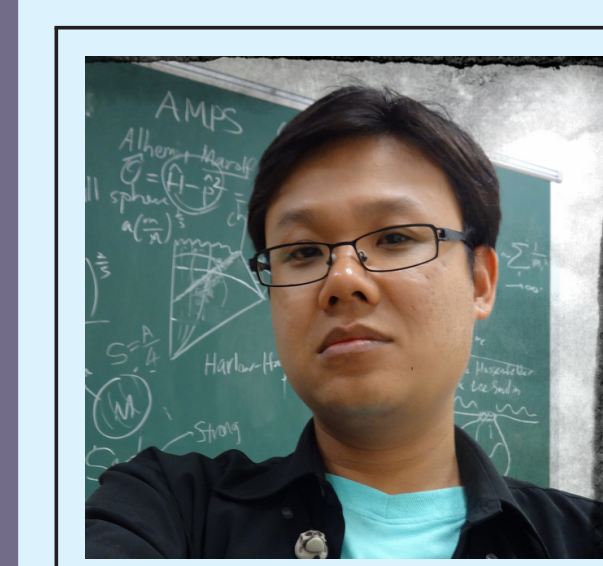
**Figure 2:** **Left:** The charge-to-mass ratio against time. **Right:** The charge-to-mass ratio against temperature. Dotted lines indicate the critical temperature below which the black holes undergo phase transition. The dot-dash lines indicate the threshold beyond which black holes become unstable due to Seiberg-Witten effect.

Our result supports Harlow-Hayden conjecture that black holes are destroyed long before Hawking radiation can be [generically] decoded, even by a quantum computer.

## References

- [1] A. Almheiri, D. Marolf, J. Polchinski, J. Sully, “Black Holes: Complementarity or Firewalls?”, JHEP1302 (2013) 062, 1207.3123 [hep-th].
- [2] D. Harlow, P. Hayden, “Quantum Computation vs. Firewalls”, JHEP06 (2013) 085, 1301.4504 [hep-th].
- [3] W. A. Hiscock, L. D. Weems, “Evolution of Charged Evaporating Black Holes”, PRD 41 (1990) 1142.
- [4] Y. C. Ong, B. McInnes, P. Chen, “Why Hawking Radiation Cannot be Decoded”, 1403.4886 [hep-th].
- [5] Y. C. Ong, P. Chen, “Charge Loss (or the Lack Thereof) for AdS Black Holes”, accepted by JHEP, 1404.5215 [gr-qc].

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