

A Critical Reassessment of the Theoretical Foundations of Hawking Radiation: From Mathematical Idealizations to Relativistic Inconsistencies

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Abstract

Hawking radiation is widely regarded as a robust theoretical prediction arising from quantum field theory in curved spacetime. While its mathematical derivation is internally consistent and broadly accepted at the theoretical level, the physical interpretation of this result rests on a set of idealized assumptions whose realizability and compatibility with General Relativity are rarely examined in detail.

The purpose of this article is not to dispute the mathematical validity of Hawking's calculation, but to critically analyze the physical and methodological assumptions underlying it. We show that several key inputs employed in the standard derivation are not physically realizable and, in some cases, are in tension with core relativistic principles. Consequently, the resulting prediction should not be treated as an unconditional physical reality, but rather as a conditional outcome tied to idealized theoretical inputs.

1 Introduction

Since its original proposal, Hawking radiation has played a central role in modern discussions of black hole physics, quantum gravity, and the black hole information problem. Within the framework of quantum field theory on a fixed curved background, the derivation predicts a thermal particle flux associated with black hole event horizons [1, 2].

Despite its influence, the physical interpretation of Hawking radiation relies on a number of assumptions that are often treated as benign idealizations. In this work, we argue that several of these assumptions are not merely idealized, but physically unrealizable or conceptually inconsistent with General Relativity. This distinction is crucial: while mathematical idealizations are often necessary for calculational closure, their physical interpretation must remain conditional.

This paper focuses on three such assumptions: the definition of observers near the event horizon, the imposition of a global vacuum state in the infinite past, and the interpretation of the event horizon as a boundary separating past and future quantum states.

2 Static Observers and Their Physical Limitations

A central element in the standard narrative of Hawking radiation is the use of a static observer arbitrarily close to the event horizon. In many presentations, this observer detects an extreme blueshift of incoming field modes.

However, such an observer is not physically realizable. A static worldline near the event horizon requires divergent proper acceleration, rendering it impossible for any material detector or physical apparatus. The static near-horizon observer therefore functions purely as a mathematical construct, not as a physically admissible observer.

The crucial implication is that the observed blueshift is a frame-dependent coordinate effect. It cannot be directly attributed to observers in free fall or to distant asymptotic observers. Consequently, the presence of blueshift in this idealized frame does not constitute evidence for a local physical emission process at the horizon.

Intuitive Clarification: What Is (and Is Not) Physically Measured Near the Horizon

A recurring source of confusion in discussions of Hawking radiation arises from the implicit identification of observer-dependent quantities with physical, observer-independent processes. In particular, the extreme blueshift often associated with field modes near the event horizon is frequently interpreted as evidence for an intrinsic energetic phenomenon localized at the horizon itself.

This interpretation conflates two fundamentally distinct notions: what is *mathematically defined* along an idealized worldline, and what can be *physically measured* by realizable detectors. The static observer arbitrarily close to the horizon belongs to the former category. Such an observer is introduced to define frequencies with respect to Schwarzschild time, but cannot correspond to any physical measuring apparatus.

By contrast, physically realizable observers fall into two broad classes: freely falling observers crossing the horizon, and distant observers remaining at finite radius. For the former, no divergence in locally measured energy or flux occurs at the horizon. For the latter, any signal originating near the horizon is subject to gravitational redshift and time dilation, leading to suppression rather than amplification.

The key intuitive point is therefore simple but often overlooked: a divergence that appears only in the frame of a non-physical observer cannot, by itself, establish the existence of a physical emission mechanism. The horizon does not act as a local engine producing radiation; instead, the appearance of particle creation arises from global field mode decompositions that depend on idealized boundary conditions and observer choices.

Recognizing this distinction helps prevent a common category error: mistaking coordinate-dependent bookkeeping for invariant physical processes.

3 Two Non-Physical Assumptions in the Hawking Derivation

3.1 Assumption of a Global Past Vacuum

The standard derivation assumes that quantum fields occupy a unique vacuum state in the infinite past. This assumption is neither observable nor experimentally testable, nor does it follow uniquely from the dynamical evolution of spacetime.

In General Relativity, there is no observer-independent notion of an absolute past, and the definition of a vacuum state is inherently observer-dependent. The notion of a globally defined past vacuum is therefore conceptually problematic and physically unattainable.

3.2 The Event Horizon as a Boundary Between Past and Future

In some interpretations, the event horizon is implicitly treated as a surface separating a vacuum past from a radiation-filled future. Such a picture is incompatible with the relativistic structure of spacetime.

Within General Relativity, the event horizon is a global causal boundary, not a local temporal interface. For a freely falling observer, crossing the horizon does not involve any sudden physical event or energetic transition. Interpreting the horizon as an intrinsic source of radiation therefore lacks a physical basis.

Methodological Statement (Locked)

The term *mathematical ideal conditions* in this discussion refers to a set of assumptions that are required for closing a calculational framework, but which are physically incompatible with realistic conditions in the universe. These include, among others, the absence of an absolute

past and the absence of an observer-independent vacuum state. While mathematically useful, such assumptions should not be conflated with physically realizable conditions.

4 The Domino Effect of Derived Theories

Treating Hawking radiation as an unconditional physical reality has led to a cascade of derived theoretical structures, including black hole evaporation, information paradox scenarios, and speculative horizon microphysics.

Because these constructions inherit the same idealized assumptions, they should likewise be regarded as conditional theoretical frameworks rather than established physical facts.

5 Comparison with Alternative Models

Comparisons with alternative gravitational models, including white-hole scenarios or modified horizon frameworks, further illustrate the sensitivity of conclusions to initial assumptions. Small changes in boundary conditions or observer definitions can lead to qualitatively different outcomes.

6 Conclusion

We have argued that Hawking radiation, while mathematically well-founded within its theoretical framework, relies on a set of physically unrealizable assumptions. Without independent experimental evidence, elevating it to the status of a definitive physical phenomenon is methodologically unwarranted.

A clear distinction between mathematical tools and physical reality is essential for the healthy progress of theoretical physics.

A Proper Acceleration of Static Observers Near the Event Horizon

This appendix presents a minimal geometric result clarifying the physical status of static observers near a Schwarzschild event horizon. The purpose is not to modify or revisit Hawking's calculation, but to explicitly state an operational constraint on physical observability.

Consider the Schwarzschild metric (in units $G = c = 1$),

$$ds^2 = - \left(1 - \frac{2M}{r}\right) dt^2 + \left(1 - \frac{2M}{r}\right)^{-1} dr^2 + r^2 d\Omega^2. \quad (1)$$

A static observer at fixed radius r follows a worldline whose four-velocity is aligned with the timelike Killing vector. The magnitude of the observer's proper four-acceleration is given by

$$a(r) = \frac{M}{r^2 \sqrt{1 - \frac{2M}{r}}}. \quad (2)$$

As the observer approaches the event horizon, $r \rightarrow 2M$, the proper acceleration diverges,

$$\lim_{r \rightarrow 2M} a(r) \rightarrow \infty. \quad (3)$$

This divergence implies that maintaining a static worldline arbitrarily close to the horizon would require infinite acceleration. No physical detector or material observer can realize such a trajectory.

References

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