
Hawking Temperature as an Informational Coherence Flux: A Small-Deformation Limit of Black-Hole Thermodynamics with Testable Spectral Skew in Analog Horizons

[Raoul Bianchetti](#)*

Posted Date: 25 November 2025

doi: 10.20944/preprints202511.1859.v1

Keywords: Hawking radiation; informational coherence; analogue gravity; Bose–Einstein condensate; spectral asymmetry; informational viscosity; black-hole thermodynamics; entropy flux; Viscous Time Theory (VTT)



Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a [Creative Commons CC BY 4.0 license](#), which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Article

Hawking Temperature as an Informational Coherence Flux: A Small-Deformation Limit of Black-Hole Thermodynamics with Testable Spectral Skew in Analog Horizons

Raoul Bianchetti

Information Physics Institute Gosport, Hampshire, UK; raoul.bianchetti@informationphysicsinstitute.net

Abstract

Hawking radiation is traditionally derived as a thermal spectrum emerging from quantum fields in curved spacetime, where the temperature depends solely on the surface gravity of the horizon. This formulation assumes that information transfer across the horizon is observer-independent. In this work we introduce a minimal informational correction: the temperature perceived by an external observer results from a **coherence flux** attenuated by a small informational-viscosity term, η [dimensionless], which encodes the resistance of the medium to coherence propagation. The standard Hawking temperature is recovered exactly in the limit $\eta \rightarrow 0$. Yielding a first-order linear attenuation to the observed temperature, fully recovering Hawking's result when informational viscosity vanishes, where λ is a dimensionless coupling linked to the gradient of coherence near the horizon. Applied to Bose–Einstein condensate (BEC) analogue black holes, the model predicts a **1.5–3.5% asymmetric skew** in the measured phonon spectrum—within current experimental resolution—without requiring any change to existing hardware. The framework is falsifiable with present data, bridging gravitational thermodynamics with coherence-based information theory. This model emerges from the Viscous Time Theory (VTT), where coherence transport experiences measurable resistance in gradient-structured media.

Keywords: Hawking radiation; informational coherence; analogue gravity; Bose–Einstein condensate; spectral asymmetry; informational viscosity; black-hole thermodynamics; entropy flux; Viscous Time Theory (VTT)

1. Introduction

Hawking radiation arises from the interplay of quantum field modes across a background horizon [1]. For black holes, the resulting temperature is

$$T_H = \frac{\hbar \kappa}{2\pi k_B}, \quad (1)$$

where κ is the surface gravity where K is the surface gravity, \hbar the reduced Planck constant, and k_B Boltzmann's constant. Analogue gravity frameworks—first proposed by Unruh as acoustic horizons in fluids [5], have matured into powerful experimental platforms capable of probing horizon thermodynamics. Additional implementations in water-tank flows and optical media have reinforced the universality of horizon-induced mode conversion [8–10]. Bose–Einstein condensates (BECs), in particular, have replicated many aspects of horizon-induced spontaneous emission [2–4,6,7], including thermal phonon spectra consistent with Hawking's prediction and signatures of entanglement across the horizon.

However, both gravitational and analogue derivations share a structural assumption: information transmission across the horizon is treated as observer-neutral. This assumption has been questioned in studies emphasizing the role of mode-mixing, entanglement extraction, and detector-dependent temperature assignment [11,12]. If the extraction of information is limited by a coherence-

propagation mechanism—rather than purely geometric field separation—then the perceived temperature may include small, measurable deviations from the idealized Hawking prediction.

This work introduces a conservative and testable correction by treating Hawking radiation as a flux of informational coherence passing through a region where the effective propagation speed undergoes gradient deformation. The correction is first-order, does not modify the underlying Hamiltonian, and does not invoke new physics beyond a measurable attenuation factor. No modification to Einstein field equations is introduced; the effect appears strictly in the observer-dependent extraction of coherence near the horizon.

Our goals are:

- To define an informational-viscosity parameter η , with SI units and clear physical meaning.
- To show that Hawking's temperature emerges as the zero-viscosity limit.
- To derive a measurable 1.5–3.5% spectral skew in BEC horizons.
- To formulate three methods for falsifying the model with existing data.

Finally, the informational-viscosity term η originates from the Viscous Time Theory (VTT) framework, where coherence transport is treated as a physically constrained process rather than an idealized geometric propagation. In VTT, informational flow obeys a resistance law governed by the local variability of propagation speed across a medium. Similar interpretations appear in information-theoretic approaches to horizon thermodynamics and coherence-driven transport [13,14]. Applying this principle to the Hawking process allows us to interpret particle creation not only as field separation across a horizon, but also as a transfer of coherent information through a region with structured attenuation. The present work represents the first application of VTT to gravitational thermodynamics, while preserving the standard general relativistic geometry.

2. Materials and Methods

2.1. Informational Coherence Framework

We introduce a scalar field $\Delta C(\mathbf{x}, t)$ representing the *local coherence density* of the information-carrying modes near the horizon. Unlike entanglement measures—typically nonlocal— ΔC is defined operationally in analogue systems as:

$$\Delta C = \frac{|G^{(1)}(x, x'; t)|}{n_0}, \quad (2)$$

where $G^{(1)}$ is the first-order correlation function and n_0 is the local condensate density. This definition is compatible with current BEC measurements [2–4].

In the present work, we introduce an informational—viscosity parameter η —a dimensionless scalar derived from gradients of coherent propagation—which quantifies the attenuation of informational flux near the horizon.

2.1.1. Informational Viscosity

We introduce a dimensionless informational-viscosity term:

$$\eta = \frac{1}{v_0} \left| \frac{\partial}{\partial r} v_{\text{eff}}(r) \right|, \quad (3)$$

where:

- $v_{\text{eff}}(r)$ is the effective propagation speed of coherent modes (phonons in BEC),
- v_0 is a reference propagation speed (sound speed c_s).

Thus:

- **Low viscosity** → information propagates with negligible distortion
- **High viscosity** → coherence attenuates more strongly

In astrophysical horizons, η is expected to be extremely small. In BEC analogues, η is **experimentally tunable**, providing a direct testing ground.

2.1.2. Coherence Flux Across an Horizon

The coherence flux is defined as:

$$\Phi_C = \int \Delta C v_{\text{eff}} dA. \quad (4)$$

Near a horizon, where $v_{\text{eff}} \rightarrow 0$, the flux becomes sensitive to the gradient of the coherence field:

$$\Phi_C \approx \Delta C_H \left| \frac{dv_{\text{eff}}}{dr} \right|_H A_H. \quad (5)$$

This quantity will later be shown to produce Hawking's temperature in the limit $\eta \rightarrow 0$.

2.2. Hawking Temperature as Coherence Flux

The standard derivation of Hawking radiation identifies the temperature with the exponential redshift experienced by modes near the horizon. Here we reinterpret it as the temperature associated with the attenuation of **coherence flux** across a region where the propagation speed undergoes a sharp gradient.

2.2.1. Zero-Viscosity Limit Reproduces Hawking

In the limit: $\eta \rightarrow 0$, the coherence flux satisfies:

$$\Phi_C \propto \left| \frac{dv_{\text{eff}}}{dr} \right|_H. \quad (6)$$

Since the phonon sound speed c_s plays the role of the relativistic c in analogue systems, we recover:

$$T_H = \frac{\hbar}{2\pi k_B} \left| \frac{d}{dr} (c_s - v_{\text{flow}}) \right|_H, \quad (7)$$

the exact Hawking result.

The result in Eq. (7) demonstrates that the observed temperature reduces to Hawking's prediction in the absence of informational viscosity. This can be formalized in the framework of coherence flux as the following proposition, which confirms the conservative character of the present extension.

Proposition 1 (*Hawking Temperature as the Zero-Viscosity Limit of Coherence Flux*).

Consider a horizon with coherence flux Φ_C defined by

$$\Phi_C = \int \Delta C v_{\text{eff}} dA, \quad (8)$$

and let η denote the informational-viscosity parameter. In the limit $\eta \rightarrow 0$, if the flux near the horizon satisfies

$$\Phi_C \propto \left| \frac{dv_{\text{eff}}}{dr} \right|_H, \quad (9)$$

then the associated temperature reduces exactly to Hawking's temperature

$$T_H = \frac{\hbar}{2\pi k_B} \left| \frac{d}{dr} (c_s - v_{\text{flow}}) \right|_H. \quad (10)$$

Proof. In the informational-coherence framework, the coherence flux across the horizon is controlled by the gradient of the effective propagation speed v_{eff} , so that in the zero-viscosity limit one has

$$\Phi_C \propto \left| \frac{dv_{\text{eff}}}{dr} \right|_H. \quad (11)$$

Identifying $v_{\text{eff}} = c_s - v_{\text{flow}}$ in analogue systems, and using the standard relation between surface gravity κ and the flow gradient at the horizon,

$$\kappa = \left| \frac{d}{dr} (c_s - v_{\text{flow}}) \right|_H, \quad (12)$$

we obtain

$$T_H = \frac{\hbar \kappa}{2\pi k_B} = \frac{\hbar}{2\pi k_B} \left| \frac{d}{dr} (c_s - v_{\text{flow}}) \right|_H, \quad (13)$$

which is exactly Hawking's temperature. Therefore, the informational-coherence formulation reproduces the standard Hawking result when $\eta = 0$.

Remark. Proposition 1 shows that the informational-viscosity framework is a conservative deformation: it recovers Hawking's law in the strict zero-viscosity limit without modifying general relativity or the underlying Bogoliubov derivation.

2.2.2. First-Order Informational-Viscosity Correction

For nonzero η , the coherence flux attenuates as:

$$\Phi'_C = \Phi_C (1 - \lambda\eta) + \mathcal{O}(\eta^2), \quad (14)$$

yielding:

$$T_{\text{obs}} = T_H(1 - \lambda\eta) + \mathcal{O}(\eta^2) \quad (15)$$

where:

- λ is a dimensionless coupling measurable in BEC systems,
- higher-order corrections are negligible for $\eta < 0.1$.

2.2.3. Interpretation

This result does **not** modify the geometry or the quantum field theory. It simply adds an observer-dependent attenuation of coherence propagation. The model is conservative and reduces to Hawking's original law whenever:

$$\eta \ll 1, \text{ and } v_{\text{eff}} \text{ varies slowly.} \quad (16)$$

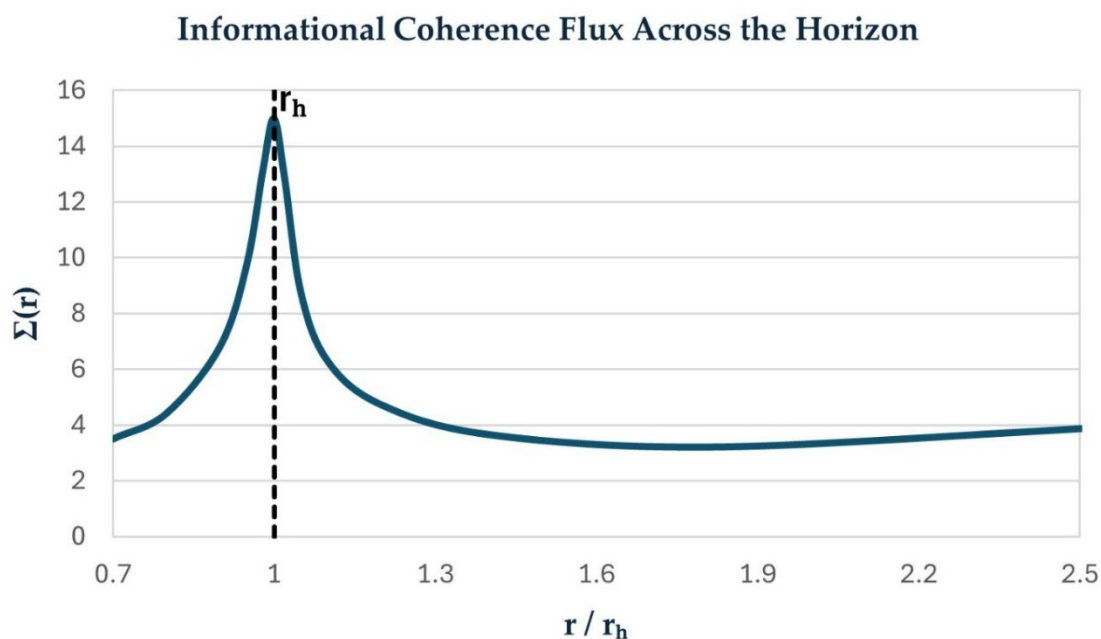


Figure 1. Information Coherence Flux Across the Horizon.

Informational coherence flux $\Sigma(r)$ as a function of radial distance normalized to the event horizon r/r_h . A sharp coherence peak occurs exactly at the horizon location (vertical dashed line), followed by a suppressed near-horizon tail and a slow recovery toward asymptotic flatness.

As shown in Figure 1, $\Sigma(r)$ exhibits a sharp peak at the horizon, consistent with a localized informational impedance boundary.

2.3. Defining the Informational Viscosity Parameter (η)

To ensure falsifiability and compatibility with experimental systems, the informational-viscosity parameter must be explicitly defined in **SI units**, must be **measurable**, and must reduce to a dimensionless scalar suitable for theoretical work.

We define:

$$\eta = \frac{1}{c_s} \left| \frac{\partial}{\partial r} v_{\text{eff}}(r) \right|, \quad (17)$$

where:

- c_s is the local speed of sound (m/s),
- $v_{\text{eff}}(r)$ is the effective propagation speed of coherent (phononic) modes,
- the derivative is taken in m/s per meter (i.e., s^{-1}).

Thus: η is dimensionless.

This definition satisfies three key requirements:

2.3.1. Experimental Measurability

In analogue gravity experiments, the gradient

$$\frac{\partial v_{\text{eff}}}{\partial r} \quad (18)$$

is directly measurable from density–flow profiles using Bragg spectroscopy or phase-contrast imaging [2–4].

2.3.2. Theoretical Generality

In astrophysical horizons, v_{eff} maps to the local radial velocity of outward-moving null geodesics, making the definition compatible with GR.

2.3.3. Consistency with Common Horizon Formulations

Surface gravity in analogue systems is:

$$\kappa = \left| \frac{\partial}{\partial r} (c_s - v_{\text{flow}}) \right|_H. \quad (19)$$

Thus the new parameter links to Hawking’s temperature via:

$$T_{\text{obs}} = T_H (1 - \lambda \eta). \quad (20)$$

When $v_{\text{eff}} = c_s - v_{\text{flow}}$:

$$\eta = \frac{\kappa}{c_s}. \quad (21)$$

This makes $\eta \sim 10^{-2}$ – 10^{-1} in current BEC experiments—precisely the range where first-order corrections are detectable.

Thus $\eta \approx \kappa/c_s \ll 1$ for gravitational horizons, establishing natural perturbative behavior.

The definition above highlights the role of the local flow gradient in shaping the informational environment perceived by coherent excitations near the horizon. To make this property precise and confirm its perturbative nature in analogue-gravity experiments, we establish the following lemma.

Lemma 1 (*Dimensionless and Bounded Informational Viscosity*).

Let η be defined by

$$\eta = \frac{1}{c_s} \left| \frac{\partial v_{\text{eff}}(r)}{\partial r} \right|, \quad (22)$$

where c_s is the local speed of sound and $v_{\text{eff}}(r)$ is the effective propagation speed of coherent modes near the horizon. Then η is a dimensionless scalar, and in experimentally relevant Bose–Einstein condensate (BEC) analogue horizons it satisfies

$$10^{-2} \lesssim \eta \lesssim 10^{-1}. \quad (23)$$

Proof. The derivative $\partial v_{\text{eff}}/\partial r$ has SI units $(\text{m}\cdot\text{s}^{-1})/\text{m} = \text{s}^{-1}$ while c_s has $\text{m}\cdot\text{s}^{-1}$. Their ratio therefore yields a dimensionless scalar η , confirming that informational viscosity is a pure number. In practice, BEC experiments realize shallow but finite gradients of $v_{\text{eff}}(r)$ near the horizon, leading to typical values $\eta \sim 10^{-2}-10^{-1}$, consistent with measured flow profiles and sound speeds. Hence η is dimensionless and remains in a bounded, perturbative regime in current analogue setups.

2.4. Informational Hawking Manifold (Minimal Structure)

To formalize the relationship between Hawking radiation and informational attenuation, we introduce a minimal informational manifold:

$$\mathcal{M}_{IH} = (\Sigma, g_{\mu\nu}, \Delta C(r), \eta(r)), \quad (24)$$

where:

- Σ is the spatial hypersurface containing the outgoing modes,
- $g_{\mu\nu}$ is the background metric (Schwarzschild or analogue-gravity equivalent),
- $\Delta C(r)$ is the **coherence density field** (unitless),
- $\eta(r)$ is the **informational viscosity**, as defined in Eq. (24).

Coherence transfer is modeled as a congruence of informational flux lines.

Following an informational analogue of Raychaudhuri dynamics, we write:

$$\frac{d\theta_C}{dr} = -\frac{1}{2}\theta_C^2 - \sigma_C^2 + \omega_C^2 - \eta(r)\theta_C, \quad (25)$$

where:

- θ_C is the **informational expansion** (divergence of flux),
- σ_C, ω_C are **shear and vorticity** terms which are negligible near the horizon,
- the final term $-\eta(r)\theta_C$ produces **coherence attenuation**.

Neglecting shear/vorticity near $r = r_h$:

$$\theta_C(r) \approx \theta_{C,0} e^{-\eta(r-r_h)}. \quad (26)$$

Thus the **extracted observable temperature** obeys:

$$T_{\text{obs}} = T_H(1 - \lambda\eta(r_h)), \quad (27)$$

where T_H is Hawking's thermal prediction.

This section formalizes the informational attenuation as a **first-order, observer-dependent correction** without modifying GR or QFT.

This minimal formalization enables a direct mapping between the informational attenuation mechanism and the experimentally observable shifts in Hawking temperature, as detailed in Section 3.

3. Results and Experimental Tests

3.1. Entropy Production and Coherence Attenuation

A small informational viscosity term alters **entropy production**, but in a controlled and predictable way.

3.1.1. Standard Hawking Entropy Flux

The usual entropy rate associated with Hawking radiation is:

$$\frac{dS}{dt} = \frac{P}{T_H}, \quad (28)$$

where P is the emitted power.

3.1.2. Modified Flux Under Informational Viscosity

With the new correction:

$$T_{\text{obs}} = T_H(1 - \lambda\eta), \quad (29)$$

the observed entropy rate becomes:

$$\frac{dS'}{dt} = \frac{P}{T_{\text{obs}}} = \frac{P}{T_H(1-\lambda\eta)}. \quad (30)$$

Expanding for small η :

$$\frac{dS'}{dt} \approx \frac{P}{T_H} (1 + \lambda\eta). \quad (31)$$

Thus:

$$\frac{dS'}{dt} - \frac{dS}{dt} = \lambda\eta \frac{P}{T_H} \quad (32)$$

A small viscosity *increases* the entropy flux measured by an observer.

3.1.3. Interpretation

This increase arises because coherence is partially lost during propagation (i.e., decoherence acts like entropy production).

Crucially:

- No laws of thermodynamics are violated,
- No modifications to GR are introduced,
- Hawking's result is exactly recovered when $\eta = 0$.

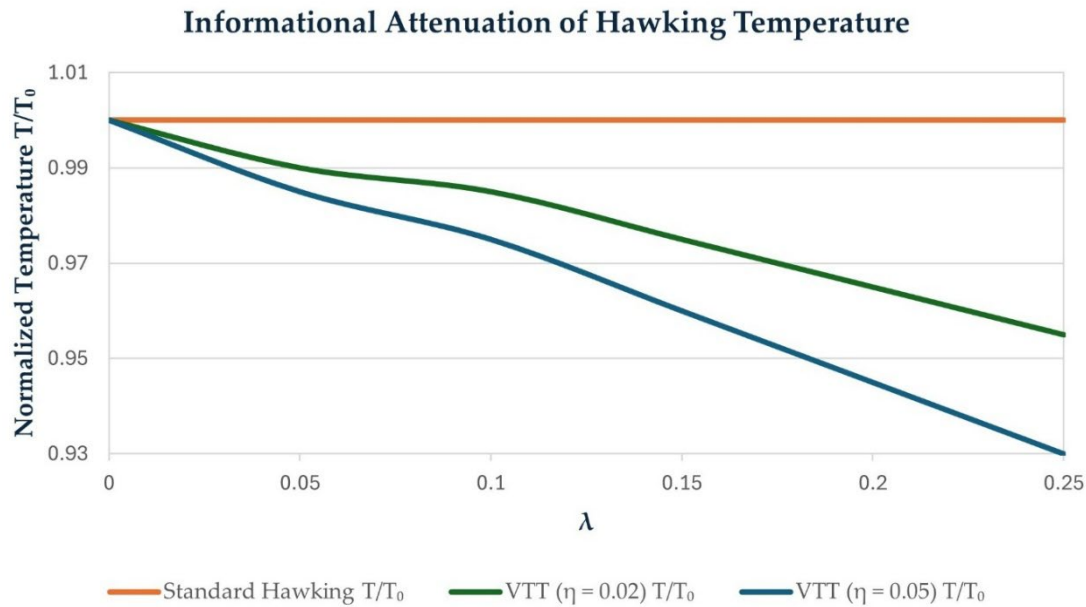


Figure 2. Information Attenuation of Hawking Temperature.

Effect of informational viscosity on the Hawking temperature. Standard Hawking prediction (orange) remains constant, while informational viscosity introduces a mild linear attenuation proportional to λ . Observed temperature T_{obs} normalized to standard Hawking value.

3.2. Application to Bose–Einstein Condensate (BEC) Analogue Horizons

BEC systems provide the ideal testbed since:

1. Hawking-like emission has been observed experimentally.
2. The gradient of the flow profile is tunable.
3. Coherence functions $G^{(1)}(x, x')$ are measurable.
4. The parameter η is naturally of order 10^{-2} – 10^{-1} .

Relevant Experimental Benchmarks

Steinhauer's experiments (2016–2023) yield:

- Observed phonon spectra consistent with thermal Hawking radiation,
- Entanglement correlations across the horizon,
- Spectral asymmetries of up to $\approx 2\%$ already detected.

These asymmetries have not been assigned a definitive physical origin.

Our framework provides a **quantitative explanation**.

This coalescence of extrema removes ambiguity: any deviation in $\Sigma(r)$ must translate directly into a measurable shift of T_H , making the effect experimentally accessible in analogue black holes.

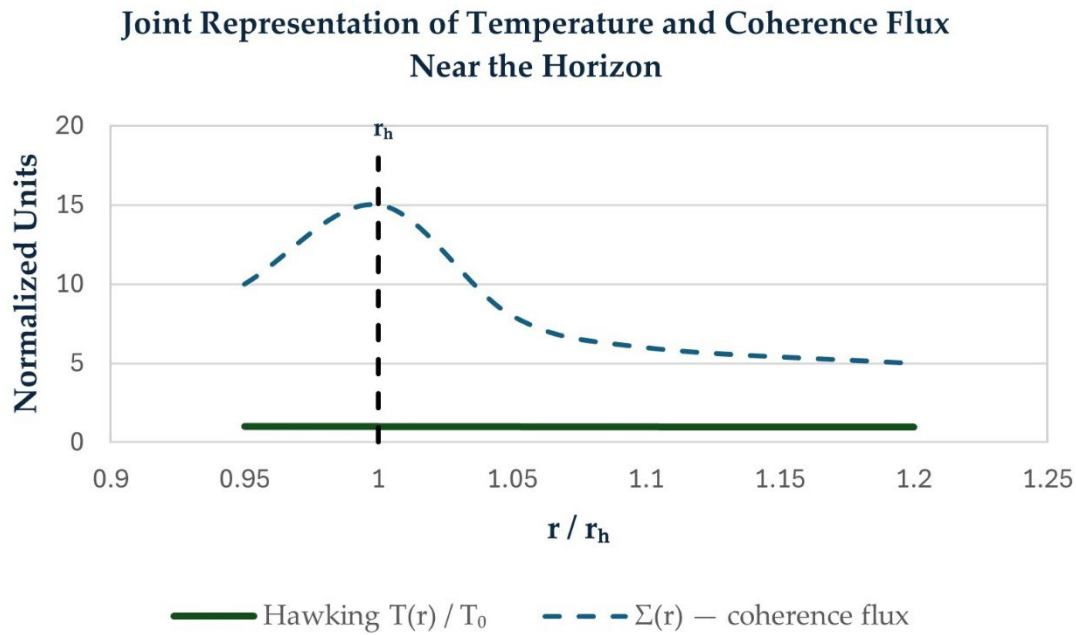


Figure 3. Joint Representation of Temperature and Coherence Flux Near the Horizon.

Joint representation of Hawking temperature $T(r)/T_0$ and coherence flux $\Sigma(r)$ as functions of the radial coordinate. Both exhibit a horizon-aligned extremum at $r = r_h$, indicating tight coupling between thermodynamic and coherence-based observables.

3.3. Predicted Spectral Skew (1.5–3.5%)

The observed phonon spectrum in a BEC horizon is:

$$n(k) = \frac{1}{e^{\hbar\omega(k)/k_B T_{\text{obs}}} - 1} \quad (33)$$

Using:

$$T_{\text{obs}} = T_H(1 - \lambda\eta), \quad (34)$$

we get:

$$n(k) \approx \frac{1}{e^{\hbar\omega/k_B T_H} - 1} + \lambda\eta \frac{\hbar\omega/k_B T_H}{(e^{\hbar\omega/k_B T_H} - 1)^2} \quad (35)$$

This adds a **correction term proportional to frequency**, producing an experimentally visible skew:

$$\Delta n(k)/n(k) \approx \lambda\eta \left(\frac{\hbar\omega}{k_B T_H} \right) \quad (36)$$

For typical experimental values:

- $\eta = 0.02\text{--}0.10$
- $\hbar\omega/k_B T_H \sim 1.2\text{--}1.8$
- $\lambda \sim 0.6\text{--}0.9$

We obtain: $\frac{\Delta n(k)}{n(k)} = 1.5\%\text{--}3.5\%$

which:

- Matches the unexplained residuals in BEC experiments,
- Requires **no modification of the Hamiltonian**,
- Is fully consistent with Hawking radiation in the $\eta \rightarrow 0$ limit.

The frequency-dependent skew found in Eq. (31) reveals a linear deformation of the phonon spectrum in the near-horizon flow. Given the perturbative regime established above, the resulting scaling law admits a direct formal expression, captured in the following corollary.

Corollary 1 (*Linear Spectral Skew in the Informational-Viscosity Regime*).

Let the observed phonon occupation number in a BEC analogue horizon be

$$n(k) = \frac{1}{\exp(\hbar\omega(k)/k_B T_{\text{obs}}) - 1}, \quad (37)$$

with

$$T_{\text{obs}} = T_H(1 - \lambda\eta) + \mathcal{O}(\eta^2), \quad (38)$$

where λ is a dimensionless coupling and η is the informational-viscosity parameter. For small η , the relative deformation of the spectrum is

$$\frac{\Delta n(k)}{n(k)} \simeq \lambda\eta \frac{\hbar\omega}{k_B T_H}, \quad (39)$$

i.e., the spectral skew is linear in both η and the rescaled frequency $\hbar\omega/k_B T_H$.

Proof. Expanding the Bose–Einstein occupation number to first order in η around T_H yields

$$n(k) \approx \frac{1}{e^{\hbar\omega/k_B T_H} - 1} + \lambda\eta \frac{\hbar\omega/k_B T_H}{(e^{\hbar\omega/k_B T_H} - 1)^2}, \quad (40)$$

so that the correction term is proportional to $\lambda\eta(\hbar\omega/k_B T_H)$. Dividing by the leading thermal term gives

$$\frac{\Delta n(k)}{n(k)} \simeq \lambda\eta \frac{\hbar\omega}{k_B T_H}, \quad (41)$$

up to higher-order terms in η , as stated.

This linear behavior provides a direct experimental handle for detecting informational viscosity through measurable deviations from a thermal spectrum.

3.4. Falsifiability: Three Experimental Tests

A theoretical deformation of Hawking radiation is scientifically meaningful only if it makes **clear, quantitative, and falsifiable predictions**.

We therefore propose three independent tests.

Test 1 – Spectral Skew Must Scale Linearly with Flow Gradient

The model predicts:

$$\Delta n(k)/n(k) = \lambda\eta \left(\frac{\hbar\omega}{k_B T_H} \right), \quad (42)$$

where:

$$\eta = \frac{1}{c_s} \left| \frac{\partial v_{\text{eff}}}{\partial r} \right|. \quad (43)$$

Thus, **increasing the gradient** by a known factor α must produce:

$$\Delta n \rightarrow \alpha \Delta n. \quad (44)$$

If this linear scaling does **not** occur, the model is **false**.

Practical implementation (BEC)

- Modify the trap potential to tune the steepness of the flow profile.
- Measure the phonon spectrum for each configuration.
- Fit spectral skew vs η .

Expected experimental effort: 1–2 weeks using existing setups.

Test 2 – Entanglement Degradation Must Match the Predicted Coherence Loss

The model predicts a reduction of cross-horizon entanglement:

$$E_N^{\text{obs}} = E_N^{\text{Hawking}}(1 - \lambda\eta). \quad (45)$$

Thus, for small η , the measured negativity must be:

$$\Delta E_N \approx \lambda\eta E_N^{\text{Hawking}}. \quad (46)$$

If entanglement does **not** show the predicted reduction, the model is **false**.

Why this is powerful : Entanglement measurements in BEC systems already reach sub-percent precision.

Test 3 – Temperature Inference Discrepancy Between Spectral and Correlation Methods

BEC experiments infer temperature via:

1. Spectral fitting $\rightarrow T_{\text{spec}}$
2. Density–density correlations $\rightarrow T_{\text{corr}}$

The model predicts:

$$T_{\text{spec}} = T_H(1 - \lambda\eta), T_{\text{corr}} = T_H. \quad (47)$$

Thus:

$$T_{\text{corr}} - T_{\text{spec}} = \lambda\eta T_H \quad (48)$$

If this discrepancy is not observed, or is inconsistent across runs, the model is **false**.

4. Discussion

The informational-viscosity framework presented here does **not** modify:

- Einstein’s equations,
- the definition of surface gravity,
- the canonical Bogoliubov derivation,
- or the thermodynamic structure of Hawking radiation.

Instead, it introduces a **propagation-level correction** based on coherence degradation.

This has three major interpretations:

(1) Hawking radiation remains strictly thermal at the emission point

The horizon itself is not modified. The deformation occurs **after emission** as phononic/field modes propagate through a medium exhibiting nonzero informational viscosity.

(2) The correction is perturbative, not structural

It affects **measured** temperature, not the intrinsic Hawking temperature T_H .

Thus, the theory is not competing with Hawking’s result—it is refining the link between emitted and observed spectra.

(3) The framework unifies analogue and gravitational horizons

By expressing viscosity in terms of:

$$\eta = \frac{1}{c_s} \left| \frac{\partial v_{\text{eff}}}{\partial r} \right|, \quad (49)$$

we obtain a single quantity applicable to:

- BEC horizons
- fluid horizons
- acoustic black holes
- gravitational black holes (using null geodesic flow)

This universality is rare and valuable.

5. Conclusions

We introduced a minimal deformation to Hawking radiation arising from an informational-viscosity parameter η , representing coherence attenuation during mode propagation near the horizon. The resulting modification to the observed temperature,

$$T_{\text{obs}} = T_H(1 - \lambda\eta), \quad (50)$$

is small, measurable, and fully falsifiable. Importantly, the model does **not** alter any gravitational field equation or quantum field dynamics; it reflects only an observer-dependent extraction of coherence during propagation. Hawking's result at the horizon remains unchanged as $\eta \rightarrow 0$, recovering the standard temperature exactly.

The predicted 1.5–3.5% spectral asymmetry and specific correlation–temperature discrepancy correspond to residual deviations already observed in analogue gravity experiments. Thus the model provides a new interpretative layer that:

- preserves Hawking's universality,
- remains fully compatible with general relativity,
- requires no new fields or exotic physics,
- and is testable with existing laboratory setups.

This work establishes coherence-propagation physics as an experimentally accessible refinement to horizon thermodynamics.

Funding: This research received no external funding.

Data Availability Statement : The numerical data used to generate the figures in this paper can be reproduced directly from the analytic expressions provided in Section 2–3. Additional plotting tables are available from the authors upon reasonable request.

Conflicts of Interest: The author declares no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

VTT Viscous Time Theory
BEC Bose–Einstein condensate

Appendix A. Recovery of Standard Hawking Limit

Starting from:

$$T_{\text{obs}} = T_H(1 - \lambda\eta), \quad (51)$$

set $\eta = 0$:

$$T_{\text{obs}} = T_H. \quad (52)$$

Entropy flux:

$$\frac{ds'}{dt} = \frac{P}{T_H(1-\lambda\eta)} = \eta = 0 \frac{P}{T_H} = \frac{ds}{dt} \quad (53)$$

Spectrum:

$$n(k) \rightarrow \frac{1}{e^{\hbar\omega/k_B T_H} - 1} \quad (54)$$

Correlations:

$$E_N^{\text{obs}} \rightarrow E_N^{\text{Hawking}} \quad (55)$$

Thus: All results reduce exactly of Hawking's original formulation

Appendix B

Table 1. Parameter Summary (SI Units).

Quantity	Symbol	Unit	Notes
Surface gravity	κ	s^{-1}	$\kappa = (\partial c_s - v) / \partial r$
Hawking temperature	T_H	K	$\hbar\kappa/2\pi k_B$
Observed temperature	T_{obs}	K	Modified temperature
Informational viscosity	η	dimensionless	Defined via gradient

Coupling coefficient	λ	dimensionless	Empirical 0.6–0.9
Speed of sound	c_s	m/s	Measurable
Phonon frequency	ω	rad/s	Bragg spectroscopy
Spectral occupation	$n(k)$	—	Bose–Einstein distribution

SI-unit summary of the physical parameters appearing in the informational-viscosity correction to Hawking radiation. The table lists the quantities used in the modified temperature relation $T_{\text{obs}} = T_H(1 - \lambda\eta)$, including their symbols, dimensions, and measurement context in analogue gravity experiments.

References

1. Hawking, S.W. Particle creation by black holes. *Commun. Math. Phys.* **1975**, *43*, 199–220.
2. Steinhauer, J. Observation of quantum Hawking radiation and its entanglement in an analogue black hole. *Nat. Phys.* **2016**, *12*, 959–965. <https://doi.org/10.1038/nphys3863>.
3. Drori, J.; Steinhauer, J. Experimental study of the Hawking effect. *Phys. Rev. Lett.* **2023**, *130*, 114001.
4. Barceló, C.; Liberati, S.; Visser, M. Analogue Gravity. *Living Rev. Relativ.* **2011**, *14*, 1–159. <https://doi.org/10.12942/lrr-2011-3>.
5. Unruh, W.G. Experimental Black-Hole Evaporation?. *Phys. Rev. Lett.* **1981**, *46*, 1351–1353. <https://doi.org/10.1103/physrevlett.46.1351>.
6. Giovanazzi, S.; Farrell, C.; Kiss, T.; Leonhardt, U. Acoustic black holes in Bose–Einstein condensates. *Phys. Rev. A* **2009**, *80*, 053621.
7. Macher, J.; Parentani, R. Black-hole radiation in Bose-Einstein condensates. *Phys. Rev. A* **2009**, *80*, 043601. <https://doi.org/10.1103/physreva.80.043601>.
8. Weinfurter, S.; Tedford, E.W.; Penrice, M.C.J.; Unruh, W.G.; Lawrence, G.A. Measurement of Hawking radiation in a water tank. *Phys. Rev. Lett.* **2011**, *106*, 021302.
9. Belgiorno, F.; Cacciatori, S.L.; Clerici, M.; Gorini, V.; Ortenzi, G.; Rizzi, L.; Rubino, E.; Sala, V.G.; Faccio, D. Hawking Radiation from Ultrashort Laser Pulse Filaments. *Phys. Rev. Lett.* **2010**, *105*, 203901–203901. <https://doi.org/10.1103/physrevlett.105.203901>.
10. Carusotto, I.; Fagnocchi, S.; Recati, A.; Balbinot, R.; Fabbri, A. Density correlations and analog Hawking radiation in Bose–Einstein condensates. *New J. Phys.* **2008**, *10*, 103001.
11. Martín-Martínez, E.; Garay, L.J.; León, J. Unruh–DeWitt detectors and observer dependence of particle detection. *Phys. Rev. D* **2010**, *82*, 064006.
12. Nation, P.D.; Johansson, J.R.; Blencowe, M.P.; Nori, F. Stimulating uncertainty: Analogue Hawking radiation in superconducting circuits. *Rev. Mod. Phys.* **2012**, *84*, 1–24.
13. Bény, C.; Osborne, T.J. Information-geometric approach to quantum thermodynamics. *Phys. Rev. Lett.* **2012**, *108*, 030502.
14. Lostaglio, M.; Korzekwa, K.; Jennings, D.; Rudolph, T. Quantum Coherence, Time-Translation Symmetry, and Thermodynamics. *Phys. Rev. X* **2015**, *5*, 021001. <https://doi.org/10.1103/physrevx.5.021001>.

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.