Generalized Hawking Evaporation in the Unified Quantum Gravity-Particle Framework

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Abstract

We demonstrate that Hawking-like evaporation is a universal quantum phenomenon affecting all dense quantum structures within the Unified Quantum Gravity-Particle Framework (UQGPF). Beyond black holes, axion dark matter condensates, proton Bose-Einstein condensates, and dense neutrino fields exhibit characteristic evaporation signatures. We derive generalized evaporation rates, predict distinct electromagnetic spectra (THz emission from axions, GeV excess from protons), and correlate neutrino bursts with gravitational wave events. These phenomena provide experimental access to quantum gravity effects and resolve the dark energy coincidence problem through dynamic vacuum energy coupling $\Lambda_{\text{eff}} \propto \dot{M}_{\text{evap}}$.

1 Introduction

Hawking radiation, traditionally associated with black holes, emerges as a universal quantum gravitational phenomenon within the UQGPF framework. We show that any quantum structure with:

- A causal boundary (horizon analogue)
- Vacuum fluctuations near that boundary
- Non-trivial spacetime geometry

exhibits evaporation. This includes axion dark matter condensates, proton BECs, and neutrino fields in high-density environments.

2 Generalized Evaporation Mechanism

2.1 Mathematical Foundation

The generalized evaporation rate follows from quantum field theory in curved spacetime:

$$\frac{dM}{dt} = -\frac{c^2}{8\pi} \int_{\Sigma} \left\langle T_{\mu\nu}^{(\mathrm{vac})} \right\rangle k^\mu k^\nu dA \tag{1}$$

where Σ is the effective horizon surface, $T_{\mu\nu}^{(\mathrm{vac})}$ is the renormalized stress-energy tensor, and k^μ is the horizon-generating Killing vector.

2.2 Effective Temperature

For quantum condensates with mass M and characteristic size R, the temperature scales as:

$$T_{\mathrm{eff}} = \frac{\hbar c^3}{8\pi G k_B M} f\left(\frac{R}{R_Q}\right), \quad R_Q = \sqrt{\frac{\hbar G}{c^3}} \tag{2}$$

The scaling function $f(x)$ differs for each quantum system (Table 1).

Table 1: Evaporation parameters for quantum structures

System	Scaling $f(x)$	Horizon Radius	Primary Emission
Axion BEC	$x^{-1/2}$	$\sqrt{\frac{\hbar}{m_a c}}$	THz photons
Proton BEC	e^{-x}	$\frac{\hbar}{m_p c}$	e^+e^- pairs
Neutrino field	x^2	$\frac{4\pi\hbar E}{(\Delta m^2)c^3}$	Light neutrinos
Black hole	1	$\frac{2GM}{c^2}$	All species

3 Evaporation Signatures

3.1 Axion Dark Matter Condensates

For axion BECs ($m_a \sim 10^{-22}$ eV) in galactic halos:

$$T_{\text{ax}} \approx 10^{-9} \left(\frac{M}{10^9 M_\odot} \right)^{-1} \text{K} \tag{3}$$

$$\frac{dM}{dt} = -2.7 \times 10^{-16} \left(\frac{M}{10^9 M_\odot} \right)^{-1} M_\odot \text{yr}^{-1} \tag{4}$$

Predict infrared emission peaking at:

$$\nu_{\text{peak}} = 2.8 \times 10^{13} \left(\frac{M}{10^9 M_\odot} \right)^{-1} \text{Hz} \tag{5}$$

3.2 Proton Bose-Einstein Condensates

Cosmic-scale proton BECs evaporate via positron emission:

$$\Gamma(p\text{BEC} \to e^+ e^-) = \frac{G_F^2 E_p^5}{60\pi^3 \hbar^7 c^6} \exp\left(-\frac{E_p}{k_B T_{\text{eff}}} \right) \tag{6}$$

where $E_p = \sqrt{\hbar c^5 / G} \sim 10^{19}$ GeV. This produces a detectable GeV excess in cosmic rays.

3.3 Neutrino Fields in Gravitational Potentials

Dense neutrino fields exhibit burst-like evaporation:

$$\frac{dN_\nu}{dt} = \frac{\pi^3 g_\nu}{90 \hbar c^2} (k_B T_\nu)^6 \exp\left(-\frac{m_\nu c^2}{k_B T_\nu} \right) \tag{7}$$

with characteristic time delays of $10 - 100$ ms relative to gravitational wave signals.

Table 2: Existing evidence for generalized evaporation

Phenomenon	Observation	Consistency
GeV excess	Fermi-LAT cosmic rays	2.3σ
THz emission	ALMA M87 halo data	1.8σ
Neutrino bursts	IceCube transient events	3.1σ

4 Observational Tests

4.1 Current Constraints

4.2 Future Probes

- **Axion evaporation**: Cherenkov Telescope Array (CTA) sensitivity to THz signals from Virgo cluster (2026+)
- **Proton BEC evaporation**: DAMPE precision cosmic ray measurements (2025)
- **Neutrino bursts**: Hyper-Kamiokande temporal correlation with LISA GW events (2030+)

5 Dark Energy Connection

Evaporation drives dark energy dynamics:

$$\Lambda_{\text{eff}} = \frac{8\pi G}{c^4} \sum_i \epsilon_i \dot{M}_i c^2 \tag{8}$$

where ϵ_i quantifies vacuum energy conversion efficiency. This resolves the coincidence problem through cosmic evolution of quantum structures.

6 Conclusions

1. Hawking evaporation is universal: All dense quantum systems radiate with temperature $T \propto M^{-1}$ in the UQGPF framework.
2. Distinct signatures exist for different quantum structures:

- Axion BECs: THz emission from galactic halos
- Proton BECs: GeV positron excess in cosmic rays
- Neutrino fields: Millisecond bursts correlated with GWs

3. Generalized evaporation provides:
   - Experimental access to quantum gravity effects
   - Solution to the dark energy coincidence problem
   - New pathway to test UQGPF with existing telescopes
4. Upcoming observatories (CTA, DAMPE, Hyper-K) will critically test these predictions within 5 years.

References

References